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Minimum Mean Square Error Algorithm for Improving Spectral Efficiency by Reducing Power Consumption of Beamforming in 5G Networks

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ABSTRACT

This research is guided to evaluate and determine various beneficial roles and substantial contributions of the Minimum mean square error (MMSE) algorithm in providing less power consumption and significant energy and spectral efficiencies for a larger number of users and massive data transfer capacity. A comparative analysis was led with the help of MATLAB simulations and numerical analysis to validate the relevances of the MMSE algorithm compared with ZF Hybrid, Kalman, MSE Fully Digital, and Analog-only precoding algorithms. Spectral efficiency was compared for all those five algorithms under a Signal-to-Noise Ratio range of 0 to 30 dB. According to the MATLAB numerical analysis and simulations, the results revealed that the spectral efficiency of the MMSE algorithm outpaced that of the other four algorithms considering analog and digital precoding schemes. For this reason, it can be concluded that the MMSE can be actively adopted and used for a large number of users without consuming considerable power or generating significant emissions.

1. INTRODUCTION

Over the last decades, the world witnessed significant evolvement and advancements in communication networks, through which a 5G cellular network was established in 2020, and a 6G mobile network will be operated in 2030 [1], as illustrated in Figure 1. These critical innovations contributed to faster data transfer, enhanced communication efficiency, and larger data capacity [2]. Additionally, the 5G mobile network is characterized by its lower latency compared with old mobile networks. It can support 100× more traffic potential, providing real-time access of a 10× reduction in end-to-end latency down to one milli-seconds [3, 4].

Notwithstanding, 5G mobile networks face some challenges mirrored by the considerable growth in the number of subscribers and network users, which led to more extensive traffic, higher energy consumption, less spectral efficiency, and a substantial amount of Greenhouse Gas GHG emissions, influencing the performance, quality, and efficiency of data transfer and downloading speed [5].

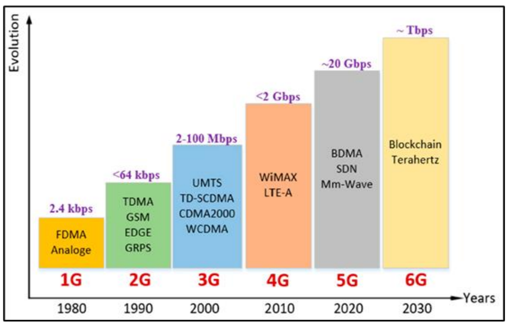

Figure 1. The evolution and development of cellular networks over the years

Due to the development and prevalence of modern mobile network technologies in various nations containing 4G and 5G cellular technologies, it is observed that the number of users has significantly expanded globally. Nonetheless, the existing communication infrastructure cannot meet this considerable increase in the number of subscribers because of more significant power consumption, more remarkable data traffic, and higher pressure on downloading speed, affecting the 5G mobile networks performance, efficiency, and reliability to serve all users. In this context, several scholars and communication engineers have dedicated significant Research and Development RD efforts to enhancing communication efficiency and improving the rate at which data is transferred.

This research will focus on one of these green communication technologies that play a critical role in optimizing energy consumption, reducing GHG emissions, fostering the 5G mobile network performance, and enhancing spectral efficiency. This technology comprises Artificial Intelligence AI. A unique example of AI algorithms is the Minimum mean square error MMSE optimization algorithm. MMSE intelligent algorithm will be employed to optimize the power consumption and mitigate the GHG emissions, taking into account the enhancement of spectral efficiency and data transfer speed and performance of the 5G cellular network. Also, this research will make a comparison among MMSE, Analogue-only, fully digital, Zero-forcing, and Kalman Hybrid precoding.

The scope of this research is limited to the examination and investigation of the functional role and advantageous contributions of the MMSE to optimize the power consumption of the 5G cellular network, alleviate GHG emissions, and enhance the spectral efficiency to help 5G cellular wireless technology serve a larger number of users as possible with higher degrees of sustainability, reliability, and effectiveness. The location of this research is limited to Iraqi regions in which the performance and power consumption of some 5G mobile networks are examined and inspected in Iraq. To accurately address the importance and precision of the MMSE optimization algorithm, some indices and factors are determined and defined, which consist of Signal-to-Noise Ratio (SNR), Number of paths, Number of users, and Number of transmitted and received antennas.

2. RESEARCH OBJECTIVE

The major aims of this research are to:

(1) Addressing the relevance and critical benefits of the MMSE algorithm in improving spectral efficiency and mitigating the power consumption of Iraqi 5G cellular wireless networks.

