Potential Challenges and Solutions for Implementing NOMA in Smart Grid

Muhammad Hussain[*1], Muhammad Zohaib Sohail[2] Qamar Ud Din Memon[1] and Taimoor Zafar[2]
[1]Software Engineering Department, Bahria University, Karachi, Pakistan
[2]Electrical Engineering Department, Bahria University, Karachi, Pakistan
***Correspondence:** Muhammad Zohaib Sohail, mzohaib.bukc@bahria.edu.pk

Citation | Hussain. M, Sohail. M. Z, Memon. Q. D, Zafar. T, "Potential Challenges and Solutions for Implementing NOMA in Smart Grid", IJIST, Vol. 6 Issue. 2 pp 632-651, June 2024
DOI | https://doi.org/10.33411/ijist/202462632651
Received | May 17, 2024 **Revised |** May 29, 2024 **Accepted |** June 05, 2024 **Published |** June 09, 2024.

Efficient two-way communication is crucial for Smart Grid (SG) networks, enabling real-time monitoring, data collection, and control. This study introduces the novel integration of Non-Orthogonal Multiple Access (NOMA) into SG systems to enhance spectral efficiency and support numerous smart devices, addressing the limitations of traditional communication methods. A comprehensive survey of existing wired and wireless communication technologies was conducted, followed by the implementation of a NOMA scheme tailored for SG environments. Results demonstrate that NOMA significantly improves spectral efficiency, enables access to a large number of smart meters, and enhances the system's resilience to electromagnetic interference. Additionally, the study addresses challenges such as impulse noise, optimizing spectral and energy efficiency tradeoffs, and power consumption in interference cancellation. These findings underscore the potential of NOMA to revolutionize SG communication infrastructure. Conclusively, integrating NOMA in SG networks offers a robust solution for future smart grid communication needs.

Article Reading Keys
Smart Grid (**SG**)
Non-Orthogonal Multiple Access (**NOMA**)
Smart Meter (**SM**)
Power Division Multiple Access (**PDMA**)
Successive Interference Cancellation (**SIC**)
Advanced Metering Infrastructure (**AMI**)
Home Area Networks (**HANs**),
Neighborhood Area Networks (**NANs**)
Wide Area Networks (**WANs**)
Impulse Noise (**IN**)
Successive Interference Cancellation (**SIC**)
Energy Efficiency And Spectral Efficiency (**EE-SE**)
Orthogonal Frequency Division Multiple Access (**OFDMA**)
Successive Interference Cancellation (**SIC**)
Quality of Service (**QoS**)
Neighborhood Area Network (**NAN**)
Field Area Network (**FAN**)
Wide Area Network (**WAN**)
Local Area Networks (**LANs**)
Automated Meter Reading (**AMR**)
Narrowband PLC (**NB-PLC**)
Broadband PLC (**BB-PLC**).
Bit Error Rate (**BER**)
Electromagnetic Interference (**EMI**)
Building Area Networks (**BAN**)
Power Line Communication (**PLC**)

Keywords: Smart Grid (SG), Smart Meter (SM) Non-Orthogonal Multiple Access (NOMA), Power Division Multiple Access (PDMA), and Successive Interference Cancellation (SIC).

Introduction:

The Smart Grid (SG) is transforming into an intelligent power grid, driven by numerous goals. First, it aims to ensure the delivery and production of power is more economical. Second, to deliver energy to customers with electronically accessible information, helping them make more knowledgeable choices about their energy utilization and pricing control. Third, to minimize the production of greenhouse gases by allowing greater usage of renewable resources. Fourth, to increase the reliability of the system. Fifth, it enables the power grid to support the development of electric vehicles, thereby reducing the dependency on oil [1].

The SG encompasses two key categories of delivery: bidirectional energy delivery and two-way information exchange. The concept of bidirectional energy delivery refers to the flow of energy from power stations to consumers and vice versa, encompassing energy generation and consumption dynamics. Similarly, the approach involves real-time data exchange between power companies and consumers, facilitating efficient monitoring and control of energy parameters within the SG. The SG comprises multiple sub-units for precise operations, among these, the communication infrastructure plays an essential role in exchanging instantaneous information between devices and systems associated with the SG. In the SG, Smart Meters (SMs) are installed on the customer side to exchange information with the electric supply utility via Advanced Metering Infrastructure (AMI). SMs can collect data using the communication infrastructure and bidirectional communication to control applications, support decentralized generation, collect statistics about utility usage, provide information about energy storage devices or systems, and compose metering units [2].

To support innovative and autonomous grid functionalities in Home Area Networks (HANs), Neighborhood Area Networks (NANs), and Wide Area Networks (WANs) of the SG, efficient, reliable, and flexible communication technology is required. This is essential for the transformation of the conventional power grid into an automated SG, as illustrated in Figure 1. The communication requirements and capabilities of the different types of networks are characterized in Table 1.

Table 1: Communication requirements and capabilities of the different Types of Networks

Network	Coverage Range	Data Rate	Technologies
Home Area Network	10 meters	Control information, generally low bit rate	ZigBee, Wi-Fi, Ethernet, PLC
Neighborhood Area Network	100 meters	Node density-dependent network, control, and user information, the average data rate is 2 Kbps	ZigBee, Wi-Fi, PLC, Cellular
Wide Area Network	kilometers	Gateway connectivity for both the utility and the distribution control system, a few hundred Mbps to a few Gbps	Microwave, WiMax, 3 G/LTE, fiber optic links

In the existing power grid, communication exists at a small level to facilitate simple and limited automatic actions. However, the widespread adoption of extensive communication infrastructure remains largely manual-dependent, especially for control systems and wide-area monitoring that require long-distance deployments. This manual reliance often involves technicians visiting sites and completing recovery procedures. Bidirectional communication in Advanced Metering Infrastructure (AMI) is necessary for monitoring and controlling power outages. SMs in Home Area Networks (HANs) communicate with smart home appliances, while in Neighborhood Area Networks (NANs), meter-to-meter communication is required. Therefore, the latest wireless communication technology is essential not only for commercial viability but also for the robustness of the SG [3].

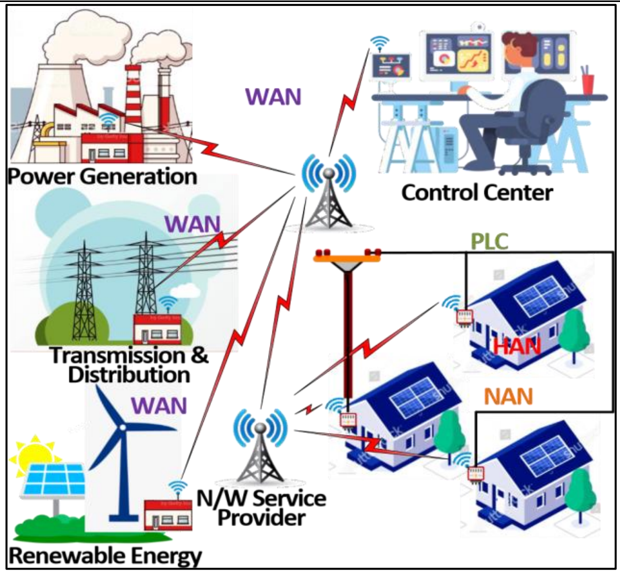

Figure 1: Smart grid communication

Wireless technologies are recognized as the primary choice for implementing SG communication networks due to their easy implementation and low installation costs. However, the performance of SMs is affected by Impulse Noise (IN) present in the power system, caused by external electromagnetic disturbances. Therefore, it is important to investigate and model the IN to achieve the expected goals of the future power grid [4]. There are significant challenges facing SG communication:

Motivation:

- The SG is not only a vast network but rather a composite network comprising a large number of sub-networks.
- There is a large number of connected SMs and other communication devices.
- Real-time transmission is required for operation and control.
- Energy-efficient transmission is necessary to increase capacity.
- Integrating energy-harvesting wireless sensors and actuators.
- High disturbance due to power system noise.

Presently, existing wireless and wired communication infrastructures are relatively adequate to tackle the demands of the SG network. However, the rapid evolution of the SG requires extraordinary communication requirements. It is believed that the newest NOMA scheme can meet these requirements.

