CAPACITY OPTIMIZATION IN SMART GRID COMMUNICATION NETWORK USING NON-ORTHOGONAL MULTIPLE ACCESS

By

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Candidate of **Master of Science in Electrical Engineering (MSEE)** at the National University of Modern Languages do hereby declare that the thesis **Capacity optimization in smart grid communication network using non orthogonal multiple access** submitted by me in partial fulfillment of MSEE degree, is my original work, and has not been submitted or published earlier. I also solemnly declare that it shall not, in the future, be submitted by me for obtaining any other degree from this or any other university or institution. I also understand that if evidence of plagiarism is found in my thesis/dissertation at any stage, even after the award of a degree, the work may be canceled, and the degree revoked.

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ABSTRACT

Capacity optimization in smart grid communication network using non-orthogonal multiple access

In contrast to the conventional electric grid, a smart grid (SG) is an innovative and modernized electric grid system. Specifically, the electric grid is upgraded by advances in information and communication technologies, where terabytes of data are generated at SG devices that must be transmitted. The anticipated size of data originates from various applications such as metering, automation, monitoring, and firmware updates. Therefore, the smart grid communication network (SGCN) requires a communication system that is spectrum efficient and does not overburden already scarce channel resources. Meanwhile, non-orthogonal multiple access (NOMA) has been envisioned to support the demands of latency, throughput, and fairness of future wireless networks. Mainly, NOMA has been studied for the objectives of capacity optimization, fairness, and energy efficiency for various communication situations. The investigation for NOMA for domains of cellular communication underwater as well as unmanned aerial vehicle (UAV) communication has demonstrated, that it has a clear advantage over conventional Orthogonal Multiple Access systems. Though, NOMA's applicability to SGCN has not undergone examination yet, and further investigation is needed. This thesis will deal with the design issues related to user pairing and power allocation for effective implementation of NOMA in the context of SGCN.

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LIST OF ABBREVIATIONS

AMI	Advanced Metering Infrastructure
AHA	Artificial Humming Bird
BAN	Building Area Network
BS	Base Station
CSI	Channel State Information
DA	Distribution Automation
DAP	Data Aggregation Points
DAU	Data Aggregator Units
D2D	Device-to-Device
DR	Demand Response
EV	Electric Vehicle
FD	Full-Duplex
GA	Genetic Algorithm
GU	Ground User
HAN	Home Area Network
HEMS	Home Energy Management System
M2M	Machine to Machine
MBPS	Mega Bit Per Second
MG	Micro grid
MIMO	Multiple Input Multiple Output
M2M	Machine to Machine
MS-ABC	Multi-Swarm Artificial Bee Colony

NAN	Neighborhood Area Network
NOMA	Non-Orthogonal Multiple Access
OAM-MIMO	Angular Momentum Multiple Input Multiple Outputs
OAM	Orthogonal Multiple Access
OFDMA	Orthogonal Frequency Division Multiple Access
PA	Power Allocation
PSO	Particle Swarm Optimization
SCA	Successive Convex Approximation
SG	Smart Grid
SDG	Sustainable Development Goals
SGCN	Smart Grid Communication Network
SIC	Successive Interference Calculation
SM	Smart Meter
SNR	Signal to Noise Ratio
SUAA	Subcarrier User Assignment Algorithm
TSP	Traveling Salesman Problem
TVWS	TV White Space
UAV	Unmanned Aerial Vehicle
UAN-SDG	United Nation Sustainable Development Goal
V2G	Vehicle-to-Grid
VLC	Visible Light Communication
WAN	Wide Area Network

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

CHAPTER 1

INTRODUCTION

1.1 Overview

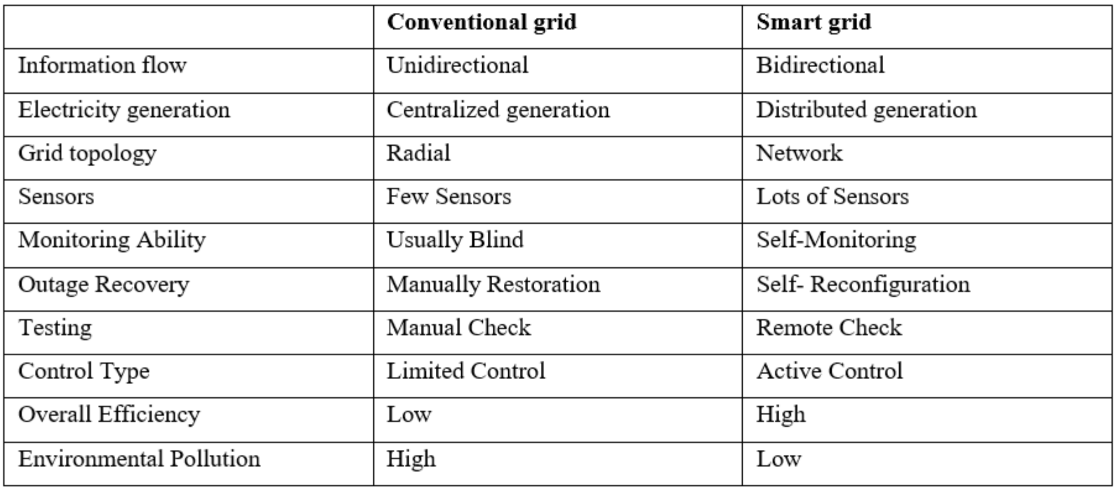
Increased electricity consumption, load shedding, system reliability, price rises, and climate change have motivated many countries to increase the efficiency of their existing conventional grids and explore alternate sources of stable electricity. This demand and motivation have resulted in the necessity for a SG, which is an upgraded electrical power infrastructure aimed at efficient generation, delivery, and feasting of electricity [1].

SG perceptions have transfigured the forthcoming of conventional electric grid by manufacturing it more competent, robust and unswerving. The SG is a modernized version of the traditional electricity grid that solves issues such as power shortages, rising electricity rates, concerns about system reliability, and the need to use eco-friendly green energy sources. SG is a globally dispersed, automated energy distribution network with a two-way electrical flow [2]. The two-way communication pattern has permitted the customers to yield control of the energy consumption and electricity bills. It can monitor electricity generation, distribution, and consumption through intelligent sensor devices and can adapt to changes. The SG has the capability to automatically safeguard and augment the performance of interconnected components and subsystems spanning from power generation to grid consumption. SG's main goals are to help utility companies manufacture and transmit power more efficiently and benefit customers save money on their energy bills [3].

In recent times, the introduction of smart grid networks has significantly impacted the way we perceive and manage electric power systems. These networks allow us to continuously collect information on the activities of consumers and suppliers, facilitated by the utilization of

SMs. The infrastructure of a SG comprises three essential elements: a unit for bi-directional energy allocation, regulator and managing element, and a two-way communication component

Table 1.1: Comparison of Smart grid and Conventional capabilities



	Conventional grid	**Smart grid**
Information flow	Unidirectional	Bidirectional
Electricity generation	Centralized generation	Distributed generation
Grid topology	Radial	Network
Sensors	Few Sensors	Lots of Sensors
Monitoring Ability	Usually Blind	Self-Monitoring
Outage Recovery	Manually Restoration	Self- Reconfiguration
Testing	Manual Check	Remote Check
Control Type	Limited Control	Active Control
Overall Efficiency	Low	High
Environmental Pollution	High	Low

The statistics created by numerous SG applications is not solitary in giant proportion but likewise miscellaneous in nature in rapports of its delay tolerance. To ensure a dependable electricity supply and enable effective monitoring, production management, and advanced generation capabilities, it becomes essential to employ a communication technology that possesses high capacity, robust security measures, reliability, and flexibility. This technology should support the erudite and autonomous functionalities of smart grid networks in both wide area network and neighborhood area network of SG infrastructure [4]. SG network has different layers shown in Figure 1.1; our working domain is the communication layer of SG. Table 1.1 shows comparison between SG and conventional electric grid.

Application layer:

The application layer offers a range of SG applications to clients and utility firms, enabling control and monitoring functionalities.

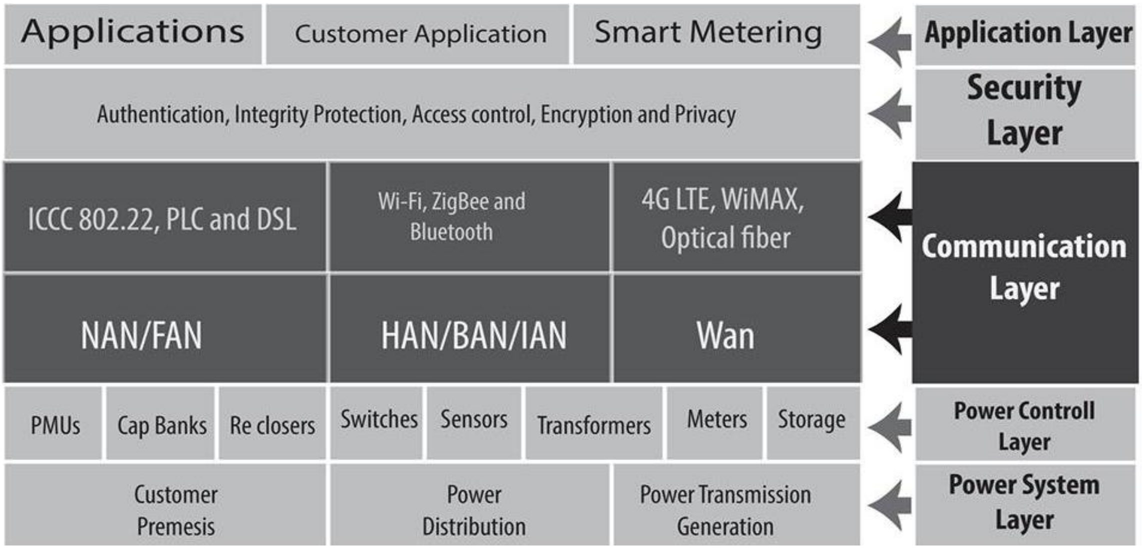


Figure 1.1: Network layers [1]

Security Layer:

Security layer of the SG offers functionalities such as user’s verification, ensuring customer’s secrecy, and maintaining data veracity.

Communication layer:

The communication layer is answerable for facilitating two-way communication within the SGCN.

Power control layer:

The power control layer specifically handles management functions related to power, encompassing activities such as monitoring and control.

Power system layer:

The power system layer concerned with power generation, transmission, distribution and consumption.

The communication layer holds significant importance within the multi-layer design of the SG. Communication layer will therefore be the foremost focus for this research. The communication layer is subdivided into three segments, distinguished by data rate, coverage area, and range: WAN, NAN, and HAN. The specific data-rate and range details of each networks type are shown in Figure 1.2.

1.2 Home Area Network

It gathers data from various smart home devices and sends control instructions to optimize energy consumption. It performs tasks like disabling air conditioners during peak load, facilitating card-activated prepayment plans and sharing usage data within home displays for better visualization and monitoring. Smart meters (SMs) turn as communication hubs between HAN and NAN, allowing information to flow between them. HANs usually span an area of up to 200 square meters and provide support for data transmission speeds that range to 10 to 100 kilobits per sec (kb/s).

1.3 Neighborhood Areas Networks

NAN is in charge of smart metering communications, which allows customers and power companies' WANs to communicate data for many, etc. NANs typically cover extensive areas spanning several square kilometers, with each smart meter requiring data transmission rate ranging to 10 to 100 kilobits per sec (kb/s). The NAN is an essential part of an SGCN since it is responsible for transmitting a large amount of information between utility companies and many devices mounted at client premises.

1.4 Wide Area Network

It pleats information from numerous NAN and transmit it through the private networks of utility providers. They cover extensive distances to establish connections among power plants, substations, distributed energy resource stations, control centers, and other data aggregation points (DAPs). WANs have the capacity to connect thousands of devices over a wide region, typically spanning thousands of square kilometers, with data transfer rates ranging from 10 to 100 megabits per second (Mbps) [5].

Smart grid applications embrace a diverse array of technologies and systems that significantly progress the consistency, competence, and sustainability of the electrical power grid. Key applications include Advanced Metering Infrastructure (AMI), Renewable Energy Integration, Energy Storage Management, Distribution Automation (DA), Grid Monitoring and Analytics, Electric Vehicles (EVs), Micro-grids (MG), Demand Response (DR) etc.

Advanced Metering Infrastructure:

Advanced metering infrastructure permits bi-directional communication among the service benefactors and customers, letting to real time observing of electricity usage and providing consumers with detailed energy information. This enables demand response programs and helps optimize energy consumption.

Distribution Automation:

Distribution automation uses sensors, smart switches, and communication mechanisms to oversee and manage the transmission of electricity effectively. It improves fault detection and restoration, reduces outage duration, and enables efficient load balancing.

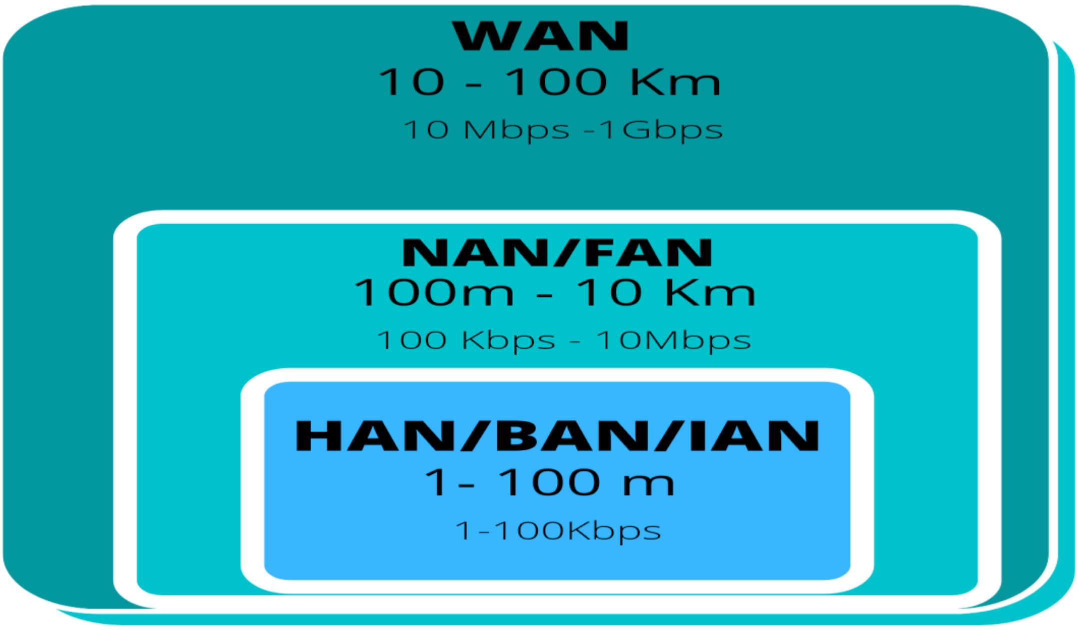


Figure 1.2: Communication requirements for HAN, NAN, and WAN [2]

Renewable Energy Integration:

Smart grid technologies empower the seamless incorporation of renewable energy foundations. This involves monitoring renewable vigor generation, managing grid stability, and facilitating bi-directional power flow.