(2) Identifying and address the critical contribution of the MMSE algorithm to optimize the power consumption and enhance spectral efficiency of Iraqi 5G mobile networks.

(3) Conducting a comparative analysis between the MMSE model and the other four algorithms, helping classify the rate of accuracy and performance of the MMSE techniques compared to other digital algorithms.

(4) Investigating the impacts of SNR, number of paths, number of users, and number of transmitted and received antennas on the performance and power consumption of the Iraqi 5G cellular wireless technology.

3. LITERATURE REVIEW

3.1 Power consumption, Spectral efficiency, and Energy efficiency in massive MIMO and parameters

The authors conducted a comprehensive study to investigate key advancements and major factors influencing power consumption (PC) in 5G mobile networks. They undertook an extensive literature review to collect secondary data that would address their research objectives.

Power consumption (PC) challenges and energy efficiency issues likely arise with the use of 5G mobile networks. Intelligent strategies and practical approaches are thus needed to reduce energy expenditure. A meticulous analysis of the literature revealed that since the 1990s, numerous studies have focused on exploring innovative techniques to enhance energy efficiency, decrease power consumption (PC), minimize delays, and increase throughput.

Furthermore, the comprehensive review highlighted critical factors that could impact power consumption (PC) in 5G mobile networks. These factors include the number of users reliant on the 5G mobile network, User Equipment (UE) relaying, energy throughput, the total number of nodes, cell size, and the electrical power requirements of the base station.

The authors also identified key approaches currently in use to mitigate power consumption (PC) in 5G networks. These strategies include the integration of a Massive MIMO (MM) antenna system into the base station, energy harvesting, User Equipment (UE) assistance, and the implementation of an adaptive Discontinuous Reception (DRX) system [6].

Another study embarked on research to examine the primary factors and key variables impacting power consumption and energy efficiency in 5G mobile networks. The researchers conducted an exhaustive review addressing vital aspects of power consumption and energy efficiency within 5G cellular networks.

Their in-depth review revealed a range of factors and significant variables that influence power consumption and energy efficiency in 5G mobile networks. These include the number of users, the number of equipment and devices utilizing and connecting to the 5G wireless network, the data traffic rate, and the operational energy of Radio Access Networks (RANs).

The authors also proposed that primary green techniques could lead to significant power savings in 5G mobile networks. These techniques encompass network sleeping methods, cell zooming, Device-to-Device (D2D) communication, Massive MIMO (MM), relay usage, radio resource management, cyber-foraging, local caching, traffic offloading, Visible Light Communication (VLC), mobile edge computing, Cloud RAN, and the application of green and sustainable energy harvesting methods [7].

Recently, cell zooming mechanisms have attracted considerable attention in the literature. In scenarios involving cell zooming, the primary challenge is to reduce overall energy consumption while adjusting the spectral efficiency target to match the actual system load, all while maintaining the quality of service (QoS). To conserve energy, the cell zooming approach deactivates certain cells during periods of low traffic, when they are not required. When some cells are turned off, the remaining cells typically zoom out to ensure service availability across the entire area. Weng et al. [8] framed the cell zooming mechanism as an optimization problem and also proposed an (m, n)-off scheme to address insufficient cell zooming.

The authors sought an adaptive cell zooming method that responds to the offered traffic load. Similar to the study by Weng et al. [8], the cell zooming mechanism was modelled as an optimization problem, taking into account varying traffic patterns, interference, and the need to maintain service availability throughout the whole area. Simulations were run to verify the performance of the proposed cell zooming method. These simulations considered varying traffic conditions, both temporally and spatially, within a traditional 19-cell configuration.

The results showed that the proposed scheme achieved a reduction in energy consumption by up to 4.72 times for urban environments and 3.78 times for rural environments, as compared to traditional static cell operation. This was accomplished while maintaining satisfactory throughput and full-service coverage. Though only three power levels were used in this work to curb computational complexity, the authors plan to apply the particle swarm optimization (PSO) algorithm to find an optimal solution [9].

3.2 S/W and H/W solutions to minimize power consumption and improve energy efficiency

In an effort to reduce power consumption (PC) and enhance the energy efficiency of 5G mobile networks, researchers conducted a study focused on identifying beneficial strategies and active techniques utilizing software solutions. They performed numerical analyses and software simulations to uncover practical methods for diminishing power consumption (PC) and augmenting the energy efficiency of the 5G network. Their findings indicated that software simulations and solutions were more effective at minimizing power consumption (PC) and promoting energy efficiency than LTE systems. When compared with LTE approaches, these software solutions also demonstrated improved performance in the context of the 5G network [10].