Objective:

- Enable dynamic power allocation schemes to facilitate the dynamic deployment of complex networks.
- Massive connectivity by accommodating more users simultaneously.
- Low computational complexity scheme for Successive Interference Cancellation (SIC), making NOMA suitable for real-time transmissions.
- Attain a better trade-off between energy efficiency and spectral efficiency (EE-SE).
- Incorporating energy-harvesting mechanisms.
- Managing the noise by controlling the signal level through power division access.

The communication channel of the SG is often affected by power system noises and interferences. This research aims to address these challenges by presenting appropriate noise models and accounting for these interferences. It utilizes simulation results to demonstrate the performance of the proposed scheme. NOMA is a proposed multiple-access scheme for wireless communication. It is based on power division, contrasting with time and frequency division. Despite the popularity of recent multiple access techniques such as Orthogonal Frequency Division Multiple Access (OFDMA), which offers lower energy costs, higher spectrum efficiency, and significantly reduces interference, OFDMA alone may not be sufficient to meet the requirements of the SG due to division of bandwidth.

In NOMA, each user effectively utilizes the entire bandwidth of the system concurrently and at the same frequency. All users' signals are superimposed and transmitted through the same channel. At the receiving end, each closer user cancels the signal of other farther users through Successive Interference Cancellation (SIC), while the farthest user treats other users' signals as noise [5][6]. NOMA's characteristics align well with the Quality of Service (QoS) and communication requirements arising in Neighborhood Area Network (NAN), Field Area Network (FAN), and Wide Area Network (WAN) implementations in the SG. However, for HAN and Building Area Networks (BAN), existing technologies like Bluetooth, Zigbee, and WiFi can be utilized. In particular, NOMA offers high data rates and meets the diverse service needs of SG applications due to its high bandwidth [7]. A summary of available technologies contributing to SG communication is itemized in Table 2 [8].

Table 2: Communication requirements and Capabilities of the different Types of Networks

Applications	Coverage Range	Data Rate	Technologies
AMI, HAN User data	30-50 m	250 Kbps	ZigBee
AMI, Fraud Detection	1-3 km	2-3 Mbps	PLC
AMI, Demand Response	10-50 km(LOS) 15 km(NLOS)	Up to 75 Mbps	WIMAX
AMI, Demand Response, HAN	1-10 km	384 kbps-2 Mbps	3 G
AMI, Demand Response, HAN	1-10 km	Up to 170 kbps	GPRS
AMI, Demand Response, HAN	1-10 km	UP to 14.4 kbps	GSM

The performance of a wireless communication system is affected by IN produced by power lines due to appliances and other sources. Therefore, there is a need to initially model IN, and then estimate the performance of NOMA in the presence of IN [9]. In this research, we investigated the performance degradation of IN of SG wireless communication. We have presented the best suitable models for IN available in the literature to date. We propose NOMA as a suitable candidate for SG wireless communication and justify this claim.

Contribution:

- Presented a comprehensive study on the architecture of SG communication.
- Discussed potential challenges associated with the implementation of NOMA in SG.
- Presented an existing technological comparison.
- Provided appropriate IN models for SG communication.
- Evaluated the performance of NOMA user pairs in different real-life IN scenarios and compared them with OMA.
- Described actual losses due to IN.
- Justified through simulation that NOMA with IN has a better EE-SE trade-off than OFDMA without IN.
- Provided a trade-off between SIC computation and the peak point of EE-SE.

The rest of the article is planned as follows: Implementation of wireless/wired communication in the SG is reviewed in detail in section II. Potential challenges associated with the implementation of NOMA in SG are presented in section III. The system model, including noise models and solutions to challenges, is presented in section IV. Results and discussions are presented in section V. Finally, we conclude the article in section VI.

Background:

Transforming the conventional power grid into an SG is impossible without the appropriate wireless or wired technology. The National Institute of Standards and Technology (NIST) has released a report on SG standards, presenting a comprehensive review of numerous wireless and wired communication infrastructures that can be utilized for the SG [10]. In consideration of NIST's standards, the contributions of existing technologies in SG communication are as follows:

Wired Communication for SG:

Power Line Communication (PLC) has been identified as a well-balanced solution for remote application and monitoring within the framework of the SG, as claimed by researchers in the literature [11]. It is also suggested that leveraging the widely available existing power line infrastructure for SG communication establishes a 'No New Wired Technology' approach, enabling ubiquitous, reliable, and secure connections. PLC is currently being utilized in in-home Local Area Networks (LANs) and Automated Meter Reading (AMR), among other applications. Based on frequency bandwidth, researchers have classified PLCs into two types: Narrowband PLC (NB-PLC) and Broadband PLC (BB-PLC). For interconnected applications of the SG, NB-PLC is deemed suitable, such as in smart metering, where high data rates are not required. PLC has already been deployed in medium voltage power line networks for fault location and detection. The literature presents significant efforts wherein researchers have reviewed procedures for combined transmission, utilizing both wireless channels and power lines, to enhance reliability in the SG. [12][13].

Additionally, The PLC channel is prone to noise sources such as radio interference, electric motors, and power switches, resulting in noise characteristics. Moreover, power lines exhibit highly time-varying characteristics, further complicating communication reliability. Consequently, PLC has not been widely accepted as a reliable communication medium, leading to a degraded Bit Error Rate (BER) in communication over power lines. Furthermore, researchers have expressed security concerns when utilizing PLC networks for data communication. The unshielded and untwisted structures of power cables create Electromagnetic Interference (EMI), which may affect the receiving module. Attempts to model the characteristics of the PLC channel have been made, such as the adaptive communication protocol designed by researchers in [14], aiming to address the dynamic nature of the wireless channel. However, existing models of the PLC channel still fall short of accurately expressing its frequency-selective and time-varying characteristics. Consequently, a standardized model for the PLC channel remains unavailable. PLC requires significant attention from power utilities and standardization parties to achieve extensive recognition within the framework of the SG.

Low Coverage of Wireless Communication for SG:

The ZigBee Standard and ZigBee Smart Energy Profile have been described by NIST [12] within the realm of wireless communication technology. In [15], authors have noted that ZigBee is known for its low power consumption and corresponding low data rate, making it suitable for control and automation applications such as remote meter reading, smart lighting control, and home area networks. However, a core issue with ZigBee lies in its coexistence with other technologies, notably wireless LAN (WLAN), as it operates within the unlicensed ISM band network. Authors in [16] have discussed Bluetooth for SG applications, its advantages and disadvantages, and its utilization in Frequency Hopping Spread Spectrum (FHSS) as an access technique, which helps to mitigate interference and eavesdropping, thus ensuring reliable and secure communication. However, Bluetooth's network area coverage is limited to 100m, and supports only a limited number of nodes.

In [17], authors suggested that IEEE 802.11 WLAN represents an uninterrupted communication technology with higher data rates for SG communication. WLAN offers reliable communication over a network with low-cost deployment, simple installation, high device mobility, and high data rates, suitable for applications such as home/building area networks and advanced metering infrastructure. However, ensuring data security in WLAN networks requires robust encryption techniques, especially considering the transmission of important metering data through every access point. Conversely, for long-distance SG communication, a high-coverage wireless infrastructure is necessary, as discussed below.

High Coverage of Wireless Communication for SG:

The extensive coverage and high data rates offered by WiMAX make it a suitable option for SG communication applications such as long-distance meter reading, real-time price estimation, and outage detection. The performance of WiMAX for meter reading purposes in the SG has been analyzed by authors in [18], where they present a comparison between WiMAX-WLAN and standalone WiMAX networks for smart metering applications. The capacity of both types of networks is evaluated, and the authors propose bandwidth allocation using radio resource management algorithms to decrease latency across diverse categories of traffic in WiMAX networks.

Furthermore, authors in [19] have conducted a comprehensive review of multiple companies utilizing various technologies such as UMTS, WCDMA, CDMA, GPRS, and GSM for SG communication. Telecom companies are considering the utilization of GSM networks for smart metering applications. Cellular technologies, with their well-established infrastructures, can be effectively leveraged for SG communication without incurring additional deployment costs. Thus, GSM (2G), CDMA (2.5G), UMTS (3G), and LTE (4G) technologies can be utilized for smart metering over broad coverage areas.