Energy Storage Management:

Energy storage systems, including batteries, show a vital part in the SG as they store surplus electricity during periods of low demand and discharge it during peak demand or when there is insufficient renewable generation. Smart grid applications optimize the utilization and control of energy storage systems.

Grid Monitoring and Analytics:

Smart grid applications employ advanced monitoring and analytics tools to collect and analyze data from various grid components. This enables proactive maintenance, early fault detection, load forecasting, and optimization of grid operations.

Electric Vehicle (EV) Integration:

Smart grids facilitate the integration of electric vehicles by managing charging infrastructure, optimizing charging patterns to match grid conditions, and enabling vehicle to grid (V2G) capabilities. This permits EVs to assist as disseminated energy resources and subsidize to grid stability.

Micro grids:

Micro grids are localized energy systems capable of functioning autonomously or being interconnected with the primary grid. Smart grid technologies enable efficient management and coordination of micro grids, enhancing their resilience, reliability, and ability to integrate renewable energy sources.

Demand Response:

Demand response curricula provide incentives for consumers to alter their energy consumptions in accordance with grid conditions or price signals. By reducing demand during peak periods, demand response helps alleviate strain on the grid and improves its overall efficiency.

With SGCN's rapid development, it has progressively become a focus for wireless communication researchers. Massive development is currently being made in the advancement of bi-directional information exchange. Due to the extensive deployment of SMs and enormous amount of data they produce in SG devices, such as meter reading data, demand response, automation, monitoring data, firmware update, application update date, etc. This data needs to be transmitted cost-effectively. Nevertheless, the wireless communication technologies currently available in this era do not adequately fulfill the communication needs of SG systems. The progress of an advanced technology that can efficiently address the immediate demand response needs of smart grid network [6].

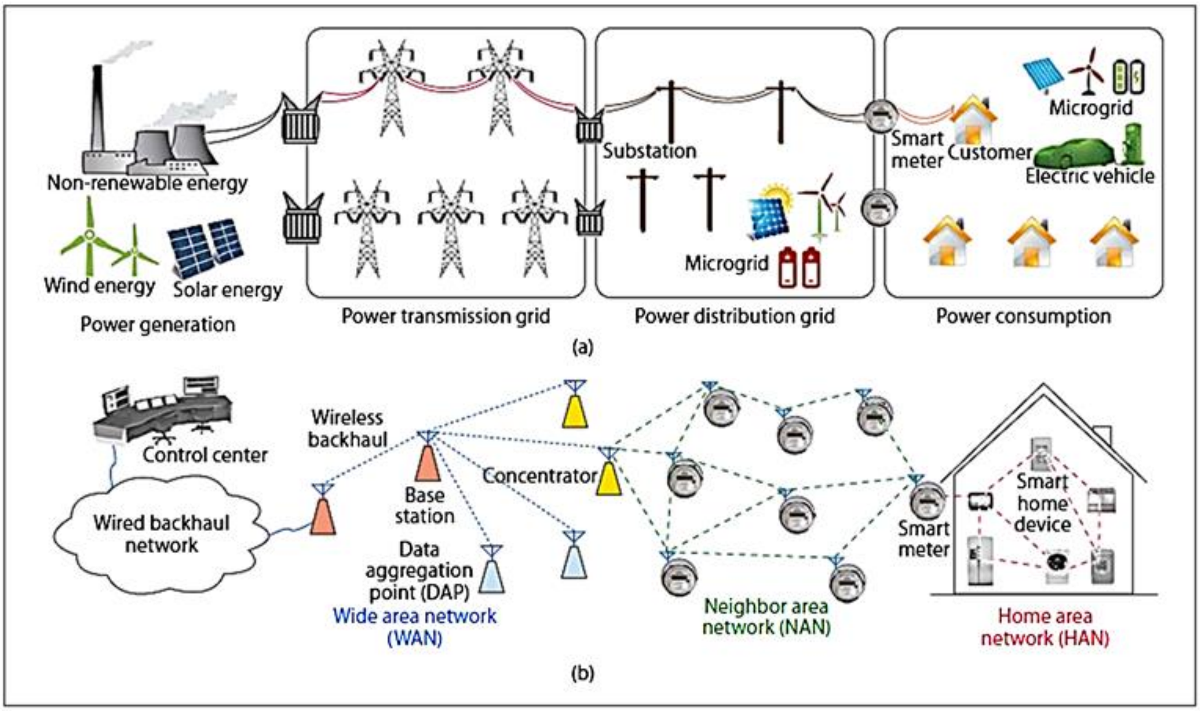


Figure 1.3: Smart grid communication layer segments in comparison with power layer segments [4]

1.5 Background

In demand to fulfill the evolving needs, including high throughput, spectral efficiency, data rate, connectivity for numerous smart meters, user fairness, and reliability, recent research has focused on identifying a suitable multiple access method that could be incorporated in SGC systems. Currently, NOMA, is seen as a key for enhancing spectral efficiency. OMA scheme, however, can achieve satisfactory system performance. As there is no reciprocal interference amidst users in an ideal scenario. However, OMA lacks the potential in addressing evolving challenges because of the receiver high intricacy [7] .

When thoroughly examining NOMA, it becomes evident that non-orthogonality is deliberately introduced in terms of frequency, code and time. In power domain-multiplexing, signals are distinguished at the receiver based on the significant power difference between two users, employing a method known as successive-interference-cancellation (SIC) [8]. In NOMA, users exploit same time frequency resources. In the downlink NOMA, the user located farther away receives more power compared to the nearby, while the nearby user performs more SIC than the farther user. In the uplink, the BS practices SIC to separate signal from different users. In code-domain multiplexing, distinct codes are assigned to users for multiplexing over the shared time-frequency resources. In contrast, in case of OMA, the obtainable bandwidth is divided in to smaller sub bands, with each user allocated a dedicated sub band for communication. These sub bands are designed to be precisely orthogonal to each other and are commonly referred to as subcarriers [9].

In recent times, there has been a growing implementation of multiple antenna schemes in communication systems to enhance coverage and increase overall signal strength. Typically, these antennas are added to the base station (BS) infrastructure. However, in such systems with multiple antennas, the transmission speed is relatively limited as the BS cannot simultaneously convey data to all users. Congestion problems can still occur even if users occupy different frequencies but share the same time slot. These communication schemes offer benefits in reducing co-channel interference and their simplicity. However, they suffer from drawbacks such as low throughput and slow transmission speed. As wireless communications continue to evolve rapidly, substantial endeavors have been devoted to enhancing data-rates, system-throughput, and channel capacity. One approach involves enabling multiples user to communicate simultaneously using the same frequency and time-slot, called as multiuser communication [10].

Nevertheless, OMA scheme face limitations in case of subsidiary a hefty number of customers, especially when there was a need for gigantic connectivity in the context of 5G network. These limitations become a significant constraint [11]. Furthermore, it had been hesitantly confirmed that OMA may not constantly reach the highest sum-rate in multi-user-wireless networks. To overcome these limitations associated with OMA, researchers have recently explored the concept of NOMA as alternative design approach. NOMA stands out due to its ability to support a larger number of users by employing non orthogonal resource allocation as a key feature.

1.6 Motivation

It is observed in the above studies that terabyte of data is produced in SG. So how to efficiently communicate this data in SGCN is a big optimization problem. The NOMA is used for capacity optimization, energy efficiency, fairness, etc. Hence NOMA is a possible solution to the SGCN, whereas SGCN has diversified capacity requirement. Keeping in view the requirement, NOMA is an appropriate technique. However, the recital of NOMA in SG situation is unidentified. Furthermore, the various design parameters of NOMA need to be investigated for the case of SGCN. The inspiration behind this research is to investigate the application of NOMA in SG for capacity optimization. The following table compares and contrasts between NOMA and OMA.

Table 1.2: Comparison of NOMA and OMA

Specifications	OMA	NOMA
Full Form	Orthogonal Multiple Access	Non Orthogonal Multiple Access
Receiver Complication	Low	High
Energy Consumption	Less	More
No. of Users	Higher	Lower
No. of User pairs	Higher	Lower
System Throughput	Smaller	Larger

1.7 Problem Statement

Forecasted data that will be thousand of terabytes to be generated in fully functional SG. The efficient and reliable transmission of this homogeneous data is one of the main requirements in SGCN. Moreover, the capacity optimization for SGCN is essential in view of scarce channel resources, lower latency and immense traffic load. Meanwhile, NOMA has been envisioned to handle the requirements of beyond 5G networks. However, the suitability of NOMA for SGCN has not been established in literature. Specifically, the design issues of users pairing and power allocation for effective implementation of NOMA for SGCN needs further studies.

1.8 Aim & Objectives

Aim:

- To investigate the application of NOMA in SGCN having diverse communication requirements for capacity optimization.

Objectives:

- To jointly optimize user power allocation and user pairing using NOMA.
- To compare the performance of different user pairing schemes for capacity optimization.

1.9 Scope of Research

SGCN is a very broad topic, having multiple segments. There is plenty of numerous applications of NOMA in many communication scenarios. This study is limited to application of NOMA in NAN segment of SG. Moreover, large volume and variety of data created by SG applications, NOMA technology is required for efficient handling. The NOMA technology has shown to be the most efficient technique for increasing spectrum utilization and transmission capacity in wireless networks to enable large-scale data transmission. This research is in line with several United Nations Sustainable Development Goals (UN SDGs). One of the main ways it can contribute is by addressing issues related to affordable and clean energy and industry, innovations and infrastructure.

1.10 Sustainable Development Goals and Social Impact

Sustainable Development Goals (SDGs), also stated to as the universal objectives, were recognized by the United Nations in 2015 to serve as a global initiative aimed at exterminating poverty, safeguarding environment, and endorsing peace and success by 2030. Containing 17 goals, the importance of SG emphasizes on achieving a harmonious balance among social, economic, and environmental sustainability, recognizing that decisions made in one domain impact outcomes in others. Addressing each situation necessitates the collective utilization of society's creativity, knowledge, technology, and financial resources to accomplish the SDGs [12]. Through improving and modernizing energy generation and management practices, SG plays a decisive part in reaching SDGs. SG improves user experience through monitoring and handling energy transmission and facilitating effective communication between efficiencies and end users. The massive volume of energy information that the SG deals with are made useless by improper approaches for information collecting, monitoring processing, and result making. Better grids visualization is made possible by big-data analytics when used in conjunction with the SG, which advances sustainability. The 17 goals of SG are shown in Figure 1.4.

SDG7, which provision to pertain affordable and clean energy, target to guarantee worldwide access to reliable, maintainable, affordable and contemporary energy for everyone. It is assessed that around 1.31 billion peoples still dearth access to electricity worldwide. The objective of this goal is to underscore the importance of transitioning to renewable energy sources and achieving significant enhancements in energy efficiency on a global scale [13]. This research can also contribute to SDG 7 as SG solves issues such as power shortages, rising electricity rates, concerns about system reliability, and the need to use eco-friendly green energy sources. SG's help utility companies manufacture and transmit power more efficiently and benefit customers to save money on their energy bills.

Figure 1.4: Sustainable Development Goals [12]

Moreover, this research has the potential to make a valuable contribution to SDG 9, which focuses on industry, innovation, and infrastructure. Investment in infrastructure plays a pivotal role in attaining sustainable development objectives. The targets of this goal encompass promoting innovative and environmentally friendly practices in industrial development, as well as exploring inventive approaches to repurposing existing materials. The present research offers cost-effective and flexible solutions to address the diverse challenges related to next-generation wireless networks [14]. This research holds a significant role in driving technological innovation in the digitalization of the electricity sector, primarily through the implementation of SMs. SMs play a crucial role in promoting energy efficiency among end users, which can potentially lead to a reduction in energy demand during peak hours. This benefits both consumers, who enjoy lower energy costs, and energy utilities, who can better manage the energy supply. The incorporation of SMs and SG technologies has the potential to increase profitability by 20 to 30% for companies operating in the energy and utilities sector. The SG ensures a reliable power supply through optimized grid management and aggregation of resources

An effectual and reliable communication network is the key enabler for SG technologies. The proposed solution is concentrated on the efficient use of current communication resources to create the necessary backbone network, providing affordable, environment friendly, and clean energy while also promoting industrial innovation.

1.11 Resource Requirement

MATLAB (Matrix Laboratory) is a programming software that enables the expression of problems using familiar mathematical notations, while providing the ability to present solutions in both mathematical and graphical formats. It facilitates operations on matrices, allows for the use of functions, data plotting, and implementation of algorithms. In our study, MATLAB was utilized for simulations and to visually illustrate the outcomes through graphical representations. To conduct a comprehensive literature review and gain insights into the background and existing research in the field of SG, NOMA, heuristic approaches and research journals are necessary. Additionally, photo shop was employed for creating visual aids such as figures and diagrams to effectively represent the SG network and present other relevant details in a visual format.

1.12 Organizational Structure of Report

Chapter one is opening section, providing a fundamental indication of the problem at hand. It delves into the research background, project scope, application areas, and the specific requirements necessary for this research. Chapter two conducts an extensive literature review, examining existing work and research conducted in the relevant field. Chapter three focuses on the detailed workings of the research, including the mathematical model and software particulars. This encompasses algorithms, mathematical formulations, and implementation details. Chapter four concentrates on the validation of simulations, presenting the scientific accomplishments and the required output results through the use of flow charts, figures, and graphs. Chapter five concludes the research by summarizing the key findings and discussing any limitations encountered. It also highlights future improvements for potential areas in the field. References and appendices of the report are given at the end, following to the IEEE format.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

A complete literature examination of this section will present smart grid communication, regarding its network requirement, NOMA based communication and heuristic techniques.