In [20], authors discussed the significance of improving network capacity for SG using the Orthogonal Frequency Division Multiple Access (OFDMA) scheme in LTE. The results indicate that OFDMA offers significantly reduced interference and enhanced system capacity.

The historically declining costs of services and equipment, coupled with efficiency improvements, have positioned satellite communications (SATCOM) as a notable option for implementing SG applications. Authors in [21] have provided analytical methods to quantify the feasibility of satellite systems with various orbit configurations for SG applications. Additionally, the author in [21] has outlined how satellite communications can facilitate remote communications in the SG context, including applications such as emergency management and environmental monitoring [21].

Existing technologies possess the capability to transfer the conventional grid into an SG. Table 3 provides a summary of SG-assisted wireless communication technologies. However, the continuously evolving functionalities and increasing number of connected devices in the SG necessitate next-generation technologies, such as the unconventional multiple access scheme of wireless communication, NOMA. Potential challenges associated with the implementation of NOMA in SG communication include:

Potential Challenges Associated with the Implementation of NOMA in SG Communication:

Noise in Smart Grid:

The implementation of wireless communication in the SG faces challenges due to various types of noise stemming from different environmental factors. While the traditional wireless communication model relies on the Additive White Gaussian Noise (AWGN) model for thermal noise, the SG environment experiences IN due to specific indoor and outdoor surroundings. Common household appliances such as hair dryers, microwave ovens, photocopiers, and printers are major sources of IN in wireless channels [22][23].

In addition to these everyday environments, IN within the electric power system is a dominant characteristic. Actions such as circuit breaker opening and closing can generate strong IN in the communication systems of substations. Narrowband noise and colored background noise are also significant contributors to background noise, characterized by slow variations in amplitudes over time. However, impulsive noise, predominantly generated by electrical appliances, remains the most crucial type of noise in SG communication networks. IN is recognized as the primary cause of data transmission inaccuracies over SG channels [4].

- **Periodic Impulsive Noise**: This type of noise is primarily generated by switched-mode power supplies. It occurs asynchronously with the cycle of the main AC power.
- **Synchronous Impulsive Noise:** This type of noise is produced by rectifier diodes present in electrical equipment. It synchronizes with the cycle of the main AC power.
- **Aperiodic Impulsive Noise:** This type of noise results from activities such as drilling, electrical motors, and on/off switching transients.

Massive Connectivity:

The implementation of wireless communication in the SG presents several significant design challenges. The proliferation of renewable energy sources and sensors generates a substantial volume of data that necessitates a heterogeneous communication system [16]. Simultaneously, there is a limitation on data rates due to the constrained wireless spectrum [1]. A typical power supply communication network comprises the following components:

- A central high-bandwidth network, typically incorporating high-speed wireless communication.
- An advanced multiple access technique that provides high EE-SE.
- A wide area network (WAN) to facilitate the aggregation of this vast amount of data.

NOMA technology can address the aforementioned communication requirements in Table 2 for SG communication. NOMA's non-orthogonal division of resources means that the number of devices or supported users is not constrained by their scheduling granularity or available resources. Consequently, NOMA can accommodate more users compared to Orthogonal Multiple Access (OMA) through non-orthogonal resource sharing.

Real-Time Operation with SIC Receiver Variations:

In the SG, real-time processing of information from various devices or users is crucial for tasks such as demand and supply management, authentication, monitoring, and responding to scenarios like disasters, medical emergencies, and traffic congestion for smart vehicles. While NOMA offers high spectral efficiency, it requires SIC to distinguish signals from different users. However, SIC entails canceling out interference from other users' signals sequentially or serially, which is more effective when users are at an appropriate distance from the Base Station (BS).

Users closer to the BS perform more SIC computations, leading to significant time delays as the number of users increases. For instance, if each stage of SIC cancellation introduces a one-bit delay, then the total delay introduced by K users is K-1 bits. Consequently, while decoding the desired signal may be faster for users farther from the BS, they also experience higher propagation delays compared to nearer users. This creates challenges in achieving high-performance real-time operations in the SG, as there is a trade-off between decoding speed and propagation delay.

The variation in SIC receiver performance poses a significant challenge for real-time operations in the SG. Addressing this challenge requires a unified framework to study the variation of SIC in wireless networks with arbitrary propagation and computational delays. Such a framework would enable better understanding and management of delays in real-time operations, enhancing the overall performance and reliability of SG communications.

Energy Efficient Transmission: The tradeoff between unit energy consumption and throughput in wireless communications is a crucial performance parameter known as EE-SE tradeoff. Here, throughput typically refers to the actual data transmitted, excluding transmission errors, signaling bits, headers, and duplicate packets, though it may encompass all transmitted bits. Most research in energy efficiency focuses on optimizing transmit power while discounting circuit power and the power required for device cooling. However, to achieve significant power savings, it's essential to consider all constraints. Various SG applications, such as demand management, distributed generation, and dynamic pricing, are significantly impacted by the performance of Information and Communication Technologies (ICT) services.

New multiple access techniques like NOMA offer high Spectral Efficiency (SE) with a large number of users. In addition to SE, the energy efficiency (EE) of NOMA systems has gained considerable attention as the demand for energy-efficient communication grows, becoming a major economic and technological concern globally. An energy-efficient power allocation scheme can maximize EE. Literature reviews have shown that NOMA outperforms conventional OMA in terms of EE because NOMA simultaneously serves multiple users through power division, thereby increasing the energy efficiency of the system.

Table 3: Summary of state-of-the-art Smart Grid assisted Wireless Communications

Reference No.	Objective	Solution Approach	Technologies	No. of User Supported
[24]	Dense and complex scenario of SG	Enabling spectrum reuse for dense and heterogeneous network	Device-to-Device	Large
[25]	Communication between SMs and the corresponding gateway	LTE pilot installation and pilot symbols collection during the campaign	Band-31(450MHz) LTE-A	Large
[26]	Enhance the physical layer reliability of SG	Continuous Phase Modulation (CPM) mapper in an OFDM	802.11 OFDM	Moderate
[11]	To increase the tolerance to noises, performance, and efficiency of SG	PLC multipath with OFDM Technique used for channel and the noise model are presented	OFDM over PLC	Moderate
[27]	Improve the SM receiving sensitivity in difficult channel estimation scenario	The adaptive OFDM-MFSK, which selects the best M value for minimum PER and higher throughput	OFDM-MFSK	Moderate
[21]	Deployment in those scenarios in which terrestrial communication infrastructures do not exist	SATCOM two-way communication systems provide IP services for machine-to-machine (M2M) communication for extensive coverage and rapid installation	SATCOM	Huge
[28]	To enable Demand-Response applications of	Compare the uplink performance of the LTE FDD and TDD modes	LTE FDD and LTE TDD	Large

	Advanced Metering Infrastructure (AMI)	for a large number of devices sending small to medium-sized AMI packets		
[19]	To improve automated Smart Grid infrastructure	Analytical and simulative traffic engineering models for SG with wireless technology approaches using GPRS, UMTS, and LTE in cellular networks	GPRS, UMTS, and LTE	Huge
[29]	Advanced Metering Infrastructure (AMI)	Reengineering principles have been applied to access granted and data transmission stages of the GSM access	GSM/GPRS	Huge
[30]	Interoperability, the choice of frame duration, type of service, scheduling strategies	The simulation-based evaluation indicates a priority-based scheduler as an appropriate solution for scheduling time-critical SG applications	WiMAX	Large
[31]	Monitoring and control Application	Hybrid mixing of CDMA/IDMA and Optical-CDMA/Optical-IDMA systems over powerline/optical fiber	CDMA, IDMA, OCDMA and OIDMA	Large
[32]	Security and privacy	CDMA-based data aggregation method provides access to utility in the root node while keeping the smart metering data secure	CDMA	Large

Energy Harvesting:

In SG applications, Wireless Sensor Networks (WSNs) are used for monitoring crucial parts of power distribution grids that contain limited battery backup. Reducing the power utilization of sensor nodes is essential due to severe energy limitations imposed by WSN nodes because of the ruthless transmission characteristics of SG surroundings. A possible approach to decrease the power utilization is to use transmitted power, which is modified as per channel conditions. An alternative way is to employ an energy harvesting system to supply more power for nodes by utilizing environmental energy resources. In outside substation environments, electromagnetic and solar energies are potential environmental energy sources. Electromagnetic energy is available at any time, on the other hand, solar power can be effectively used on a bright day. Therefore, energy harvesting using radio frequency is currently considered a superior solution.