2.2 SGCN Requirements and Challenges

A detailed review of smart grid communication is presented in [1], where the authors presented the communication requirements of HAN, NAN and WAN. Moreover, a cognitive radio-based communication framework for the SGCN was also proposed. Authors in [15], conducted an investigation of SG enabling technologies, SG metering, and cloud-computing. Furthermore, applications of SG, opportunities and future were described in detail. In [16], the authors recognized the constraints of LTE, investigated the problems, and recommended cellular technology architecture and protocol modifications to accommodate NAN applications. And authors came to the conclusion that device-to-device (D2D) communication improves wireless communication performance in a variety of ways. And D2D communication has been highlighted as a possible solution for NAN operation over public cellular networks in the future. The authors in [17], introduced a novel model for Machine to Machine (M2M) communication and spectrum sighting scheme focused on enhancing energy efficiency. Through numerical analysis, demonstrated enhancements in both reliability and energy efficiency within the context of SG.

An inclusive examination of the features and architectures of SG, along with their provisioning for SG applications, has been provided in [18]. This research also discusses the primary challenges and unresolved matters pertaining to this domain. The authors in [19], have addressed issues such as the utilization of cognitive radio, standard interoperability, and cybersecurity in communications within the context of SGs. In [20], the authors have explored the utilization of TV White Spaces (TVWS) and industrial, medical and, scientific (ISM) bands in a flexible way to enhance reliability, latency and data rate in SGCN. They have developed optimization criteria to maximize throughput while considering the limitations of the outage rate. Authors in [21], provides an intriguing review that not only identifies challenges, issues, and ongoing research efforts but likewise sheds light on the implementations and practices of SGs in different areas across the globe. In [22], the authors conducted a comprehensive review of nearly 70 models of Home Energy Management Systems (HEMS). They also introduced a novel model that emphasizes the active involvement of end-users in the electricity value chain. [23] Features a survey conducted by the authors on the subjects of communication technology, security requirements and smart metering, of software and hardware. The survey focuses on both the cyber and physical aspects of the infrastructure. In [24], the researchers presented a survey on anticipated data in smart power systems. They initially discussed the reasons behind the substantial amount of data generated in such systems. Subsequently, they examined the significant concerns related to architectures, important equipment, and calibrations for data analytics in smart power systems. In [25], the authors highlighted the importance of communication standards in relation to SG applications. They emphasized that these standards are crucial and should be given serious consideration during the architectural design and implementation of energy upgrades to existing infrastructure. In [26], the researchers discussed certain SG difficulties that can be overcome using data analytics processing. Moreover, concluded that, to deal with the extreme size of data, the SG requires modern data analytics, data management, and robust monitoring systems to deal with the massive amounts of data.

A hierarchical big-data wireless communication architecture was presented by the authors in [27]. In addition, authors proposed a big data enabled storage planning scheme. The design has four levels: data resource, data transport, data storage, and data analysis. The optimization is then carried out using a hybrid approach that includes genetic algorithm for storage planning. And authors came to the conclusion that the proposed storage planning method lowers customer costs significantly in the long run. The authors discussed IOT applications in power grid also integrating renewable energy foundations to generate sustainable energy and avoid climate change in [28]. The authors emphasized importance of processing and storage the immense quantities of information composed by various campaigns and meters in the IOT. And concluded that latency and reliability are the reasons for real time application in smart power grid. Also resulted that fog computing architecture provided a platform for real-time applications in the smart power grid. The researcher proposed big-data technology that could be applied with SG data were presented in [29]. Furthermore, offered a platform for real-time massive data stream processing in SGs. Authors conducted a literature study of big-data sources and types of information in the SG, provided big data technologies that may be used on the vast amounts of data generated by SGs, and reviewed recent advancements, particularly in the last decade. And also supplied well designed commercial big data solutions for SGs, which have been used by various organizations and utilities throughout the world. And authors came to the conclusion that different sorts of technologies should be used for real-time solutions in SG.

The researcher presented big-data in SG, which included progresses in SG, in a broader study [30]. Then there was a debate about the issues of big-data in SGs, which involved issues like quality and security. It also explored future work on SG big data applications and the part they play in making the grids more dependable, efficient, transparent and accurate. In more comprehensive study [31], researcher presented a summary of data management for SGs. Authors summarized the issues for the huge data of SGs, and discussed the requirements and steps to implement solution in the SG context. In [32], researcher presented an ideal power allocation strategy in heterogeneous HAN for enhancing downlink capacity for SG applications. It addresses the constraints and derives the optimal solution using convex optimization techniques. The results demonstrate significant capacity improvements and highlight the rewards of the proposed method over equal power allocation.

2.3 NOMA in Wireless Communications

The authors presented an overview of recent developments and the current power domain multiplexing NOMA approaches. The fundamental concepts of NOMA were explained. The research tasks, openings, and likely solutions were also recognized in [33]. The researchers in [34], compared prevailing NOMA systems to other power domain multiplexing NOMA, which outlined limitations of present NOMA research efforts and proposed prospective results. The author also proposed design principles for NOMA systems. And demonstrated that NOMA has been examined from a variety of perspectives, including resource allocation and fairness. Moreover, indicated possible research possibilities for the future. In [35], the researchers discussed NOMA performances, and demonstrated that NOMA is next generation multiple access technology, which practices SIC at the receiver and super position at the transmitter. It discussed how NOMA when it's joint with other renowned wireless communication techniques including supportive communication and multiple input multiple output. It also addressed a number of critical concerns related to NOMA implementation.

A power allocation scheme were anticipated in [36], which maximize network energy efficiency. A downlink transmission situation is considered, a single antenna BS and system bandwidth is taken to enable n-single antenna user with least rate constraints. They solved fractional optimization problems and consequent a closed form expression of each user of power coefficient. In downlink NOMA network, the distributed matching algorithm was presented in [37], to improve user pairing between weak and strong users. As a result, despite its minimal complexity, the centralized algorithm's performance adaptively modified the code rate based on instantaneous channel conditions. The collaborative design process yields substantial reciprocal benefits for all users, and increased throughput. Authors in [38], presented NOMA augmented edge computing model by decreasing mobile edge computing user’s by leveraging the benefits of uplink NOMA. Furthermore, developed a NOMA base optimization system that elevates user clustering, resource distribution, and convey power to reduce user’s energy consumption. Authors in [39], examined the performance for NOMA in mm-wave frequency bands in the context of system capacity, which includes resource allocation, pairing probability, and power allocation. And concluded that by employing beam widths of around

30° requires no additional transmission power, and that adding NOMA into the system can result in a capacity boost of 20%. In addition, the prospective obstacles of employing NOMA in the mm-wave region were underlined.

Researchers in [40], presented NOMA techniques and the importance of cognitive radio. The key functions of spectrum optimization strategies were evaluated by integrating NOMA with CR. Authors discovered viable ways for solving frequency spectrum difficulties. And showed that NOMA and CR are capable of meeting 5G requirements. In [41], researchers proposed a NOMA based orbital angular momentum multiple input multiple output system to boost channel capacity for multiple users of downlink NOMA. In [42], rate optimization techniques were presented, in which power domain NOMA scheme is shared with MIMO. Moreover, power circulation for different consumers with varied rates was examined. The major consequence on the performance of these NOMA permitted techniques were presented, and optimization methods were employed to maximize the promising rates.

Author in [43], introduces two subcarrier user assignment algorithms(SUAA) for NOMA schemes. The first WSF-SUAA algorithm prioritizes subcarriers based on worst channel gain to enhance data rate and fairness for weak users. The second SEM-SUAA algorithm maximizes spectral efficiency. Simulation results show that both algorithms improve weak user data rate, spectral efficiency, user fairness and outage probability compared to current algorithms. In [44], author proved that in case of channel capacity, MIMO NOMA surpasses MIMO OMA except when only one user is involved. It establishes that MIMO NOMA can accomplish good results that are severely superior to those accomplished through MIMO OMA over appropriate power split. Furthermore, it demonstrates that MIMO NOMA accomplishes higher sum capacity than MIMO OMA.

In [45], researcher explores pairing schemes in 5G system for NOMA, focusing on appropriate coupling distances between users. The proposed approach, EPD-NOMA, utilizes non-maximum coupling distances to enhance paired user numbers and overall throughput. Numerical results demonstrate substantial improvements in paired users and radio capacity compared to existing schemes. In [46], authors presented a comparison of spectrum efficiency and energy of NOMA and orthogonal frequency division multiple access for forthcoming machine to machine communication on 5G network. Simulation results validate that NOMA overtakes OFDMA in case of spectrum efficacy and energy. The findings suggest that NOMA is an auspicious technology for cooperative a large amount of M2M devices while refining efficiency in 5G networks. In [47], research introduces Fair-NOMA power allocation approach in NOMA that ensures each user achieves at least the information capacity of OMA. The derived power allocation coefficients are based on channel gains, and the analysis shows capacity improvements for each user and the overall system. Fair power allocation in NOMA leads to consistent performance enhancements, with flexibility in maximizing either user's capacity while maintaining fairness.

2.4 NOMA in Capacity Optimization

[48] Investigates the working of SIC in NOMA system. It introduces a generalized multiuser diversity (GMD) scheme that selects multiple users with high signal to noise ratios (SNRs) to improve throughput. The investigation shows a potential throughput gain of 1 bps/Hz equated to multiuser diversity, particularly of large K values and in delay-limited transmission scenarios. In recent times, researchers have devoted significant attention to the study of traditional NOMA networks. For instance, in [49], the authors have explored the utilization of NOMA in full-duplex communication schemes. In another related study [50], NOMA has been employed in cooperative transportation system. The inspiration of this exertion is to exploit energy efficiency through effective resource allocation strategies. Furthermore, in the study [51], NOMA has been implemented in an intelligent transportation system. Recent research has also explored the practice for NOMA in UAV cellular communication as a means to improve the capacity of prevailing cellular network.

In [52], the authors addressed the essential tradeoff between UAV altitude and antenna beam width in various communication models. The objective was to optimize throughput in light of this trade-off. In [53], the authors introduced a distributed NOMA (D-NOMA) system. This system leverages the inter-group gap in channel gain among user to attain greater data rates matched to conventional NOMA techniques. Power allocation and users pairing are mutually augmented for a multicell MIMO-NOMA downlinks situation. The impartial of this optimization is to enhance energy efficiency in the system [54]. [55] Discusses user distribution scenario, where users are farther away from the BS and have lower channel gains. In contrast to OMA and C-NOMA, the author's user pairing strategy pairs a close user with two distant users, ensuing in a higher sum capacity. In [56], an adaptive user pairing algorithm is introduced, seeing the scenario of imperfect SIC. The proposed algorithm demonstrates improved performance of user's data rate when associated for innumerable NOMA user scheme. The researchers focused on an uplink NOMA communication scenario and proposed a combined optimization tactic for power allocation and user pairing [57]. The objective of this approach was to exploit the sum capacity and data rate for the paired user.

The authors in [58] introduced a novel process for power allocation and user pairing based on compressive sensing theory. This algorithm offers advantages such as low complexity while achieving a high sum-rate in the system. A machine learning (ML) based approach was discussed in [59], for the mutual optimization of transmission power provision and the trajectory of NOMA UAV BS (Unmanned Aerial Vehicle Base Station) deployment. This approach utilizes ML techniques to elevate both the power allocation and trajectory, enabling efficient NOMA UAV BS placement. In [60], a channel allocation methodology based on PSO was projected for minimizing the required transmission power in various NOMA systems. The PSO based approach aims to efficiently allocate channels in demand to decrease transmission power requirements within the NOMA system.

In [61], researcher focus on incorporating NOMA in aerial network for efficient device deployment. It optimizes power allocation, user pairing, and elevation in NOMA deployments compared to OMA. The study introduces cat swarm optimization for NOMA user pairing and demonstrates improved performance over PSO. Results show significant reductions in transmission power and operating altitude, also highlighting the advantages of NOMA in aerial networks. Author in [62], investigates the outage recital of supportive transmission in two user NOMA arrangements with concurrent wireless data and power transmission for near users. The best near best far user (BNBF) assortment system is anticipated. The study derives closed form appearance for OP and shows that the BNBF system achieves a diversity order of M + 1, regardless of the number of near users.

In [63], researchers proposes a novel MIMO NOMA framework for enhancing the recital of NOMA system. It utilizes signal alignment and stochastic geometry to derive analytical results for evaluating system performance with random user and interferer deployments. The study also investigates the effect of different power allocation strategies. Simulation results validate the projected framework and analytical findings. Authors presents a downlink and uplink NOMA scenarios for dynamic power allocation scheme in [64], providing flexibility in meeting eminence of service necessities. The proposed scheme improves performance and offers tradeoffs among user equality and system throughput. Analytical outcomes and simulations validate its effectiveness. Future directions include integrating the scheme with user pairing algorithms and extending it to MIMO scenarios with imperfect CSI. [65] Introduces a tactic to proficiently employ the spectrum in NOMA systems of unpaired users by pairing manifold similar gain users to a single reserved user. The proposed strategy addresses the pairing problem when the number of far user exceeds the number of near user. Analytical and simulation results demonstrate a substantial rise in system capacity compared to conventional NOMA and OMA. Future research will explore extending the strategy to a general model for multiple users. Author in [66], examines the accurateness of distance-based user grading in NOMA systems. It analyzes coverage probability and introduces the concept of accuracy probability. Results show dependencies on user count, path-loss exponent, and user pairing. Future work may explore additional channel models.

Researchers in [67] theoretically compares the recital of OMA and NOMA scheme with user fairness in mind. It derives the closed form expression for the finest sum rate in NOMA and proves that NOMA outperforms both OMA case II and OMA case I for optimized power, time and frequency allocation. Computer simulations validate the findings and demonstrate the rewards of NOMA in concrete rayleigh fading channels. Authors proposes ANOMA, a symbol-asynchronous NOMA scheme for downlink transmissions. ANOMA utilizes symbol-offset and pre-coding to reduce interference and simplify signal detection with WD detection at UEs. The scheme outperforms asynchronous NOMA with SIC detection and synchronous NOMA, improving achievable rate regions. Numerical results confirm the effectiveness of ANOMA with precoding and WD detection [68].