To extend the lifespan of energy reserves in networks and maintain network connectivity, NOMA offered energy harvesting as a promising solution. For NOMA, using RFEH, researchers have considered time allocation-based wireless energy harvesting along with data rate optimization. The authors proposed, combining power transfer and wireless information networks in NOMA. Particularly, NOMA users located near the energy source act as energy-harvesting relays to assist farther NOMA users. In the end, by correctly selecting the constraints of the system for example power dividing constant and transmission, system efficiency can be improved even if the users don’t utilize their specific batteries.

System Model:

The SG communication system is depicted in Figure 2, where the grid station acts as the BS, transmitting data to SMs. Let's consider the transmission of a Binary Phase Shift Keying (BPSK) information signal, denoted as s, through the channel, where it encounters combined IN amplitude and additive white Gaussian noise amplitude n. When the same BPSK modulated symbol is transmitted over the channel, the symbol yi is received at the output following matched filtering and can be expressed as $r_i = h_i s_i + n$, where s is the transmitted BPSK information-bearing signal with average energy E_b (takes a value of $s_1 = \sqrt{E_b}$ or $s_0 = -\sqrt{E_b}$ with equal a priori probabilities), h is the channel gain multiplier.

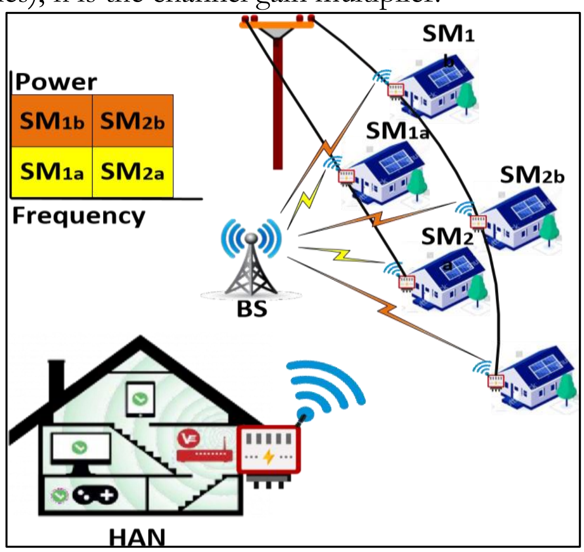

Figure 2: Smart grid communication

Impulsive Noise:

In the context of SG communication systems where channels experience both background and impulsive noise, it's essential to develop a unified statistical noise model to account for both types of noise. IN typically varies more rapidly over time compared to background noise. Two commonly used models in the literature for this purpose are the Bernoulli-Gaussian (BG) model and the Laplacian-Gaussian (LG) model.

The BG and LG models serve as foundational tools for analyzing IN. By accurately representing the statistical properties of signals and noise, these models assess the impact of noise and interference on received signals, thereby enhancing signal quality. Ultimately, these models contribute to achieving the research objectives of improving spectral efficiency, accommodating a large number of smart devices, and establishing a robust communication infrastructure for smart grid deployments.

Bernoulli-Gaussian Model:

In this model, the arrival of impulses is considered as a Bernoulli sequence modulated over Gaussian noise with On/Off Keying. This means that the occurrence of impulses follows a Bernoulli process, where each impulse is represented by a binary random variable indicating its presence or absence (On or Off). The impulses are then modulated over Gaussian noise.

Laplacian-Gaussian Model: In this model, IN is modeled by a Laplace distribution, which has a heavier tail compared to the Gaussian distribution. The occurrence of impulses is still represented by a Bernoulli sequence, similar to the BG model. However, the amplitude of the impulses follows a Laplace distribution instead of a Gaussian distribution. The Laplace distribution better models the amplitude of impulses due to its heavier tail, which allows for the representation of occasional large amplitude noise events.

Each model has its advantages and drawbacks. The LG model provides a closer representation of impulse amplitude due to the heavy tail of the Laplace distribution, while the BG model allows for easier modeling of impulse width due to the rapid drop-off of the Gaussian probability density function close to zero. The choice between these models depends on the specific characteristics of the noise in the communication channel and the requirements of the application.

In SG networks, the channel is susceptible to IN, which can elevate noise power and diminish SNR. NOMA distinguishes users by assigning varying power levels, and any change in signal power can impact transmission. Thus, precise information regarding signal power is essential. The BG and LG models furnish accurate insights into signal power by modeling IN, a critical element for NOMA implementation.

Methodology:

The methodology section delves into the intricate process of modeling IN within SG communication systems, crucial for understanding and optimizing their performance. Two primary models, the BG and LG models, are considered for this purpose. The BG model offers simplicity by characterizing IN as a Bernoulli process modulated over Gaussian noise, facilitating rapid modeling and analysis. Conversely, the LG model provides a better representation with its heavy-tailed distribution, better capturing the extreme amplitude variations typical of IN in SG environments. This choice between models depends on the need for accuracy and matching in representing IN dynamics. Given the significant impact of IN on communication performance, the LG model is preferred for its ability to accurately model the sporadic, high-intensity noise bursts common in SG channels. Additionally, empirical validation supports the LG model's statistical matching, bolstering confidence in its applicability across diverse SG deployment scenarios. By detailing the rationale behind the selection and application of the LG model, the methodology section lays a solid foundation for subsequent analyses and insights into SG communication system design and optimization.

In the methodology section, two models for representing IN in SG communication systems are discussed: the BG model and the LG model. Each model offers distinct advantages that inform its selection based on the specific characteristics of the noise environment and the requirements of the application. The BG model adopts a framework where the arrival of impulses follows a Bernoulli process modulated over Gaussian noise. This model simplifies the representation of IN by characterizing the occurrence of impulses as a binary sequence, with each impulse being either present or absent. While the BG model may not capture the extreme amplitude variations of IN as effectively as the LG model, its simplicity and ease of implementation make it advantageous for scenarios where rapid modeling and analysis are prioritized. Additionally, the BG model facilitates straightforward estimation of noise parameters such as arrival rate and variance, aiding in system performance evaluation.

Conversely, the LG model offers a better representation of amplitude variations of IN by employing a Laplace distribution, which exhibits a heavier tail compared to the Gaussian distribution. This heavy-tailed nature enables the LG model to better accommodate the infrequent large-amplitude noise events characteristic of SG environments. By accurately capturing the extreme noise amplitudes and their impact on communication performance, the

LG model provides a more comprehensive understanding of IN dynamics. Furthermore, empirical validation from practical measurements supports the LG model's statistical fidelity, enhancing confidence in its applicability across a range of SG deployment scenarios. The choice between the BG and LG models depends on factors such as the complexity of the noise environment, the need for precision in noise modeling, and the computational resources available for analysis. While the BG model offers simplicity and ease of implementation, the LG model excels in capturing the random characteristics of IN, making it particularly well-suited for applications where accuracy and fidelity are paramount.

Tools and Techniques:

The study employs several tools and techniques to achieve its objectives:

Statistical Noise Modeling:

The study utilizes statistical noise models, specifically the BG and LG models, to characterize impulsive noise in smart grid communication systems. These models enable the representation of both background and impulsive noise, allowing for a comprehensive understanding of noise dynamics.

Binary Phase Shift Keying (BPSK):

BPSK modulation is employed for transmitting information signals in the smart grid communication system. This modulation scheme facilitates the encoding of binary data onto the carrier signal, enabling efficient communication between the grid station and smart meters.

Non-Orthogonal Multiple Access (NOMA):

The study investigates NOMA as a transmission scheme for downlink communication in the smart grid. NOMA allows multiple smart meters to share the same frequency bandwidth, with power allocation distinguishing between signals. Techniques such as Successive Interference Cancellation (SIC) are utilized at the receiver to decode signals, mitigating interference from other smart meters.