Researcher in [69], tackles blind signal classification in NOMA systems for resource efficiency in IOT-based transmission. Proposed schemes involve phase rotation of symbols and pilots to reduce classification errors. Simulation results validate the improved performance in 5G and IOT networks with limited energy and spectrum resources. [70] Introduces two coordinated beamforming practices for improving the recital of NOMA with MIMO in the occurrence of inter-cell interfering. These techniques enhance user fairness, increase throughput for cell edge users, and support a larger number of connected users, making them suitable for 5G networks. Mathematical results corroborate the efficiency of the proposed algorithms. Researchers in [71], focuses on optimization and design of development and NOMA algorithm for 5G systems. It analyzes the impact of power allocation and proposes a two-step approach for proportional fairness scheduling in NOMA. The proposed algorithm is scalable, quicker and maintain higher throughput gains compared to existing algorithms. They also consider defective channel state estimate and support multiplexing of more than two users. Simulation results corroborate the efficiency and computational effectiveness of the proposed algorithms.

Another research [72], introduces a user clustering algorithm and optimization algorithm for precoding matrix in NOMA with MU-MIMO systems. The proposed algorithms consider channel correlation, channel gain, and exploit the sum rate. Numerical outcomes show the supremacy for the proposed schemes above conventional approaches. Although the iterative algorithm is complex, it establishes NOMA as an auspicious multiple access scheme in MU-MIMO systems. Researchers explores the potential of NOMA in 5G network. It develops analytical frameworks to evaluate NOMA's performance in both downlink and uplink scenarios, considering outage probability and achievable data rates. The study investigates different pairing schemes and addresses inter-cell interference. Results show that selective pairing NOMA offers performance gains over OMA and fixed power allocation can achieve significant improvements. Overall, NOMA demonstrates advantages in dense wireless networks [73].

In [74], authors introduces a novel method for user set selection in NOMA downlink systems. The proposed method reduces complexity by considering an ailment amongst the frailest two users inside a set. Through simulations, it is shown that the proposed method achieves similar entire and cell edge throughput as the ideal method while significantly reducing usual amount of rifled user sets. Further research is needed to apply the method to realistic systems with modulation and coding schemes. [75] focuses on fairness in NOMA downlink systems and investigates PA techniques for achieving fairness. Two gears, involving instant CSI and average channel state information, are considered. Despite non-convex nature of the problems, low-slung complexity polynomial processes are established to obtain finest solutions in both cases. Mathematical outcomes reveal the efficiency for NOMA in attaining high fairness recital, outperforming time division multiple access by approximately a demand of magnitude, and highlighting its potential as an auspicious multiple access system of future 5G communication systems.

[76] Explores energy efficient communication in a NOMA based cloud radio access network (CRAN). The goal is to exploit energy efficiency while considering front haul capacity and transmit power constraints. The proposed NOMA scheme outclasses conventional OMA approaches in rapports of throughput and energy efficiency. This research presents a two-layer algorithm that tackles the non-convex problem and utilizes the '1-norm technique and weighted minutest mean square error tactic. Imitation outcomes corroborate the efficiency for the proposed NOMA system. In [77], researchers investigates the recital of NOMA with practical SIC schemes in a NOMA-MIMO system. The authors proposition an interfering-predicted minutest mean square error IC scheme and an enduring interference predicted MMSE IC system to improve system performance. Imitation outcomes spectacle that the IC systems outpace conventional OMA in rapports of bit error rate (BER). The research highlights the necessity of investigating IC schemes for NOMA and suggests further exploration with greater number of users in future. Researchers focuses on a NOMA cognitive radio system with simultaneously wireless information and power transmission [78]. The motive is to exploit the obtaining power of each energy reaping receiver by optimizing resources. A weighted Tchebyheff method is castoff to resolve the non-convex optimization issues. Results demonstrate that the performance underneath the linear energy reaping model is superior to that underneath the nonlinear energy

reaping model, and nearby is a tradeoff amongst reaping energy and the amount of data decoding users. Researchers in [79], proposes a system for 5G networks, using relay nodes and NOMA to assist manifold cell edge users with guaranteed data rates. It derives a finest power allocation system to diminish outage probability and approximates the ergodic sum capacity in high SNR scenarios. Mathematical outcomes reveal the preeminence of the system with NOMA over OMA in rapports of outage probability and capacity recital.

In [80], researchers explore capacity in UAV communication systems using NOMA. It contemplates mutual optimization of UAV elevation, power provision and user pairing. The algorithm demonstrates the efficiency of NOMA compared to OMA and shows that PSO outperforms genetic GA in improving the sum rate, especially in suburban environments. Authors in [81], researchers propose a joint optimization framework for NOMA MEC in IOT network to maximize system capacity and energy efficiency. It addresses progresses in wireless transmission, chore offloading verdict-making, admission control, cunning resource allocation, user clustering, and transmit power rheostat. The proposed algorithm is shown to be effective in enhancing system capacity and achieving energy savings through simulations. Overall, it offers a promising approach for optimizing performance in NOMA-MEC-based IOT systems allocation and user patterning, decomposing convex optimization delinquent into sub problems for autonomous solving.

Researchers in [82], presents a mutual user imitating and power allocation approach for a MIMO NOMA communication scheme. The proposed framework improves channel capacity through a convex approximation algorithm and matching theory techniques. Results reveal the sovereignty of the augmented MIMO NOMA scheme equated to conventional OMA and other NOMA schemes. The paper provides a comprehensive solution for power allocation and user pairing, decomposing the non-convex optimization delinquent into sub problems for independent solving. Researchers focuses on energy effective infrastructures and user capacity in a CR MIMO symmetric system using the underlay mode [83]. It proposes a non-orthogonal slot allocation method with SCMA to increase the amount of secondary users accessing the system. The greed algorithm is used to improve time slot allocation, and simulation results show significant energy consumption reduction and interference improvement compared to orthogonal slot allocation. The proposed scheme allows for an extensive rise in the numeral of secondary users while staying within interference limits, making it highly appealing for large-scale implementation.

Authors in [84], proposes an implicit MIMO NOMA scheme for 5G communication, combining MIMO and NOMA techniques. The system features a low-complexity receiver with an LMMSE multi-user detector and iterative processing using message-passing decoders. Through asymptotic analysis, the system achieves performance close to the speculative capacity. Results demonstrate the system's consistency and sturdiness under various conditions. The proposed system outperforms other competitive approaches, making it an appealing result for the MIMO NOMA uplink in 5G communication. In [85], authors propose a Reflective In Band Full Duplex(R-IBFD) supportive communication scheme that combines Full Duplex (FD) and NOMA technologies. The R-IBFD system improves spectrum utilization, secrecy capacity, and system parameters for 6G smart city requirements. It addresses co-channel interference and security issues, minimizing their impact on wireless communication. The proposed R-IBFD scheme enhances secrecy capacity, achieves high spectral efficiency, and reduces interference, making it suitable for the high data demand of 6G communication.

Researcher presents novel AI methods for downlink power allocation in NOMA networks [86], achieving near-optimal performance with reduced computational costs. The proposed approaches outperform traditional exhaustive search by up to 120 times in calculation time. The method achieves a speedup of approximately 396 times for K = 2, completing execution in 0.2 ms, while the normal equation method is 48 times faster for K = 10, executing in half a second. These AI models offer efficient alternatives to computationally heavy power allocation algorithms in NOMA. Authors in [87], explores sub channel scheduling, power allocation and task assignment in OMA and NOMA in MEC schemes. It formulates an energy optimization problem under latency constraints and proposes a low-complexity algorithm. Closed form results for chore assignment and transmit power is derived. The results demonstrate improved MEC system energy consumption and highlight potential areas for future research. In [88], author introduces a cooperative NOMA scheme in amalgam VLC/RF systems to progress system fairness and sum rate. It exploits the weighted sum rate by determining strong-weak user pairs, serving links, and power allocation. The cooperative NOMA outclasses conventional NOMA in presence of sum rate and fairness, significantly enhancing VLC network performance. The cooperative approach extends coverage and provides poorly serviced users with the opportunity to be assisted over an amalgam VLC/RF connection. They optimized system model and algorithms yield notable improvements in fairness and a slight enhancement in sum rate compare to outmoded OMA system.

In [89], an innovative NOMA mechanism merging code domain and power domain practices to provision a superior number of users in 5G wireless communication. By adding small data rate users on topmost of an SCMA system, the optimization problem of resource and power distribution is resolved to deed the attainable sum rate. Consequences reveal that the proposed mechanism supports more users and achieves a greater overall sum rate compared to the novel SCMA-based system. The NOMA mechanism, beside with optimum power allocation, certifies comparable sum rates for SCMA users contempt interference from the added low data rate users. Researchers in [90], presents a sheltered communication system for NOMA in UAV-MEC systems in the presence of a flying eavesdroppers. The projected scheme maximizes the regular computation capacity while ensuring a minimum requirement for each ground user (GU). Mathematical analysis is performed to study the worst security situation, and an optimization delinquent is resolved using successive convex approximation (SCA) and block coordinate descent (BCD) approaches. Results exhibit the preeminence of this scheme in presence of systems securities computation performance. Future work includes considering additional factors such as hovering effects, active eavesdropping of the eavesdropper and statistical behavior of channels behavior.

In [91], researchers investigate the utilization of mm-wave and NOMA strategies to achieve high data rates in dense 5G networks. It tackles power issues in NOMA arising from deliberate interference by suggesting the application of directional mm-wave transmission for power reduction. Simulations demonstrate a 40° beam width enhances system capacity by 30% without additional power. The study emphasizes the tradeoffs involving capacity, pairing probability, and power within mm-wave NOMA networks due to beam width fluctuations. The conclusion provides an overview of forthcoming challenges concerning NOMA in mm-wave bands. Researchers in [92], explores 5G's adaptability in use cases such as ultra-reliable low latency communication and industrial multimedia. Effective radio resource management (RRM) is crucial to meet demanding requirements. The research suggests integrating power domain NOMA techniques into 5G RRM for factory automation. It designs, evaluates, and contrasts diverse RRM algorithms, considering metrics like capacity and users. Results demonstrate that NOMA-enhanced RRM significantly boosts spectral efficiency, particularly for capacity and unicast optimization.

In [93], researchers introduce CFM-UPPA, an innovative technique for optimizing capacity and equity in NOMA systems through user pairing and power allocation. By analyzing power allocation coefficients and channel gain ratios, the paper presents CFM-PA, which optimizes power distribution while adhering to SIC criteria. CFM-UP strategically pairs users based on channel strengths, thus maximizing system capacity and fairness. Simulation outcomes establish CFM-UPPA's superiority over OMA and random NOMA UP methods, while CFM-PA also enhances the performance of other UP algorithms. The research underscores CFM-UPPA's robust efficiency in enhancing NOMA system recital. In [94], researchers introduce an inventive optical backhaul-based NOMA setup within visible light communication (VLC), aimed at resolving challenges in both indoor and outdoor optical wireless networks. The approach involves cooperative transmission via a fiber backhaul, encompassing closed-form equations for outage probability, throughput, capacity, and error rate. Notably, this method surpasses traditional OMA systems under medium to high SNR ratios. Additionally, a deep learning-infused framework is showcased to precisely estimate ergodic capacity, effectively mitigating complexity. The study offers both theoretical insights and pragmatic feasibility, underscoring its potential to enhance NOMA-VLC system performance through optical backhaul integration.

Authors in [95], investigates NOMA as an advanced 5G technology, moving away from conventional orthogonal sharing towards power-driven user distinction. SIC is utilized for detecting uplink and downlink signals, ordered by channel strength. Power allocation is based on channel strength, with reduced power for higher strength. The shift from power-domain multiplexing to constraint optimization is studied, suggesting particle swarm optimization

(PSO) and backpropagation neural network for power allocation in NOMA downlink. Experimental findings underscore the effectiveness of this approach in enhancing power allocation for downlink NOMA. In [96], researchers examines orbital angular Momentum (OAM) utilization in 6G wireless communication, enhancing capacity and degrees of freedom via mode orthogonality. The study explores OMA and NOMA within OAM downlink configurations, introducing mode-selection algorithms for OMA-OAM and a non-convex optimization approach for NOMA-OAM. These methods optimize sum-capacity for multi-user scenarios, displaying superiority compared to conventional OMA-OAM approaches through simulations. Moreover, a computationally efficient successive convex quadratic programming framework effectively manages non-convex capacity functions. The study's scope extends to non-coaxial cases, confirming the efficiency of mode-division OMA-OAM and NOMA-OAM strategies in capacity optimization.

[97] Examines integrating NOMA into a limited-front haul fog radio access network. It optimizes resource allocation in the downlink NOMA-based FRAN with multiple resource blocks through mixed-integer optimization. The paper proposes a hybrid solution approach and two methods (Hungarian-based and Multiple-Choice Knapsack-based) for user assignment. Power distribution and NOMA power splitting optimization. Simulation outcomes reveal the preeminence of these methods over conventional OMA and other baselines in various network setups. Researchers in [98], focuses on optimizing energy efficiency in dense small cell networks for 5G by managing carrier allocation, power usage, and dynamic cell activation. The proposed model aims to minimize energy consumption while maintaining coverage and capacity, optimizing the ON/OFF status of small cells for better efficiency. Additionally, a multihop backhauling strategy is proposed for dual-hop transmissions. Results demonstrate significant power savings and enhanced throughput, particularly for random and hotspot user distributions. Challenges include integrating NOMA with MIMO and addressing fluctuations in backhaul link quality. Future research seeks to enhance robustness and manage parameter uncertainties.

Authors in [99], centers on improving wireless communication efficiency via massive MIMO and NOMA technologies. It presents a power distribution technique based on asymptotic capacity computation for small-scale MIMO-NOMA, scalable to massive arrays. This method maximizes sum capacity with low complexity for large arrays, surpassing alternatives, even under challenging scenarios. The asymptotic approach correlates with the optimal method, exhibiting superior power optimization for MM-NOMA systems. In [100], the researcher aims to enhance vehicle-to-vehicle (V2V) communication considering rising tele-traffic and channel complexities. It innovatively combines spatial modulation and NOMA into NOMA-SM, optimizing V2V robustness and bandwidth efficiency. The study employs simulations to analyze bit error ratio and capacity, encompassing Rician K-factor, antenna correlation, and power allocation effects. The introduced power allocation algorithms bolster quality of service and throughput for varying priority levels. In summary, NOMA-SM effectively integrates SM and NOMA to elevate V2V link reliability and bandwidth efficacy.