Simulation Tools:

MATLAB is used as the simulation tool to evaluate the performance of the proposed NOMA scheme and compare it with existing schemes like Orthogonal Frequency Division Multiple Access (OFDMA). Simulation parameters and assumptions align with standards such as 3GPP LTE, ensuring consistency and relevance in the evaluation process.

Performance Metrics:

Various performance metrics are employed to assess the effectiveness of the NOMA scheme, including spectral efficiency (SE), energy efficiency (EE), sum rate capacity, and bit loss due to impulsive noise. These metrics provide insights into the trade-offs between spectral efficiency, energy consumption, and data transmission reliability.

Analysis of Impulse Scenarios:

Different impulse scenarios, categorized based on environmental conditions (weakly disturbed, moderately disturbed, heavily disturbed), are analyzed to understand their impact on system performance. Practical measurements, including average disturbance ratios, are utilized to characterize these scenarios and assess their implications on data rates and system efficiency.

Bernoulli-Gaussian and Laplacian-Gaussian Model:

In smart grid communication systems, where channels often experience a combination of background and impulsive noise, the BG model provides a simplified yet effective way to model impulsive noise occurrences. It allows for the characterization of impulsive noise events in terms of their presence or absence, aiding in the analysis of system performance and the design of noise mitigation strategies. The LG model provides a more accurate representation of impulsive noise characteristics. By accounting for the heavier-tailed distribution of noise amplitudes, the LG model better reflects the random high-intensity noise bursts experienced in smart grid channels.

The BG model adopts a framework where the arrival of impulses follows a Bernoulli process modulated over Gaussian noise. This model simplifies the representation of IN by characterizing the occurrence of impulses as a binary sequence, with each impulse being either present or absent. While the BG model may not capture the extreme amplitude variations of IN as effectively as the LG model, its simplicity and ease of implementation make it advantageous for scenarios where rapid modeling and analysis are prioritized. Additionally, the BG model facilitates straightforward estimation of noise parameters such as arrival rate and variance, aiding in system performance evaluation.

Conversely, the LG model offers a better representation of amplitude variations of IN by employing a Laplace distribution, which exhibits a heavier tail compared to the Gaussian distribution. This heavy-tailed nature enables the LG model to better accommodate the infrequent large-amplitude noise events characteristic of SG environments. By accurately capturing the extreme noise amplitudes and their impact on communication performance, the LG model provides a more comprehensive understanding of IN dynamics. Furthermore, empirical validation from practical measurements supports the LG model's statistical fidelity, enhancing confidence in its applicability across a range of SG deployment scenarios.

The IN model enables researchers and engineers to assess the impact of impulsive noise on system performance metrics such as signal-to-noise ratio (SNR), bit error rate (BER), and overall communication reliability. By understanding the statistical properties of impulsive noise through the IN model, system designers can implement coding and modulation schemes to mitigate its effects, thereby improving communication efficiency and reliability in smart grid environments. In BG noise model, the noise can be written as, $n = n_G + bn_I$. where n_G and n_I are the AWGN with mean zero and variance σ_G^2 and σ_I^2, respectively, and b is the rate of arrival of IN for Bernoulli random sequence, independent of n_G and n_I, with parameter p [33]. Since noise is i.i.d. random variables, with p.d.f. given by

$$P_n(x) = (1-p)\boldsymbol{G}(x,0,\sigma_G^2) + p\boldsymbol{G}(x,0,\sigma_G^2+\sigma_I^2) \quad (1)$$

Where $G(v,0,\sigma_G^2)$ is a Gaussian p.d.f. with mean μ_x and variance σ_x^2. The average noise power N_o is, $N_0 = E[n^2] = E[n_G^2] + E[b^2]E[n_I^2] = \sigma_G^2 + p\sigma_I^2$

Laplacian noise with havier PDF tail with zero mean and variance $2c^2$. According to LG noise model, the average noise power can be written as, $N_0 = E[n^2_G]+E[r^2]E[n^2_I] = \sigma_G^2 + p\,2c^2$, where r is the rate of arrival of impulsive noise, defined as Bernoulli random variable with parameter p [34].

Non-Orthogonal Multiple Access:

In non-orthogonal SG downlink transmission, the GS simultaneously transmits signals to multiple SMs at the same time and frequency. Each SM utilizes a fraction of the total power allocated by the GS. As a result, multiple SMs can share the same frequency bandwidth, with their signals distinguished by the power levels allocated by the GS. During reception at the SMs, the decoder employs SIC to detect the signals for its own SM. In this process, the signals from other SMs are treated as interference or noise. By iteratively canceling out the interference from composite signals, the decoder can isolate and decode the signals on its own, even in the presence of interference from other SMs sharing the same frequency bandwidth [35]. The received signal for SM_i can be written as, $y_i = \sqrt{\alpha_i P} h_i^2 s_i + \sum_{j=1, j\neq i}^{i-1} \sqrt{\alpha_j P} h_i^2 s_j + n_o$, where n_o denotes the additive noise and second term $\sum_{j=1,j\neq i}^{i-1} \sqrt{\alpha_j P} h_i^2 = n_{int}$ is inter-cell interference for SM_i. P is the total power for all user/meters. α is power allocation coefficient, $\alpha_1+\alpha_2+\alpha_3+\cdots+\alpha_i = 1$ and h^2_i is the fading coefficients wireless channel. Now above equation becomes, $y_i = \sqrt{\alpha_i P} h_i^2 s_i + n_{int} + n_o$. SNR for SM_i can be written as $SNR_i = \frac{\alpha_i P h_i^2}{N_{int}+N_o}$. Therefore, sum rate capacity of NOMA downlink system in presence of IN can be written as:

$$C = W\sum_{i=1}^{K} log_2\left(1+\frac{\alpha_i P h_i^2}{N_{int}+N_o}\right) \quad (2)$$

Where W is the total bandwidth for K number of SM_s.

Impulse Scenarios: To investigate the performance of a wireless system in the context of IN for the SG, three IN scenarios based on environmental conditions are considered: weakly disturbed, moderately disturbed, and heavily disturbed. The characteristics of these scenarios are derived from practical measurements, including the average disturbance ratio (dr) for medium disturbed is 0.00632, for weakly disturbed is 0.00135 and for heavily disturbed is 0.327 [36]. Therefore, for i^{th} user, data rate in terms of dr can be written as $R_i = log_2\left(1+\frac{\alpha_i P h_i^2}{N_{int}+drN_o}\right)$. Total sum-rate capacity can be written as:

$$C = W\sum_{i=1}^{K} \log_2\left(1+\frac{\alpha_i P h_i^2}{N_{int}+drN_o}\right) \quad (3)$$

Impulses in IN typically have a very short duration but occur with high amplitude, which can significantly increase the noise level, sometimes up to 5dB or more. However, the amplitude of the impulses alone cannot fully explain the extent of data loss or interference caused by impulsive noise. Instead, IN is characterized by two main parameters:

Average Impulse Rate (λavg):

This parameter describes the average number of impulses that occur per second. A higher average impulse rate indicates a higher frequency of IN occurrences, which can lead to more frequent disruptions in the communication signal.

Disturbance Ratio (dr):

This parameter represents the actual disturbed time, expressed as a ratio relative to the total transmission time. $dr = \frac{\sum_{i=1}^{i} t_{w,i}}{T_{tot}}$ indicates the proportion of time during which the communication signal is affected by impulsive noise. A higher dr signifies a greater proportion of time during which the communication signal is corrupted by impulsive noise, leading to increased data loss and degradation of communication performance.

Where l is the number of impulses that occur in T_{tot} (seconds) and $t_{w,}$ is the width of the i_{th} impulse. The average IN duration in unit time can be calculated using the expression for the dr. Since a Poisson process is used to model the arrival of impulsive noise, with the number of impulses per second represented by λ, the following expression is considered for the average disturbance ratio: $dr_{avg}=\lambda T_{noise}$, where T_{noise} is the average impulse duration. After substituting this dr into the expression of Signal-to-Noise Ratio (SNR), we can determine the degraded $SNR_{Loss} = SNR_{WithoutImpulse} - SNR_{WithImpulse}$. Therefore, the actual loss of bits (LoB) of any user can be written as:

$$R_{LoB} = W\log_2\left(1+\frac{dr\alpha_i P h_i^2}{N_{int}+drN_o}\right) \quad (4)$$

Where dr can be average or instantaneous.

Energy Efficiency and Spectral Efficiency Tradeoff:

The SG requires energy-efficient transmission for its low-power applications, as well as high spectral efficiency to accommodate a large number of connected devices. Therefore, we examine both the spectral efficiency (SE) and energy efficiency (EE) of the proposed NOMA scheme and the existing OFDMA. EE (bit/joule) for SM_k is denoted by $EE = \frac{R}{WP}$ and SE (bit/sec/Hertz) for SM_k is denoted by $SE = \frac{R}{W}$.

SIC Power Consumption:

The total power consumption at the receiver combines the power used by the information waveform with the constant power dissipation of the system caused by the circuit/power amplifier and the power utilized in SIC computation [8]. For the downlink, the achievable sum rate is $= \sum_{k=1}^{K} R_i$. The total power consumed at the receiver is denoted as P, P

$= P_t + P_c + P_{SIC}$. Where $P_t = \sum_{k=1}^{k} \alpha_k P$ is the consumed transmitting power, P_c is the constant power consumption of the circuit, P_{sic} is the SIC power consumption for one iteration and $P_{SIC} = \sum_{i=1}^{k-1} P_{i(sic)}$ is the total power consumed to perform SIC computation.

Result and Discussion:

IN poses a significant challenge to the performance and reliability of smart grid communication systems, extending beyond the scope of statistical models. Beyond the statistical representations provided by models like the BG and LG models, the real-world impact of IN encompasses various facets affecting system functionality. IN introduces abrupt and erratic fluctuations in received signals, leading to heightened data loss and error rates. These errors, stemming from unpredictable noise bursts, compromise the integrity of transmitted information, potentially disrupting critical grid operations. Moreover, IN acts as interference, degrading signal quality and impeding accurate data extraction, particularly detrimental in scenarios requiring precise sensor readings or command signal transmission. The reliability and availability of smart grid communication systems are consequently jeopardized, as IN-induced outages or connectivity issues undermine system dependability, especially during emergencies. Furthermore, IN-induced data loss and errors engender inefficiencies in energy and resource utilization, as repeated transmission attempts to mitigate errors escalate energy consumption and diminish spectral efficiency. Hence, a comprehensive understanding of IN's multifaceted impacts necessitates integrating theoretical models with empirical observations, driving the development of resilient communication strategies and technologies for smart grids.

Implementing NOMA in practical smart grid environments presents several significant challenges and considerations. One of the primary challenges lies in the complexity of resource allocation. NOMA requires sophisticated power allocation techniques to optimize resource utilization among multiple users sharing the same frequency band. Determining the optimal power allocation coefficients for varying channel conditions and traffic demands can be computationally intensive and may require frequent updates, adding complexity to system design and operation. Additionally, managing interference becomes crucial. NOMA's performance heavily relies on effective interference management to mitigate inter-user interference, especially in scenarios with overlapping coverage areas or dense deployments of smart meters. Balancing fairness and efficiency in resource allocation becomes challenging, particularly in asymmetric channel environments commonly encountered in smart grid communication systems. Furthermore, hardware and implementation constraints pose significant hurdles. Upgrading existing infrastructure to support NOMA may incur substantial costs and deployment complexities, especially in legacy smart grid deployments with heterogeneous communication technologies. Moreover, ensuring security and privacy in NOMA-based smart grid networks is paramount. Addressing these challenges requires collaborative efforts among stakeholders to develop robust solutions and standards that can enable the seamless integration and deployment of NOMA in smart grid environments while ensuring reliability, scalability, and security.

Table 4: Simulation Parameters

No.	Parameters	Values
1	Number of SMs	i, $i \geq 2$
2	Available bandwidth, B	8.64MHz
3	Detection threshold of SIC receiver	10 dBm
4	Noise density at receiver, N_0	169dBm/Hz
5	Average impulse noise, N_I	-30dBm ~ -35dBm
6	Disturbance ratio, dr	0.00135,0.00632,0.0327
7	Number of antennas at each SM	1
8	Antenna gain at BS and SM	0dBm
9	Inter-site distance of NOMA users	0.6Km

To investigate the performance of the proposed scheme, NOMA, it was compared with existing schemes such as OFDMA. The simulation assumptions and parameters followed those outlined in 3GPP LTE [37] and listed in Table 4. The channel is considered a quasistatic channel therefore during transmission, channel characteristics remain the same. Since the performance of wireless channels for SMs is affected by impulse noise, average and instantaneous impulse noise levels are considered in performance measuring metrics [36].

The effect of different impulse scenarios on NOMA user pairs' data rates when the channel is asymmetric, and a comparison with OFDMA, are illustrated in Figure 3. In NOMA, the data rate of each user depends on the power allocation of both users. In our simulation, we assumed that the nearer user has a good channel condition, with a 10dB higher SNR compared to the farther user. As shown in Figure 3, the increasing dr affects the farther user more than the nearer user because the nearer user utilizes SIC cancellation to suppress the farther user's signal, which also suppresses the part of the IN superimposed on the farther user. Meanwhile, Figure 3 also shows that due to high spectral efficiency, NOMA achieves 1 bit/sec/Hz higher data rate. Moreover, NOMA with weakly and medium distributed scenarios performs better than OFDMA in scenarios without IN. In OFDMA, each new user divides the entire bandwidth, thereby reducing the total system capacity.

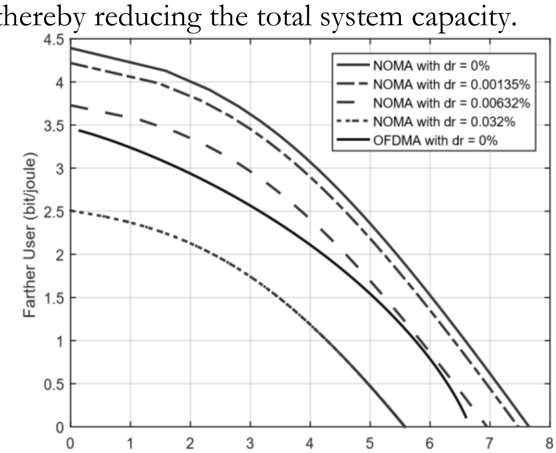

Figure 3: Effect of different scenarios on NOMA pair user rate with 'dr'

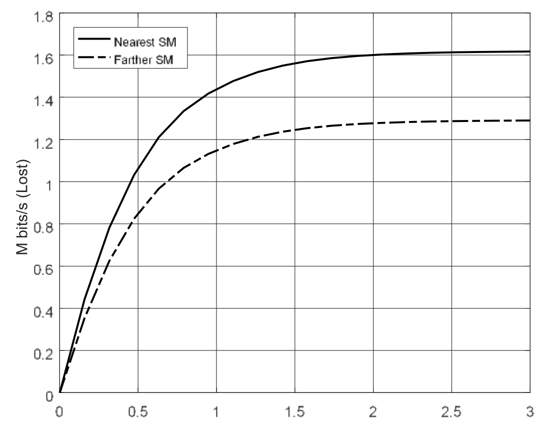

Figure 4: Bit loss due to different impulse levels

The instantaneous and average loss of bits are described in Figure 4. The simulation results show that the bits lost in the farther user are greater than those in the nearer user. This discrepancy occurs because, in NOMA, the farther user experiences more interference than the nearer user, which is considered as noise. Meanwhile, the nearer user employs a cancellation scheme, SIC, to mitigate this interference. It is observed from the graph that the loss of bits increases exponentially. Once we surpass the average value of No = 1, the maximum loss has already been incurred. Therefore, beyond this threshold value, the environment is not suitable for wireless communication without utilizing impulse mitigation techniques.

Figure 5 illustrates the tradeoff between energy efficiency and spectral efficiency, which are key metrics for evaluating network performance in the presence of IN. Simulation results show that NOMA exhibits a considerably increased peak point compared to OFDMA. Even NOMA with weak and medium dr demonstrates better EE-SE than OFDMA without IN. In NOMA, a power division multiple access scheme is employed, providing better control over the tradeoff between spectral and energy efficiency. NOMA achieves 1.5 bits/joule more energy efficiency and 1 bit/sec/Hertz more data rate than OFDMA. By utilizing power control schemes, the degree of efficiency of fluctuating total power can be adjusted.