Authors in [101], focuses on improving V2V communication's safety and infotainment using full duplex and NOMA techniques. It addresses challenges in data transmission, user connectivity, security, and privacy. The research introduces a cooperative NOMA V2V system with an FD relay, emphasizing security at the physical layer. Analytical findings and an optimization approach for enhancing secrecy sum rate using real-time channel state information are provided. The proposed strategy effectively improves secrecy sum rate compared to fixed-power transmission, accounting for factors such as distance and SNR. Researchers delves into end-to-end learning to revolutionize communication's physical layer design, focusing on finite-alphabet inputs and superposition coding in NOMA [102]. It establishes the capacity region using a closed-form expression for conditional mutual information and devises a precise lower bound on mutual information for reliable estimation. The proposed end-to-end learning framework optimizes NOMA's encoders and decoders while considering mutual information and bit error rate limitations, validated through simulations for capacity achievement and enhanced bit error performance. Further exploration is recommended for integrating NOMA and sensing communication using an end-to-end strategy.

Researchers in [103], examines the effects of hardware impairments on cooperative NOMA within $\alpha - \mu$ fading channels. It considers imperfect channel state information and SIC. Two NOMA scenarios are presented: non-cooperative and cooperative. Analytical expressions for outage probability, ergodic capacity, and energy efficiency are derived, along with relay location optimization. Unique characteristics emerge at high SNR, including diversity order and EC rate ceilings. Cooperative NOMA outperforms non-cooperative NOMA in high SNR conditions. The study comprehensively addresses realistic factors and scenarios, focusing on fading channels and hardware impairments in NOMA networks.

Authors in [104], focuses on addressing uneven and diverse traffic distribution in satellite communication networks with multiple beams. The objective is to optimize resource allocation to improve the offered capacity to requested traffic ratio while maintaining fairness. To achieve this, the introduction of NOMA is proposed, aimed at reducing interference and enhancing frequency reuse. A suboptimal algorithm is developed to break down the problem into manageable convex sub problems, iteratively optimizing beam power for enhanced OCTR. Simulation results demonstrate the algorithm's convergence and underscore the effectiveness of NOMA in maximizing the max-min OCTR. The utilization of NOMA in multi-beam satellite systems yields improved fairness and performance, and the potential for further enhancement through aggressive frequency reuse strategies is identified.

Authors in [105], focuses on optimizing transmit power and flight route of a multiuser MISO UAV communication system to progress the whole operative capacity. Techniques to eliminate multiuser interference such as zero imposing beamforming and block diagonalization are used. An iterative optimization algorithm, combining sequential convex optimization and block coordinate descent, is proposed to explicate the non-convex delinquent. Consequences reveal the efficiency and convergence of the proposed process. Overall, the paper addresses the delinquent of operative capacity on a MISO UAV communication scheme under a delay constraint. Authors in [106], proposes two dynamic power distribution systems for NOMA uplink systems with paired users, considering numerical delay QOS. One scheme maximizes the sum effective capacity, while the other maximizes the operative energy efficiency NOMA uplink. The optimization problems are solved using Lagrangian dual decomposition, SCA, and the Dinkelbach method. Results illustrate significant improvements in SEC and EEE compared to existing NOMA and OMA schemes.

2.5 Metaheuristic Optimization Methods

Researcher investigates PSO, a popular heuristic worldwide optimization process inspired by social behavior in nature. It explores PSO's flexibility, adaptability, and proposes a theoretical framework for improved implementation. The survey aims to benefit researchers and provide future research directions in the field of PSO and artificial intelligence [107]. Authors in [108], presents an algorithm for relay task and power distribution in SG data aggregator units (DAUs) to minimize utility costs. It formulates the problem as a nonlinear programming one and utilizes the swarm artificial bee colony algorithm for optimization. Simulation results confirm the cost reduction achieved by the ideal relay task and power allocation. The MS-ABC algorithm outperforms the improved ABC algorithm, demonstrating enhanced search capability and performance.

Authors in [109], presents the ant System(AS), a new computational pattern inspired by ant colony, for stochastic combinatorial optimization. AS utilizes positive response, dispersed computation, and a productive greedy heuristic to quickly discover good solutions. It is efficaciously pragmatic to the traveling salesman problem (TSP) and other optimization problems, showcasing its effectiveness. AS offers a novel approach to optimization with efficient search and cooperative interactions among agents. [110] Proposes a metaheuristic-based slant for augmenting the design of a sustainable off grid hydrogen based micro grid. It compares six metaheuristic algorithms and demonstrates the superior performance of the moth-flame optimization algorithm, achieving significant cost reductions. They proposed micro-grid architecture shows methodical viability and cost-efficacy, with levelized costs of electricity.

Here are some bio-inspired meta-heuristics includes, bat algorithm [111], glowworm swarm optimization [112], fruit fly optimization algorithm [113], bacterial foraging optimization [114], artificial ecosystem-based optimization [115], shark smell optimization [116], whale optimization algorithm [117], virus colony search [118], butterfly optimization algorithm [119], satin bowerbird optimizer [120], grasshopper optimization algorithm [121] . These metaheuristics, which are based on the multifaceted behaviors observed in living organisms, offer a wide range of local and global search strategies. These strategies provide researchers with a miscellaneous assortment of algorithms to address optimization problems across numerous fields.

2.6 Summary

The literature review summarized in Table 2.1 primarily focuses on smart grid communication, addressing network requirements and communication issues such as energy efficiency, spectral efficacy, ideal coverage, and capacity optimization in NOMA systems through techniques like user pairing and power allocation. While power distribution and user pairing are normally utilized for capacity optimization, their combination for this purpose is not extensively explored. Capacity optimization in NOMA based SGCN is becoming progressively popular amongst researchers due to its bearing in managing short span fluctuating traffic demands and its wide range of applications.

Table 2.1: Summary of Smart Grid and NOMA Papers

YEAR	**REFERENCE**	**TITLE**	**SUMMARY OF SMART GRID AND NOMA PAPERS**
2017	[1]	Cognitive radio based SGCN.	• A SG is the future of grid stations. • Thousands of terabytes of data are generated in various segments of SG. • Data comes from various applications of SG. • SGCN requires a communication system. • There is a need to optimize the capacity.
2017	[2]	SG communication and information technology in the perspectives of Industry.	
2018	[4]	A survey on SG technologies and applications.	
2019	[6]	Survey of SG concept and technology demonstration worldwide emphasize on the Oman perspective.	
2020	[7]	Cellular communication for SG Neighborhood Area Networks.	

2021	[8]	Big Data Issues in SG.	• NOMA provides all the needs for future communication for wireless. • Researchers used NOMA for energy efficiency and capacity optimization. • NOMA used for diversity of network. • Used for device 2 device communication. • Used for unmanned aerial vehicle. • The recital of NOMA in SG scenario is unidentified. • The various design parameters of NOMA need to be investigated for the case of SGCN.
2022	[9]	The internet of energy: Smart sensor network and big data management for SG.	
2022	[10]	Overview of big data in smart grid.	
2018	[12]	NOMA and 5G emerging technologies.	
2019	[13]	Power domain NOMA in 5G Systems.	
2019	[14]	Fairness for NOMA in 5G systems.	
2019	[15]	Survey on NOMA and spectrum sharing Technique in 5G.	
2020	[16]	Channel capacity analysis of NOMA with OAM MIMO System.	
2020	[17]	Impact of user pairing on 5G NOMA downlink transmissions.	
2020	[18]	Capacity comparison between MIMO NOMA and MIMO OMA with multiple users in a cluster.	
2021	[19]	Resource allocation in downlink NOMA for future radio access	

It is observed in the above studies that terabyte of data is produced in SG. So how to efficiently communicate this data in SG communication is a big optimization problem. On the other hand, NOMA is widely used in literature for capacity optimization. The foremost inspiration of the research is to inspect the application of NOMA in SG for capacity optimization.

CHAPTER 3

METHODOLOGY

This section provides communication scenarios in the context of the SG, exploring the specific requirements, challenges, and constraints of the communication network. Then comprehensive system model will be presented, capturing the key rudiments of the SG and the communication infrastructure. This model will serve as the foundation for the subsequent analysis and optimization. Furthermore, heuristic based user pairing algorithm is proposed, detailing its design and implementation for efficient user pairing and power distribution in NOMA.

3.1 Network Model:

We model our situation on a fixed topology. HAN represents the user premises where SMs serve as the primary devices to which all intelligent devices are connected. On the other hand, NAN pertains to the distribution system. Multiple Home Gateway Units (HGWs) are linked to data collectors (DC) which, in turn, connect to the NAN gateway. The DC are equipped with a comprehensive database that contains all the relevant information necessary for managing the transmission of data from the HGWs within the NAN. Typically, a single DC can establish connections with several hundred to even thousands of SMs in a specific area. SMs function as the intermediary between the HAN and NAN, hence they are referred to as HGW. The DC collects energy ingesting information from the SMs and spreads it to the utility company's control center via the WAN.

A severe Quality of Service restraint will arise deprived of implementing any finest spectrum distribution approach subsequently the number of HGWs are more than the existing channels. To address this issue, the DC assumes the responsibility of coordinating channel allocation within each cluster based on the continuously updated database, which is populated with spectrum sensing information. The volume of data to be conveyed over the communication links in the SGCN is significant and substantial in size. A communication scenario of NAN is considered in this research. The service area is alienated into diverse SMs, named as HGW with a DCU in the center. The complete network model is revealed in Figure 3.1.

In this research, our focus is on two key parameters of NOMA, which are user pairing and power allocation. User pairing involves intelligently grouping users together to stake the same time frequency possessions, maximizing the system capacity and spectral efficiency.

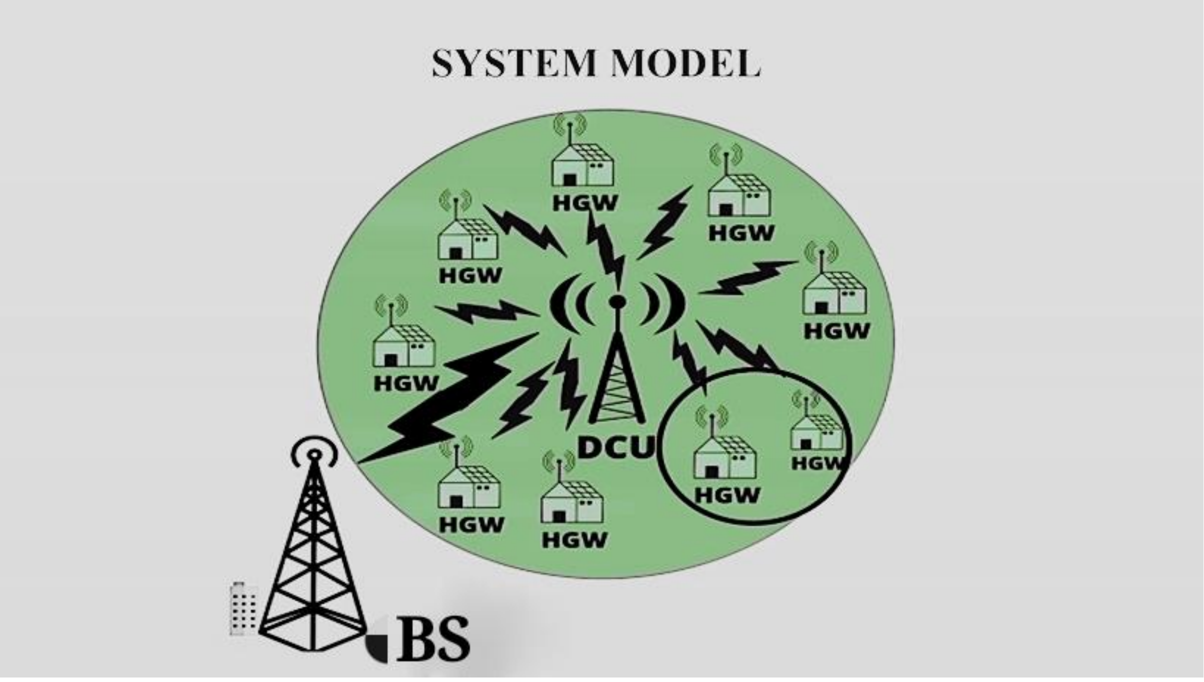


Figure 3.1: NAN Communication Scenario

To achieve efficient user pairing, we employ a heuristic technique, which is an intelligent algorithm that explores the solution space and makes informed decisions based on problem-specific knowledge. This heuristic technique allows for the optimal pairing of users, considering factors such as channel conditions, user requirements, and fairness. Additionally, power allocation is another crucial parameter, where the existing power possessions are circulated amongst the paired users to ensure optimal performance and mitigate interference.

By conjointly optimizing user pairing and power allocation, our research, ambitions to boost the overall efficiency and capacity of the NOMA scheme in a SGCN.

3.2 Mathematical Model

The proposed mathematical model is depicted in Figure 3.2, illustrating the scenario where a circular region with a radius of RC accommodates N users who communicate with a BS. In this model, we undertake that the network possesses information of the channel state information [122]. The users are randomly positioned within the region, and their current coordinates are denoted as (X, Y). The BS is positioned at the center coordinates (x_0, y_0) Consequently, the distance amongst a user and the vertical distance of the BS, positioned at (x_0, y_0), can be computed as.

$$D = \sqrt{(x_0 - x_1)^2 + (y_0 - y_1)^2} \tag{3.1}$$

The superimposed signals are transmitted by the BS to two users as shown in fig (5), with User 2 consuming a higher channel gain than User 1. In NOMA, the user with the maximum channel gain is devoted as the strongest user and the user with the minimum channel gain is recognized as the weakest user. The strongest user firstly detracts the weakest user signal using SIC. The weakest user then interprets its own signal, inspecting the strongest user signal as noise and directly decoding its own signal. To conserve impartiality, the weakest user is allocated more power in NOMA.

NOMA has demonstrated enhanced performances when pairing users with diverse channel conditions [44], specifically by pairing the user with the best channel ($|h_\nu|$) and the user with the worst channel ($|h_\tau|$) The channel coefficients of ground users can be represented as $|h_1|^2 \geq |h_2|^2 \geq \cdot \cdot \cdot \geq |h_N|^2$, where N signifies the total number of users, and the list is sorted based on increasing horizontal distance.

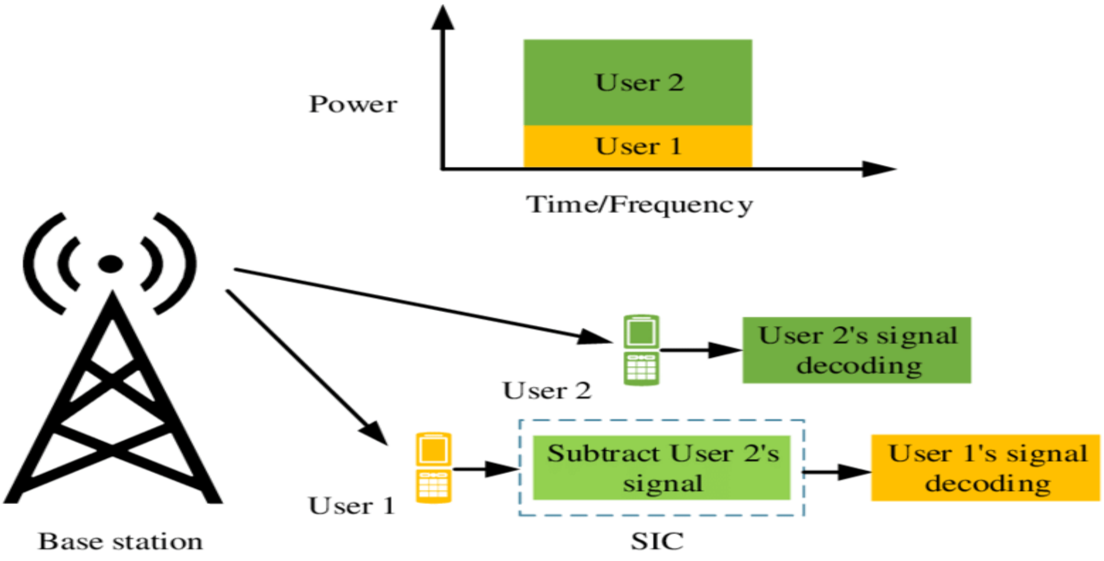


Figure 3.2: Working of SIC RECIEVER

Notably, as the horizontal distance increases, users experience poor channel conditions. Without forfeiture of generalization, suppose users τ and ν be nominated to form the m^{th} pair, where $1 \leq m \leq M$ (M represents the number of pairs). Consequently, the superimposed signal for a pair is expressed as follows:

$$x_\Gamma = \sum_{\Gamma=(\tau,\upsilon)m} \sqrt{P_\Gamma \varkappa_\Gamma}, \ \forall\, 1 \leq m \leq \mathcal{M} \tag{3.2}$$

Where PΓ is the transmission power for the τ^{th} (weak user) and ν^{th}(strong user). Next, the received signal at each user of the m^{th}pair.

$$y_\tau = h_\tau\left(\sqrt{\alpha_\tau P x_\tau} + \sqrt{\alpha_v P x_v}\right) + \eta_\tau \tag{3.3}$$

$$y_v = h_v\left(\sqrt{\alpha_\tau P x_\tau} + \sqrt{\alpha_v P x_v}\right) + \eta_v \tag{3.4}$$

Where η_τ represent the noise power. α_τ and α_ν represents the power allocation factor which are calculated using (7), To achieve an interference-free transmission rate, it is assumed that perfect SIC is implemented at the τ^{th} user of each pair [123]. Conversely, for the ν^{th} user, the signal is interpreted without eliminating the interference from the other user in the same pair. Consequently, the specific rates of the τ^{th} and ν^{th} users can be expressed as follows:

$$\Upsilon_\tau = log_2(1 + \frac{P_\tau}{Pv + \frac{1}{\Theta_\tau}}) \tag{3.5}$$

$$\Upsilon_v = log_2(1 + P_v \Theta_v) \tag{3.6}$$

Where α_τ and α_v represents the power allocation factor which are calculated using (7), and the detailed formulation can be found in [124]. The Θ_τ and Θ_v are given in (8) and (9) and P_n is the noise power.

$$\alpha_\nu = \frac{\beta_1}{\sqrt{1+p|h_\tau|^2}+1} + \frac{\beta_2}{\sqrt{1+p|h_v|^2}+1} \tag{3.7}$$

Where β_1 and $\beta_2$are the constant and their value is β_1+β_2=1 and$\alpha_\tau = 1 - \alpha_v$.

$$\Theta_\tau=\frac{|h_\tau|^2}{P_n} \tag{3.8}$$

$$\Theta_v=\frac{|h_v|^2}{P_n} \tag{3.9}$$

Where,Θ_τ represents the channel quality of the weak user τ when the interference from the τ^{th} user is considered as noise. Since the proposed scheme follows a two user pairing approach, user pairing matrix is familiarized to certify that each user is paired with only one user, and a maximum of two users share a single channel resource block. Additionally, it is crucial to compare the recital of NOMA with that of a correspondent OMA scheme to conduct a fair analysis. In the OMA scheme, each user communicates without interference in its allotted time, frequency channel resource, and the specific data rate for each OMA user is demarcated as follows:

$$\Upsilon_{OMA} = \frac{1}{2} log_2 \,(1+ \frac{P_{max}}{P_n}) \qquad (3.10)$$

The scalar factor $\frac{1}{2}$ in equation (10) represents the multiplexing loss incurred when using OMA for transmission, in assessment to the NOMA system. Consequently, the minutest transmission rate for the given problem must be at least equivalent to the rate attainable with OMA. Thus, the primary impartial is to exploit the total capacity while adhering to specific restraints by optimizing the pairing matrix and allotting power to the NOMA users. The proposed capacity maximization problem is articulated as follows:

$$F = \max_{P,U} \sum_{m=1}^{M} (\Upsilon_{\tau}^{m} + \Upsilon_{v}^{m})$$

$$C_1 : \Upsilon_{NOMA} \geq \Upsilon_{OMA} , \forall\ 1 \leq n \leq N$$

$$C_2 : \sum u_n = 1, \forall\ 1 \leq n \leq N \qquad (3.11)$$

$$C_3 : \sum u_m = 2, \forall\ 1 \leq m \leq M$$

$$C_4 : \alpha_{\tau} + \alpha_{v} \leq p^{max} , 0 < p^{max} \leq 1$$

The constraint C1 states that the capacity of each user in a NOMA system would be equivalent to or larger than the data rates attainable over OMA for each user within the coverage area. The Constraints C3 and C2 pertain to user pairing. C2 specifies that each user must be paired with another user exactly once, while C3 states that there can be a maximum of two users assigned to a single resource block. Constraint C4 is correlated to the maximum transmission power. It stipulates that the combined power allocated to the τ^{th} and ν^{th} users should not exceed a specified value denoted as P^{max} .

3.3 Proposed Methodology

Keeping in view of the research objectives, based on these performance metrics, an optimization function along with the corresponding constraints is developed in equation (11). Next, the heuristic algorithms are applied to maximize the sum rate of the NOMA users. The general optimization flow chart is presented in Fig. 3.3 and 3.4 shadowed by an overview of the objective function and accompanying techniques employed in the thesis.

The objective function of equation (11) is augmented using iterative heuristic algorithms. The optimization of the joint-user pairing matrix aims to achieve the objective described above. Solving the problem outlined in equation (11) requires finding the optimal solution and corresponding user pairing that maximizes the entire capacity of the system. However, this user pairing optimization problem is a type of combinative optimization problem, which is typically non-convex. The complete computation of the optimum user pairing for the objective function involves examining a huge number of possible user pairs. Furthermore, the proposed optimization, which aims to identify the best amalgamation of channel conditions amongst users and maximize the system's total rate, is a complex problem without a straightforward solution. Therefore, heuristic algorithms are used to tackle the user pairing problem defined in equation (11). Specifically, the user pairing problem is addressed using meta-heuristic techniques. Heuristic techniques refer to problem-solving approaches or algorithms that aim to find practical and efficient solutions by employing intuitive, approximate, or rule-of-thumb strategies [125]. These techniques do not guarantee an optimal solution but rather provide an acceptable or satisfactory solution within a reasonable amount of time. Heuristics often involve making educated guesses, using domain-specific knowledge, or employing iterative processes to narrow down the solution space and find a feasible outcome. They are commonly castoff in various fields, including artificial intelligence, optimization, decision making, and problem solving. There are several kinds of heuristic techniques that are commonly used in problem solving and optimization tasks. Some of the prominent types of heuristic techniques includes:

- Genetic Algorithm (GA)
- Artificial Hummingbird Algorithm (AHA)

- Particle Swarm Optimization (PSO)
- Cat Swarm Optimization (CSO)
- Hybrid GA-PSO
- Ant Colony Optimization (ACO)

This research focuses on the following Optimization algorithms:

- Genetic Algorithm (GA)
- Artificial Hummingbird Algorithm (AHA)

3.4 Genetic Algorithm (GA)

GA are a kind of heuristic optimization method enthused by the procedure of natural selection and evolution. They operate by forming a population of potential resolutions, also known as individuals. Through a sequence of reiterative steps, these algorithms employ genetic operators such as selection, crossover, and mutation to progressively refine and enhance the solutions across successive generations. GA are particularly effective for problems with a large search space and multiple possible solutions [126].

The algorithm commences by initializing an initial population of potential solutions. Each solution is represented as an individual or chromosome. Each individual has a set of parameters or genes that encode a potential solution. The population undergoes an iterative process consisting of several steps:

1. Initialization: Make an initial population of individuals randomly or using a predefined strategy.
2. Evaluation: Assess the fitness of each individual in the population based on an impartial function that computes the superiority of the solution. The impartial function epitomizes the optimization goal.

3. Selection: Select individuals from the population for reproduction, typically based on their fitness. Individuals with higher fitness have a higher chance of being selected, imitating the survival of the fittest principle.
4. Reproduction: Create offspring or new individuals by applying genetic operators such as crossover and mutation. Crossover comprises compounding the genetic substantial of two parent individuals to make offspring with a mix of their characteristics. Mutation presents small arbitrary changes to the genes of individuals to preserve diversity in the population.
5. Replacement: Swap some individuals in the current population with the afresh formed offspring, based on a certain replacement strategy. This ensures the population evolves over time towards better solutions.
6. Termination Criteria: Determine if the termination norms are met, like accomplishing a supreme number of iterations or attaining a pleasing solution. If the termination criteria are not met, go back to step 2 and continue the process.

By iteratively applying selection, reproduction, and replacement steps, the GA explores the search space, favoring individuals with higher fitness and gradually improving the complete population. Over multiple generations, the algorithm meets towards optimal or near-optimal solutions.GA have been efficaciously applied to various optimization complications, including function optimization, scheduling, routing, and machine learning. They offer advantages such as parallelism, robustness, and the ability to handle large and complex search spaces. The flow chart of GA is revealed in figure 3.3, while algorithm is explained step by step in Figure 3.4.

3.5 Artificial Hummingbird Algorithm (AHA)

The AHA is a nature inspired optimization algorithm that is dependent on the behavior and characteristics for humming birds. It is a population based metaheuristic algorithm that objects to discover optimal or near optimal solutions to optimization problems. The algorithm takes inspiration from the foraging behavior of hummingbirds, which involves searching for nectar-rich flowers in their environment. This behavior is translated into a search process where potential solutions, represented as hummingbirds, explore the search space for better solutions [127]. The Artificial Humming Algorithm typically involves the subsequent steps:

- Initialization: Generate an initial population of hummingbird solutions randomly or using a predefined strategy.
- Evaluation: Evaluate the fitness of each hummingbird solution based on the objective function of the problem being optimized.
- Update Positions: Update the positions of hummingbirds based on their current positions, velocities, and the influence of other hummingbirds in the population. This step involves balancing exploration and exploitation to guide the search process.
- Local Search: Optionally, perform local search operations to further refine the solutions around promising regions of the search space.
- Termination Criteria: Determine if the termination criteria are met, such as attain a maximum number of iterations or attaining an acceptable solution.
- Output: Return the best solution found during the optimization process as the result.

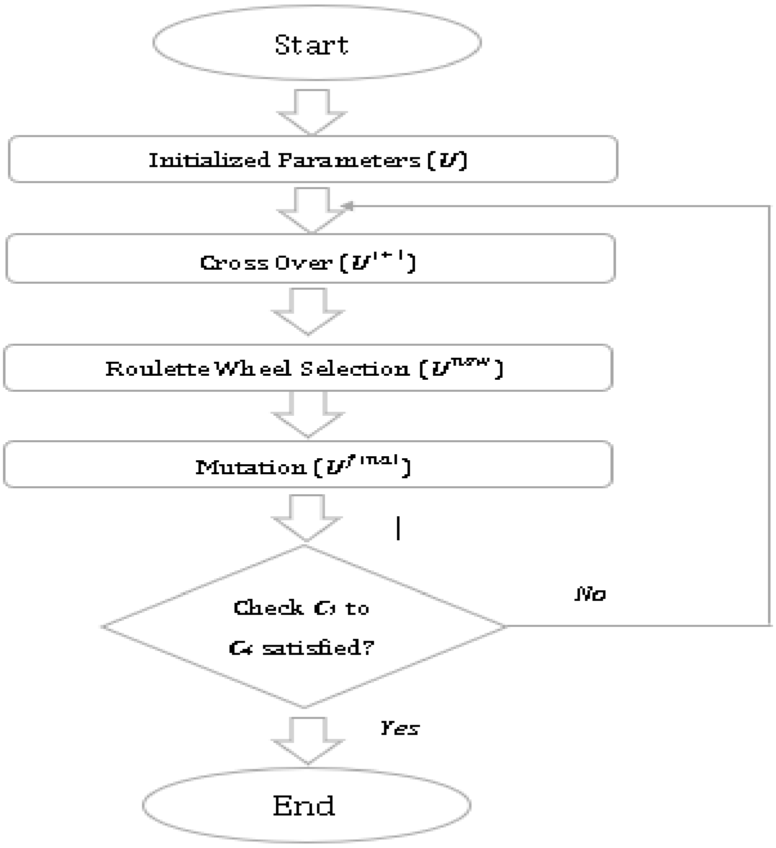


Figure 3.3: Flow chart of Genetic Algorithm

Genetic Algorithm (GA)

```
1.  Step I: Initialization
      — Set the number of chromosomes, candidate solutions, Max-Iterations, and
        mutation rate
      — Generate Initial population
2.  Step II: Fitness evaluation
      — Check the fitness of each chromosome through Eq. 11
      — Find the best solution
3.  Step III: Crossover
      — Select two solutions and identify the random position to perform crossover
      — Get the updated solution
4.  Step IV: Roulette Wheel Selection
      — Evaluate the fitness of the updated solution
      — Calculate the probability of the candidate solution according to their fitness
        value
      — Sort the solutions according to their probabilities
      — Apply Roulette Wheel Selection
      — Get the new solution
5.  Step V: Mutation
         If the final solution is not converging?
      — Select the candidate solution randomly
      — Apply mutation by swapping the position of the two users with another in the
        same candidate solution.
        else
      — Go to Step V
        end
      — Get updated sub-optimal pairing


6.  Step V: Termination Criteria

        If the Max-Iterations reached?

      — Stop the Algorithm

        else

      — Repeat step IV


        end
```

Figure 3.4: Genetic Algorithm

The Artificial Hummingbird Algorithm can be useful to numerous kinds of optimization problems, including continuous, discrete, and combinative problems. It offers a balance among exploration and exploitation, permitting for efficient search in complex and high-dimensional search spaces. It's important to note that the specific implementation details and variations of the algorithm may vary, and different researchers may have proposed their own modifications or enhancements to the basic algorithm. The flow chart of AHA is revealed in figure 3.5, while algorithm is explained in figure 3.6.