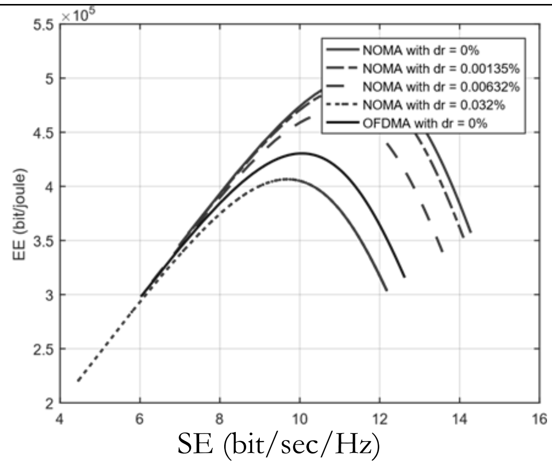

Figure 5: Energy Efficiency and Spectral Efficiency Trade-off

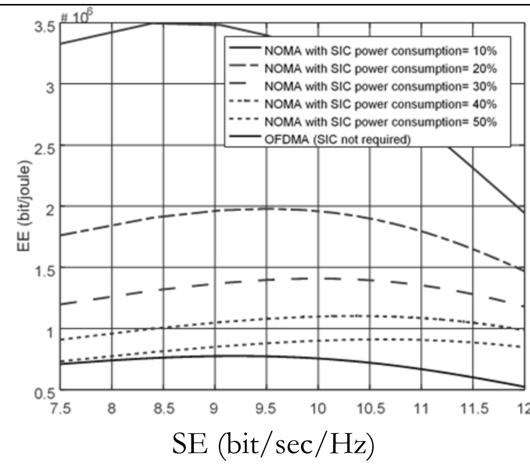

Figure 6: SIC Power Consumption- Energy Efficiency and Spectral Efficiency Trade-off

The effect of SIC computation on the EE-SE tradeoff is depicted in Figure 6. We consider unit power for each SIC iteration, including circuit power consumption. It is observed from the simulation results that the closest user requires more computation power than the farther user because it performs more SIC computations. The peak point of EE-SE is degraded by SIC computation because more computation requires more energy. Users with fewer SIC iterations face more inter-user interference. Therefore, there is a tradeoff between the peak point, SIC computation, and interference.

Discussion:

The comparison between Non-Orthogonal Multiple Access (NOMA) and Orthogonal Frequency Division Multiple Access (OFDMA) in the context of smart grid communication sheds light on the tradeoffs and advantages of different access schemes. The results demonstrate NOMA's potential to outperform OFDMA, particularly in scenarios with varying levels of impulse noise. NOMA's higher spectral efficiency allows for better utilization of the available bandwidth, resulting in increased data rates compared to OFDMA. Moreover, NOMA's ability to dynamically allocate power among users offers improved energy efficiency, making it a promising candidate for energy-constrained smart grid environments.

However, the study also highlights several challenges associated with implementing NOMA in practical scenarios. One significant challenge is the increased complexity of resource allocation, especially in dynamic and heterogeneous communication environments typical of smart grids. Optimizing power allocation coefficients for varying channel conditions and user requirements requires sophisticated algorithms and computational resources. Additionally, managing interference becomes crucial in NOMA systems, as the performance heavily relies on effective interference cancellation techniques like Successive Interference Cancellation (SIC). Balancing fairness and efficiency in resource allocation while mitigating interference poses a significant challenge.

Moreover, the study underscores the impact of impulse noise on system performance. Impulse noise can severely degrade communication quality, leading to increased data loss and interference. While NOMA exhibits resilience to impulse noise to some extent, the study highlights the need for effective impulse mitigation techniques to maintain reliable communication in adverse conditions. In conclusion, while NOMA shows promise for improving spectral and energy efficiency in smart grid communication, its practical implementation poses several challenges. Addressing these challenges requires further research and development of robust algorithms and protocols tailored to the unique requirements of smart grid environments. Additionally, strategies for mitigating impulse noise and managing interference will be essential for realizing the full potential of NOMA in smart grid communication systems.

Conclusion:

There are various technologies available for implementing communication into SG, but finding the best one is the challenging part of implementation. In this article, we discussed the architecture of SG and highlighted the available communication technologies for SG applications. Furthermore, we suggested the NOMA scheme with its high spectral efficiency as a capable contender for SG communication. We investigated the feasibility and challenges of the NOMA scheme over channels affected by IN. We provided the BG model and LG model to represent IN for SG and explore the impact of different urban noise scenarios.

To evaluate the performance of the proposed scheme, we investigated the impact of different impulse scenarios on NOMA user pairs in terms of data rate and EE-SE tradeoff. We found that NOMA achieves 1 bit/sec/Hertz more data rate and a higher peak point. We formulated the actual loss due to IN, demonstrating that the bits lost in the farther user are more than those in the nearer user, and for an average value of No = 1, maximum loss accrues. Furthermore, we investigate the impact of SIC computation on the EE-SE tradeoff by considering signal power, circuit power, and power consumption in SIC processing. The future direction of this research is the analysis and optimization of the EE-SE tradeoff among the peak point, SIC computation, and inter-user interference. This research guides towards the implementation of communication in SG, addressing availability, feasibility, challenges, the proposed scheme, and the performance of the proposed scheme.

References:

[1] C. Kang, D. Kirschen, and T. C. Green, "The Evolution of Smart Grids [Scanning the Issue]," Proc. IEEE, vol. 111, no. 7, pp. 691–693, Jul. 2023, doi: 10.1109/JPROC.2023.3284213.

[2] M. Hussain and H. Rasheed, "Communication Infrastructure for Stationary and Organized Distributed Smart Meters," 2019 2nd Int. Conf. Commun. Comput. Digit. Syst. C-CODE 2019, pp. 17–22, Apr. 2019, doi: 10.1109/C-CODE.2019.8681020.

[3] K. A. Abdulsalam, J. Adebisi, M. Emezirinwune, and O. Babatunde, "An overview and multicriteria analysis of communication technologies for smart grid applications," e-Prime - Adv. Electr. Eng. Electron. Energy, vol. 3, p. 100121, Mar. 2023, doi: 10.1016/J.PRIME.2023.100121.

[4] M. Hussain and H. Rasheed, "Performance of Orthogonal Beamforming with NOMA for Smart Grid Communication in the Presence of Impulsive Noise," Arab. J. Sci. Eng., vol. 45, no. 8, pp. 6331–6345, Aug. 2020, doi: 10.1007/S13369-020-04457-Y/METRICS.

[5] M. Hussain and H. Rasheed, "A Computational Power Allocation Scheme for Fair NOMA Downlink System," J. Inf. Commun. Technol. Robot. Appl., pp. 73–79, Jun. 2018, Accessed: May 20, 2024. [Online]. Available: https://jictra.com.pk/index.php/jictra/article/view/83

[6] M. Hussain and H. Rasheed, "Nonorthogonal multiple access for next-generation mobile networks: A technical aspect for research direction," Wirel. Commun. Mob. Comput., vol. 2020, 2020, doi: 10.1155/2020/8845371.

[7] H. Gozde, M. C. Taplamacioglu, M. Ari, and H. Shalaf, "4G/LTE technology for smart grid communication infrastructure," 2015 3rd Int. Istanbul Smart Grid Congr. Fair, ICSG 2015, Dec. 2015, doi: 10.1109/SGCF.2015.7354914.

[8] "Review of Communication Technologies for Smart Grid applications." Accessed: May 28, 2024. [Online]. Available: https://www.researchgate.net/publication/322555918_Review_of_Communication_Technologies_for_Smart_Grid_applications

[9] M. Hussain and H. Rasheed, “Performance of Orthogonal Beamforming with NOMA for Smart Grid Communication in the Presence of Impulsive Noise,” Arab. J. Sci. Eng., vol. 45, no. 8, pp. 6331–6345, Aug. 2020, doi: 10.1007/S13369-020-04457-Y/METRICS.