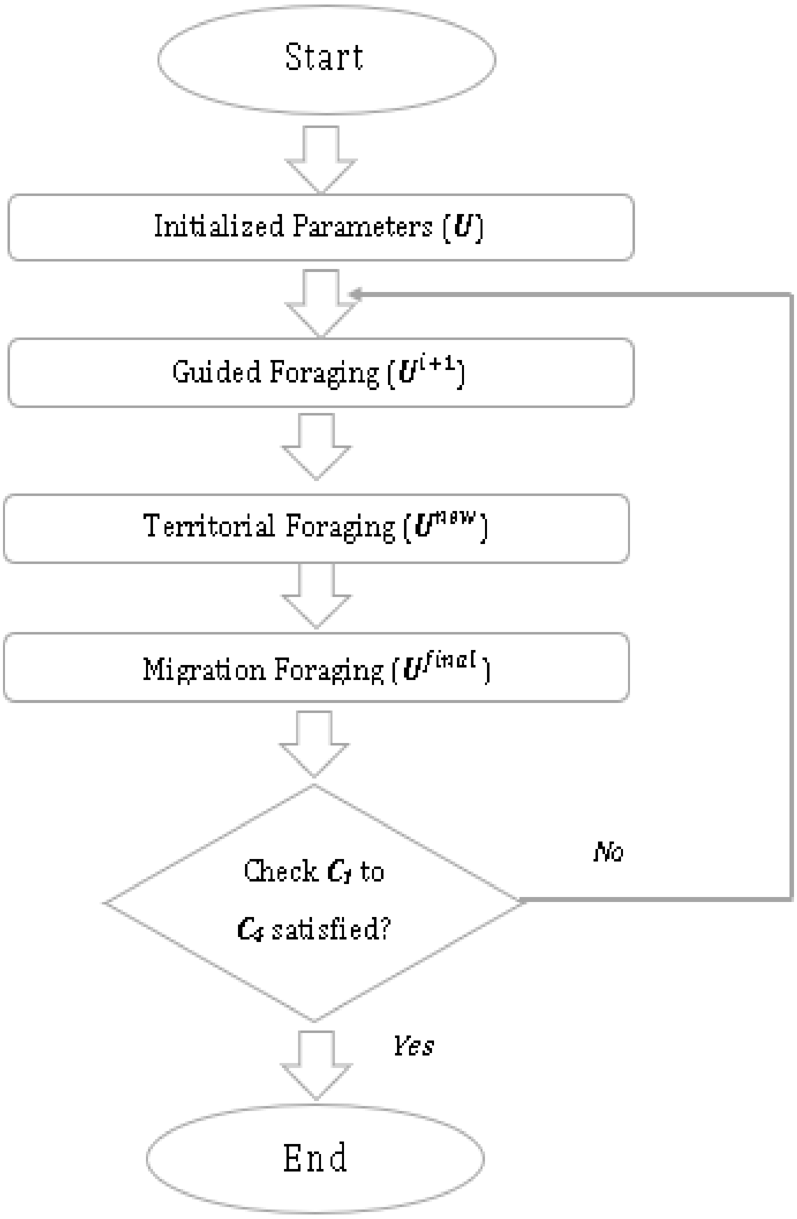


Figure 3.5: Flow chart of AHA Algorithm

Artificial Hummingbird Algorithm (AHA)

```
1.  Step I: Initialization
        — Set the population of N hummingbirds on N food source, candidate solutions,
          Max-Iterations, direction vector, and migration coefficient.
        — Generate Initial population.
2.  Step II: Fitness evaluation
        — Check the fitness of each chromosome through Eq. 11
        — Find the best solution.
3.  Step III: Guided foraging
        — Determine the food source with the highest nectar refilling rate as the target food
          source
        — Set the initial dimension Dim for the food source
          If  rand_number < 1/3

          Apply diagonal flight

        — Generate the random direction vector Dim_vector of the food source upto Dim
        — Select the random direction from the Dim_vector
        — Set the direction of that food source equal to 1
          else if rand_number > 2/3

          Apply omnidirectional flight

        — Set the direction of the current food source equal to 1
          else

          Apply Axial flight

        — Multiply the random_number with Dim and select the Direction of that food
          source equal to 1
          end

        — Get the updated direction vector
        — Get the updated solution using the direction vector


4.  Step IV: Territorial foraging
        — Apply exploration
        — Get the new solution
        — Apply greedy search between the fitness of Step III and Step IV.
        — Get the new updated solution
5.  Step V: Migration foraging

          If current iteration == 2*candidate solutions?
```

```
        —  Apply exploitation
           end
6.  Step V: Termination Criteria
           If the Max-Iterations reached?
        —  Stop the Algorithm
           else
        —  Repeat step IV
           End
```

Figure 3.6: Artificial Hummingbird Algorithm

The users are categorized into two clusters: Group A and Group B, based on their distance from the BS. Group A consists of cell-center users, who have better channel gains, while Group B includes cell-edge users, who are farther from the BS. To streamline the search process, the proposed scheme restricts user pairing within different groups. This restriction is supported by the observation that NOMA performs well once user with distinct channel conditions are assembled together [44]. Consequently, users that are farther apart after each other are considered ideal contenders for transmission as pair. User pairing occurs by randomly selecting a user from one group and pairing them with a user from the opposite group. Subsequently, sum capacity is premeditated for each potential pairing solution. The solutions are then sorted in descending order, and the corresponding sum capacity is associated with each candidate solution. The proposed approach begins by randomly pairing users from both Group A and Group B to create NOMA user pairs. Then, the optimization process proceeds by utilizing the MATLAB tool to compute the optimal solution while keeping the user pairing fixed. Following that, steps allied with GA and AHA, like crossover, mutation, and position updates, are utilized to augment the user pairing. At each step, the objective function described in equation (11), is updated, and the ideal solution is iteratively assessed while ensuring that all the restraints are satisfied. The proposed algorithm continues running for a specified number of cycles or iterations. Throughout these cycles, the algorithm aims to output the optimal user pairing and corresponding power provision, maximizing the sum rate of the NOMA scheme. The proposed algorithm for sum capacity optimization is shown in algorithm 1.

Algorithm 1: Joint User Pairing and Power Allocation Algorithm

```
1.  Step I: Initialization
        — Set U, N, $\alpha$, $\beta_{2}$, and $R_c$
2.  Step II: Smart Meters Deployment
        — Randomly distribute $N$ users in the radius of $R_c$
        — Generate distance matrix $D$ (distance from smart meters to data collector) using Eq. 1
        — Calculate the channel coefficients following the distance $D$
3.  Step III: Power Allocation and Benchmark schemes evaluation
        — Calculate the power allocation vector for the proposed pairing schemes through Eq. 7
        — Calculate the OMA rate using Eq. 10
        — Generate benchmark pairing schemes (Random pairing and Adjacent Pairing)

4.  Step IV: Apply GA or AHA

        If GA

        — Apply crossover
        — Apply Roulette Wheel Selection
        — Apply Mutation (if required)

        else if AHA

        — Apply Guided foraging
        — Apply Territorial foraging
        — Apply Migration foraging

        end

        — Get updated sub-optimal pairing


5.  Step V: Termination Criteria
        — Check constraints $C_1$ to $C_4$ satisfaction
        — Check if the required solution is obtained

        If constraints are satisfied and the required solution is achieved?

        — Stop the Algorithm

        else

        — Repeat step IV

        end
```

CHAPTER 4

SIMULATION RESULTS AND DISCUSSION

A comprehensive analysis is conducted to assess the influence of various user-pairing schemes, coverage area and SNR on the optimization of the sum rate. For the simulations, a constant maximum transmission power of 1 watt is assumed for a single pair of users. The total number of SMs deployed in the system is 50 and the coverage radius of the BS is taken as 100 meters. Cluster contains half the number of total SMs (25 in each). The signal strength attenuates moderately with path loss exponent i.e., 2.5. The optimization process runs for a maximum of 100 cycles. The imitation has been passed out in three dissimilar surroundings: urban, suburban, and dense urban taking into account different scenarios and conditions. The primary objective of the analysis is to maximize the sum rate of the system using the objective function defined in equation (11) while satisfying all the relevant constraints. A comparative study is steered to compare the performance of OMA with the optimization achieved through the GA and the AHA. Through this analysis, the aim is to determine which user-pairing scheme, along with the corresponding optimization technique, yields the highest sum rate. By evaluating the performance of OMA, GA-based optimization, and AHA-based optimization, valuable insights can be gained regarding the effectiveness and efficiency of different approaches in achieving the maximum sum rate. The subsequent niceties the proposed methodology, where an explanation of each parameter is described in Table 4.1.

4.1 Analysis of Pairing Schemes

The section focuses on analyzing four distinct user-pairing schemes in assessment to OMA. The pairing schemes examined are categorized as worst pairing, random pairing, GA pairing, and AHA-based pairing. Each scheme is evaluated with respect to its performance in comparison to OMA. The worst pairing scheme involves pairing users with the shortest distance between them, emphasizing a close-proximity approach. In contrast, random pairing selects user pairs randomly, without any specific criteria or preference. The GA pairing scheme utilizes the GA to augment the user pairing process, while the AHA based pairing scheme is proposed approach deliberated in the methodology section, leveraging the AHA for user pairing. By conducting a comprehensive analysis of these pairing schemes, their respective performances are assessed in comparison to OMA. This analysis aims to deliver treasured discernments into the strengths and weaknesses of each scheme, allowing for a better understanding of their effectiveness in achieving optimal user pairing and maximizing system performance.

Table 4.1: Simulation Parameters

Simulation Parameters	**Values**
Smart meters (N)	50
Coverage radius (Rc)	100m
Clusters	$0.5 \times (N)$
SNR	20 Db
Path loss exponent (α)	2.5
Candidate solutions (J)	30
Max iterations	100
β_2	0.2
BS coordinates	(0,0)
Max users in a cluster	2
Transmission power of a cluster (p)	1W
Genetic Algorithm (GA)	
Crossover	Single point
Selection	Roulette wheel
Mutation	Adaptive
Artificial Humming bird Algorithm (AHA)	
Migration coefficient	2J

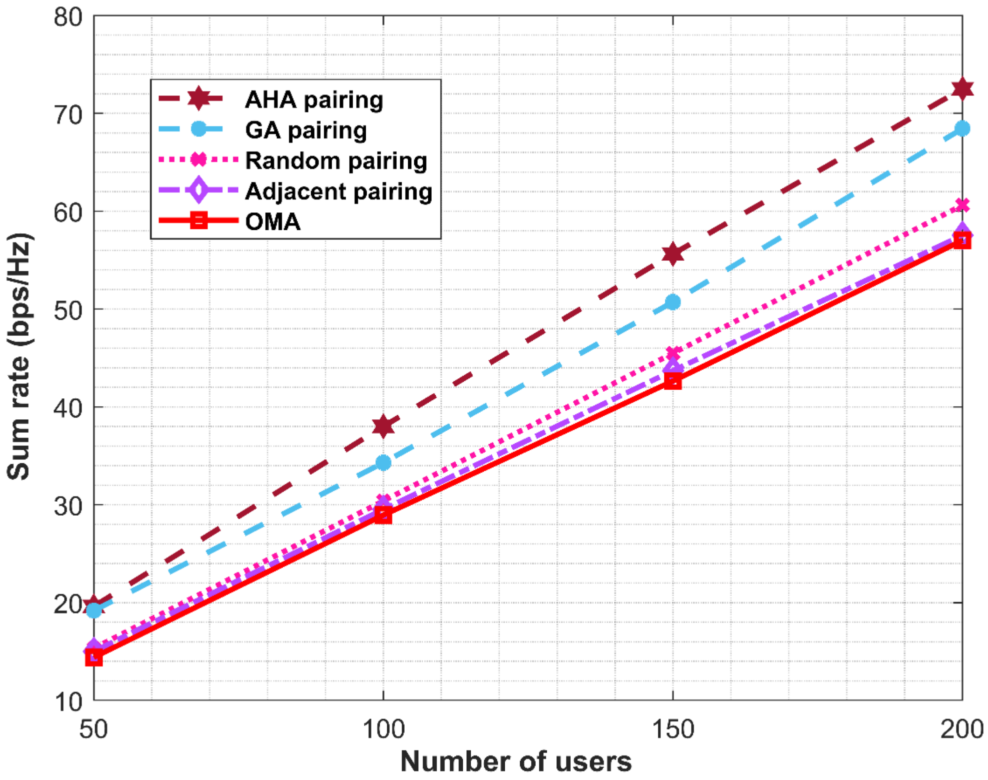


Figure 4.1: Comparative analysis of different pairings

In Figure 4.1, the "sum rate" refers to the cumulative data rate achieved by each pairing scheme. It is a measure of the total data transmission capacity or throughput achieved by the scheme. The sum rate takes into account the combined data rates of all user pairs in each pairing scheme, providing a key metric for evaluating the overall performance of the schemes. Illustrates a comparative analysis of different user pairing. The performance of different pairing schemes is matched against OMA. The optimization of sum rates is achieved through both GA and AHA-based schemes, with multiple iterations considered. When the number of users is 100, AHA demonstrates percentage improvements of 9.76% over GA, 20.02% over random, 22.28% over adjacent, and 23.84% over OMA. However, with 200 users, AHA shows higher percentage improvements: 5.59% over GA, 16.39% over random, 21% over adjacent, and 21.35% over OMA. The outcomes determine that the user pairing performed by GA and AHA overtakes OMA in rapports of sum rate optimization. The use of GA and AHA techniques in the NOMA system yields improved performance compared to the traditional OMA approach.

Furthermore, the convergence of the AHA algorithm is observed to be faster when compared to GA. This implies that the AHA-based user pairing scheme converges more rapidly to an optimal solution, resulting in a higher sum rate compared to GA over the course of the iterations.

Table 4.2 presents a comparison of different pairing schemes in different coverage radius.

Table 4.2: Comparative analysis of user pairing in different Scenario

Coverage Region (Meters)	AHA Pairing	Random Pairing	Adjacent pairing	OMA
50	24.87	23.43	24.30	21.69
70	13.82	13.63	13.76	12.51
90	8.73	7.69	8.33	7.11
110	6.27	5.96	5.76	5.25
130	4.33	3.97	4.20	3.64
150	3.75	2.97	3.0	2.74

4.2 Impact of Varied SNRs

The results obtained determine the superiority of the proposed AHA based user pairing scheme compared to other approaches. Fig 4.2 shows that the minimum sum rate necessity rises with increasing SNR values for all placement scenarios. Also presents an analysis of the impact of varied SNRs on the enactment of user pairing in all the environments considered.

Two parameters of transmitted power are considered in Table 4.3. At a power level of 50 dBm, AHA demonstrates percentage improvements of 2.72% over GA, 9.75% over random, 11.91% over adjacent, and 18.58% over OMA. When the power is increased to 100 dBm, AHA exhibits percentage improvements of 4.23% over GA, 9.83% over random, 12% over adjacent, and 18.58 % over OMA.

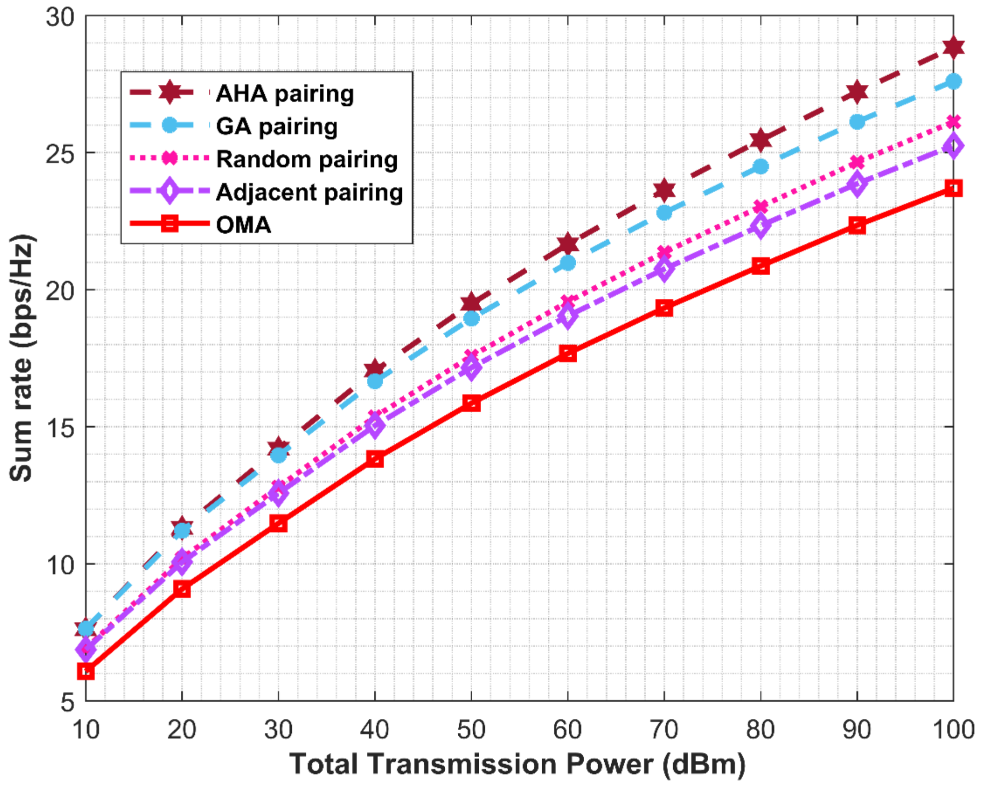


Figure 4.2: Impact of Varying Transmission Power

4.3 Impact of Environments

The outcomes highlight the enhanced enactment of the AHA-based approach matched to alternative methods, reaffirming its effectiveness and superiority. By examining the effect of different SNRs. These findings provide valuable insights for optimizing user pairing in various environments and enhancing the overall system performance.

Table 4.3: Impact of varying Transmission Power

Transmit Power (dBm)	Over GA	Over Random	Over Adjacent	Over OMA
50	2.72%	9.7%	11.91%	18.58%
100	4.23%	9.83%	12%	18.79%

Table 4.4: Effect of varying environment on system capacity for different pairing schemes

Transmitted power (dBm)	**Environments**	**AHA Pairing**	**Random Pairing**	**Adjacent Pairing**	**OMA**
30	Suburban	7.40	6.63	6.58	5.51
60		10.60	9.36	9.24	7.95
90		13.04	11.48	11.26	9.86
30	Urban	3.24	3.13	3.13	2.28
60		4.45	4.21	4.21	3.04
90		5.28	4.92	4.92	3.57
30	Dense urban	1.75	1.74	1.74	1.3
60		2.54	2.51	2.51	1.78
90		3.07	3.03	3.03	2.09

The path loss exponent serves as a key parameter to model the attenuation characteristics of wireless signals in different environments. It allows researchers to predict and optimize signal coverage, range, and performance for various scenarios, thereby guiding the design and deployment of wireless communication schemes in suburban, urban, and dense urban areas. We considered path loss exponent 2.5 for suburban. For urban we take path loss exponent 3. And for dense we use path exponent of 3.5.

It is evident from the simulations that NOMA outperforms OMA consistently across different environments, demonstrating its superior performance. The optimization of user pairing using the AHA further confirms the performance advantages of NOMA in diverse environmental conditions. NOMA elasticities enactment improvement of 44% in suburban, 31.74% in urban, and 23.4% in the dense urban environment. Figures 4.3 shows the individual rates of users of different groups. Table 4.4 shows the effect of varying environment on system capacity for different pairing schemes, also shows the improvement of AHA over different pairing.

When β_2 is 0.2, less power is allotted to the strong user, then the percentage improvement of AHA compared to GA is 2.25%, over random it's 3.4%, over adjacent it's 2.56%, and over OMA it's 1.28%. When β (beta) increases from 0 to 1, subsequently power increases, the overall capacity also increases. This results in performance improvements of

AHA with percentage improvements of 2.54% over GA, 23.2% over random, 1.34% over adjacent, and 1.87% over OMA.

Table 4.5 shows the percentage improvement of AHA over other pairing schemes when beta_2 is increased from 0.2 to 1.

Figure 4.4 shows the simulations corroborate the efficiency of the proposed algorithm, the progressive increase in power from 0 to 1dBm results in a consistent rise in overall capacity with AHA showing superior improvements in the sum rate compared to GA. Additionally, the algorithm performs better in suburban environments than in urban and dense urban settings.

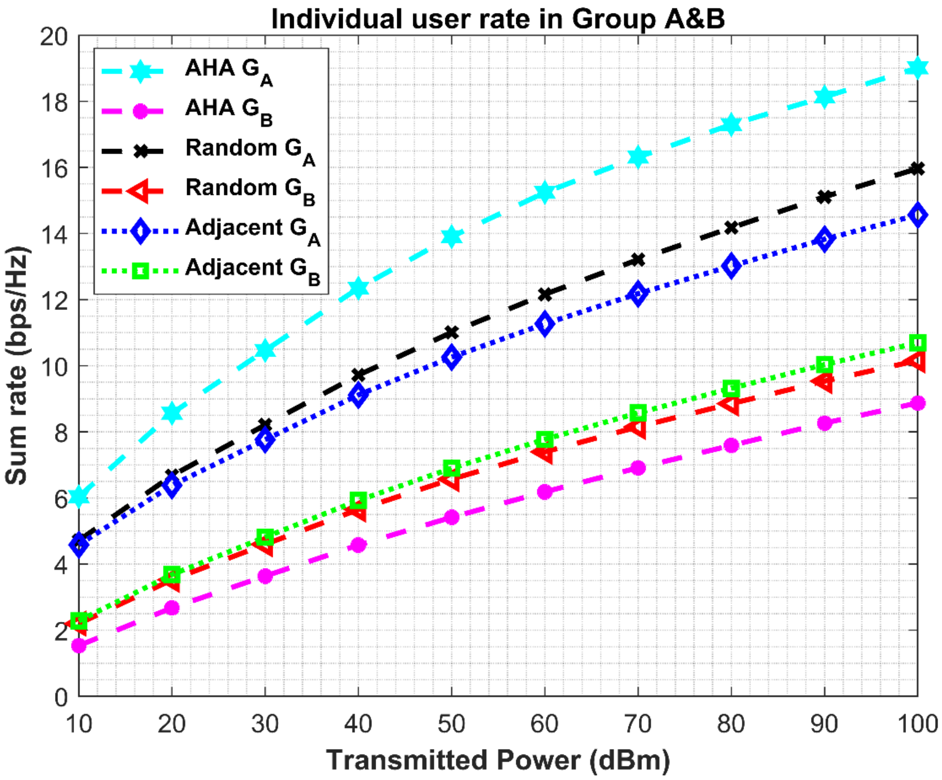


Figure 4.3: Individual user rates in Group A and B

Table 4.5: Shows percentage improvement of AHA over other pairing schemes

Beta_2	**Over GA**	**Over Random**	**Over Adjacent**
Beta_2=0.2	2.55%	9.46%	15.95%
Beta_2=1	9.81%	14.32%	18%

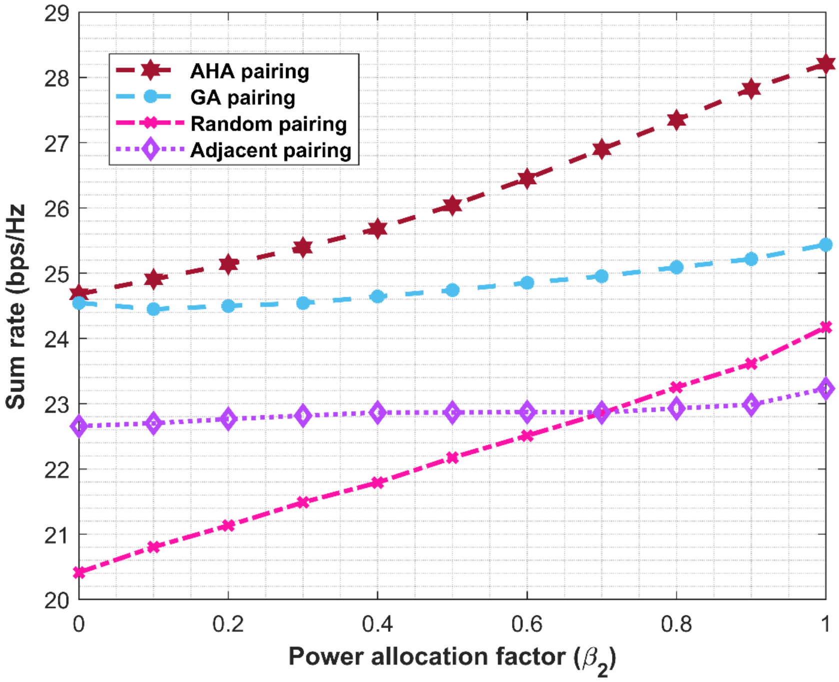


Figure 4.4: Impact of Varying β_2

The comparison of results through figures and numerical tables demonstrates that both power and user pairing algorithms effectively optimize capacity using a heuristic approach. Additionally, the detailed analysis of various user pairings highlights the efficacy of the proposed solution.

CHAPTER 5

CONCLUSION AND FUTURE DIRECTIONS

5.1 Conclusion

Efficient communication is a crucial requirement for smart grid operations, but the limited availability of spectrum necessitates optimal resource utilization. To address the challenges of capacity optimization, fairness, and energy efficiency in future wireless systems. This research emphasizes the potential of NOMA as an auspicious solution. This research focuses on the design considerations of user pairing and power allocation for implementing NOMA on SGCN. To attain efficient user pairing in a NOMA based SGCN, a comparative analysis between GA and AHA methods is conducted. The delinquent of user pairing and power optimization is articulated, and GA and AHA algorithms are engaged to perform user pairing. The capacity is then optimized using an algorithm specifically designed for this purpose. Simulation outcomes exhibit the preeminence of the proposed AHA algorithm over GA, showcasing its capability to expressively increase the sum rate. Furthermore, the research findings indicate that the sum rate performance in a suburban environment surpasses that of urban and dense urban environments. This conclude that NOMA can deliver better performance in suburban settings compared to more densely populated areas.

5.2 Contributions and Significance

In all previous studies, NOMA is not thoroughly investigated in term of SG. The utilization of NOMA to optimize the capacity in NAN based SGCN is the dire need of the present time. NAN is an important part of SGCN because its conveyances a vast amount of data among service providers in WAN and smart devices in HAN. A massive volume of SMs data needs to be transferred in NAN. Hence, this research can be helpful in capacity optimization in such scenarios

5.3 Limitations and Scope of Future Work

1. The problem is formulated for the first time in this manner, for the sake of simplicity only two user pairing was assumed. This can be further explored that what would be the effect of having more than two users in a group rather than a pair of two users.
2. The scalability of NOMA in large scale SG networks with a high density of devices needs to be further investigated. As the number of devices increases, the complexity of user pairing and power sharing algorithms may become a bottleneck in terms of computational resources and processing time.
3. NOMA relies on the efficient management of interference among users sharing the same spectrum resources. Nevertheless, in SGCN, interfering can be more significant due to the presence of various devices and communication scenarios. Future research should focus on developing interference management techniques tailored specifically to SGCN environments.
4. In this research, we focused on capacity optimization and same network model can be used to further investigate the problem of energy efficiency and fairness with a little modification in mathematical model.
5. The SG often requires real-time communication for critical operations and control. It is essential to investigate the feasibility of implementing NOMA in SGCN while meeting the stringent latency requirements of the grid. This includes examining the bearing of channel conditions, user mobility, and dynamic power sharing on real-time recital.

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