[10] “NextG Communications Research and Development Gaps Report”, [Online]. Available: https://www.nist.gov/publications/nextg-communications-research-and-development-gaps-report

[11] A. Maneerung, S. Sittichivapak, and K. Hongesombut, “Application of power line communication with OFDM to smart grid system,” Proc. - 2011 8th Int. Conf. Fuzzy Syst. Knowl. Discov. FSKD 2011, vol. 4, pp. 2239–2244, 2011, doi: 10.1109/FSKD.2011.6020014.

[12] R. Fantacci and S. Morosi, “Multicarrier spread spectrum techniques for downstream power-line communications on low voltage grid,” Int. J. Commun. Syst., vol. 16, no. 5, pp. 401–416, Jun. 2003, doi: 10.1002/DAC.599.

[13] M. Katayama, T. Yamazato, and H. Okada, “A mathematical model of noise in narrowband power line communication systems,” IEEE J. Sel. Areas Commun., vol. 24, no. 7, pp. 1267–1276, Jul. 2006, doi: 10.1109/JSAC.2006.874408.

[14] V. C. Gungor and F. C. Lambert, “A survey on communication networks for electric system automation,” Comput. Networks, vol. 50, no. 7, pp. 877–897, May 2006, doi: 10.1016/J.COMNET.2006.01.005.

[15] P. Yi, A. Iwayemi, and C. Zhou, “Developing ZigBee deployment guideline under WiFi interference for smart grid applications,” IEEE Trans. Smart Grid, vol. 2, no. 1, pp. 110–120, 2011, doi: 10.1109/TSG.2010.2091655.

[16] “Bluetooth group explores apps in smart grid - EE Times.” Accessed: May 28, 2024. [Online]. Available: https://www.eetimes.com/bluetooth-group-explores-apps-in-smart-grid/

[17] P. P. Parikh, M. G. Kanabar, and T. S. Sidhu, “Opportunities and challenges of wireless communication technologies for smart grid applications,” IEEE PES Gen. Meet. PES 2010, 2010, doi: 10.1109/PES.2010.5589988.

[18] G. D. Castellanos and J. Y. Khan, “Performance analysis of WiMAX polling service for smart grid meter reading applications,” 2012 IEEE Colomb. Commun. Conf. COLCOM 2012 - Conf. Proc., 2012, doi: 10.1109/COLCOMCON.2012.6233661.

[19] C. Muller, M. Putzke, and C. Wietfeld, “Traffic engineering analysis of Smart Grid services in cellular networks,” 2012 IEEE 3rd Int. Conf. Smart Grid Commun. SmartGridComm 2012, pp. 252–257, 2012, doi: 10.1109/SMARTGRIDCOMM.2012.6485992.

[20] V. C. Güngör et al., “Smart grid technologies: Communication technologies and standards,” IEEE Trans. Ind. Informatics, vol. 7, no. 4, pp. 529–539, Nov. 2011, doi: 10.1109/TII.2011.2166794.

[21] A. Meloni and L. Atzori, “The Role of Satellite Communications in the Smart Grid,” IEEE Wirel. Commun., vol. 24, no. 2, pp. 50–56, Apr. 2017, doi: 10.1109/MWC.2017.1600251.

[22] A. B. Bodonyi, “Effects of Impulse Noise on Digital Data Transmission,” IRE Trans. Commun. Syst., vol. 9, no. 4, pp. 355–361, 1961, doi: 10.1109/TCOM.1961.1097716.

[23] “An Advanced 2-Output DNN Model for Impulse Noise Mitigation in NOMA-Enabled Smart Energy Meters | International Journal of Innovations in Science & Technology.” Accessed: May 28, 2024. [Online]. Available: https://journal.50sea.com/index.php/IJIST/article/view/740

[24] A. Laya, K. Wang, A. A. Widaa, J. Alonso-Zarate, J. Markendahl, and L. Alonso, “Device-to-device communications and small cells: Enabling spectrum reuse for dense

networks," IEEE Wirel. Commun., vol. 21, no. 4, pp. 98–105, 2014, doi: 10.1109/MWC.2014.6882301.
[25] B. Holfeld, S. Jaeckel, L. Thiele, T. Wirth, and K. Scheppelmann, "Smart grid communications: LTE outdoor field trials at 450 MHz," IEEE Veh. Technol. Conf., vol. 2015, Jul. 2015, doi: 10.1109/VTCSPRING.2015.7146091.
[26] E. Shafter, A. Noorwali, and R. K. Rao, "OFDM systems with CPM mappers for smart grid applications," 2015 IEEE Electr. Power Energy Conf. Smarter Resilient Power Syst. EPEC 2015, pp. 424–428, Jan. 2016, doi: 10.1109/EPEC.2015.7379988.
[27] G. Al-Juboori, A. Doufexi, and A. R. Nix, "Feasibility study of OFDM-MFSK modulation scheme for smart metering technology," 2017 IEEE PES Innov. Smart Grid Technol. Conf. Eur. ISGT-Europe 2017 - Proc., vol. 2018-January, pp. 1–6, Jul. 2017, doi: 10.1109/ISGTEUROPE.2017.8260200.
[28] J. Brown and J. Y. Khan, "Performance comparison of LTE FDD and TDD based Smart Grid communications networks for uplink biased traffic," 2012 IEEE 3rd Int. Conf. Smart Grid Commun. SmartGridComm 2012, pp. 276–281, 2012, doi: 10.1109/SMARTGRIDCOMM.2012.6485996.
[29] G. C. Madueño, Č. Stefanović, and P. Popovski, "Reengineering GSM/GPRS towards a dedicated network for massive smart metering," 2014 IEEE Int. Conf. Smart Grid Commun. SmartGridComm 2014, pp. 338–343, Jan. 2015, doi: 10.1109/SMARTGRIDCOMM.2014.7007669.
[30] F. Aalamifar and L. Lampe, "Optimized WiMAX Profile Configuration for Smart Grid Communications," IEEE Trans. Smart Grid, vol. 8, no. 6, pp. 2723–2732, Nov. 2017, doi: 10.1109/TSG.2016.2536145.
[31] C. C. Tseng, L. Wang, and C. H. Kuo, "Application of hybrid mixing CDMA/IDMA/OCDMA/OIDMA for smart grid integration of renewable-energy resources," Proc. - 2016 IEEE Int. Symp. Comput. Consum. Control. IS3C 2016, pp. 878–882, Aug. 2016, doi: 10.1109/IS3C.2016.223.
[32] N. Alamatsaz, A. Boustani, M. Jadliwala, and V. Namboodiri, "AgSec: Secure and efficient CDMA-based aggregation for smart metering systems," 2014 IEEE 11th Consum. Commun. Netw. Conf. CCNC 2014, pp. 489–494, 2014, doi: 10.1109/CCNC.2014.6866615.
[33] A. Dubey, D. Sharma, R. K. Mallik, and S. Mishra, "Modeling and performance analysis of a PLC system in presence of impulsive noise," IEEE Power Energy Soc. Gen. Meet., vol. 2015-September, Sep. 2015, doi: 10.1109/PESGM.2015.7286624.
[34] S. Prakash, A. Bansal, and S. K. Jha, "Performance analysis of narrowband PLC system under Gaussian Laplacian noise model," Int. Conf. Electr. Electron. Optim. Tech. ICEEOT 2016, pp. 3597–3600, Nov. 2016, doi: 10.1109/ICEEOT.2016.7755376.
[35] A. Benjebbour, Y. Saito, Y. Kishiyama, A. Li, A. Harada, and T. Nakamura, "Concept and practical considerations of non-orthogonal multiple access (NOMA) for future radio access," ISPACS 2013 - 2013 Int. Symp. Intell. Signal Process. Commun. Syst., pp. 770–774, 2013, doi: 10.1109/ISPACS.2013.6704653.
[36] Z. M. H. Khalifa S. Al-Mawali, Amin Z. Sadik, "Time-Domain Techniques for iReduction in OFDMBased Power Line Communications: A Comparative Study," Int. Conf. Commun. Comput. Power.
[37] "An Overview of AI in 3GPP's RAN Release 18: Enhancing Next-Generation Connectivity? | IEEE Communications Society." Accessed: May 28, 2024. [Online]. Available: https://www.comsoc.org/publications/ctn/overview-ai-3gpps-ran-release-18-enhancing-next-generation-connectivity