In another study aimed at reducing the power consumption (PC) of 5G networks and increasing energy efficiency, researchers examined key software solutions that could be implemented. A thorough analysis was conducted, identifying significant software solutions and innovative techniques that could enhance the power and energy performance of 5G cellular networks. The in-depth analysis revealed that the adoption of software solutions integrating Artificial Intelligence (AI) and Internet of Things (IoT) technologies is highly practical and beneficial for monitoring 5G network performance, reducing its power consumption (PC), and boosting its energy efficiency. Furthermore, the study's results indicated that employing fog and cloud computing solutions, Z-Wave, Bluetooth Low Energy (BLE), and IPv6 over Low-Power Wireless Personal Area Networks (6LowPAN) contributed to performance improvements [11].

To minimize power consumption (PC), enhance energy efficiency, and maximize the Signal-to-Interference-plus-Noise Ratio (SINR), a researcher investigated software solutions and environmentally friendly techniques. As the coverage area associated with a base station can be expanded or contracted based on traffic volume, the researcher developed and tested a traffic-based cell zooming strategy. Using MATLAB simulations, the researcher presented a virtual cell zooming technique and confirmed its impact on power usage and energy efficiency. The researcher also applied cell zooming to deactivate low-traffic base stations, compensating for this by increasing the transmit power of nearby base stations to expand their coverage area [12].

According to the study's conclusions, implementing cell zooming for the 5G mobile network is highly advantageous and positively contributes to energy optimization and enhanced energy efficiency. Low data and voice traffic frequently result in substantial energy waste in mobile communication. Cell zooming can be utilized in these situations to match the 5G mobile capacity to the ideal range if traffic suddenly increases, without degrading service quality. The researcher also noted that a key strategy for using cell zooming is to deactivate base stations with low traffic and compensate for the reduced coverage area by boosting the transmit power of other nearby base stations. Furthermore, the researcher suggested that as the 5G mobile network evolves, older networks' power usage will significantly decrease, as illustrated in Figure 2.

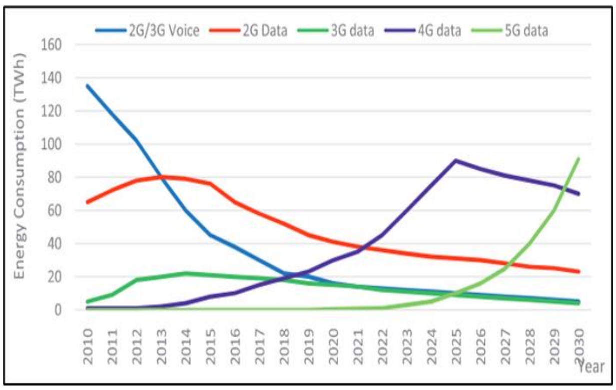

Figure 2. The energy consumption trend of different mobile networks

Furthermore, based on the research findings, the use of the proposed method to decrease the power consumption (PC) of the 5G network has led to energy savings of approximately 20% compared to static cell zooming. The expected traffic of the 2G, 3G, 4G, and 5G networks was also scrutinized and evaluated, as depicted in Figure 3.

The results further corroborated that implementing cell zooming in 5G wireless network technology could lead to substantial reductions in base station power consumption (PC), which is used to transmit data to users. The energy efficiency of the 5G cellular network can be enhanced through cell zooming. Prior to the adoption of cell zooming technology, Dahal's study in 2022 inspected the amount of energy consumption and the level of traffic for base station No. 1, as illustrated in Figure 4.

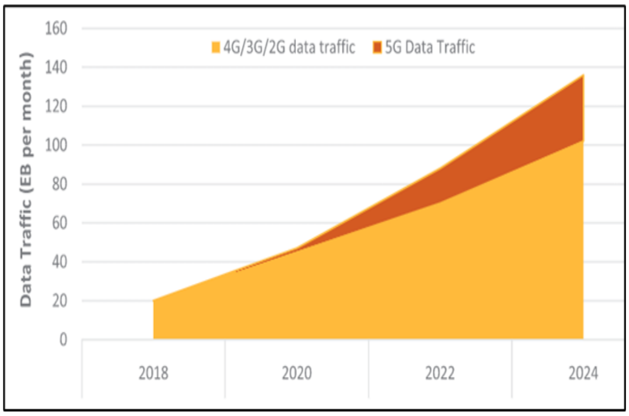

Figure 3. The expected traffic of 2G, 3G, 4G, and 5G networks

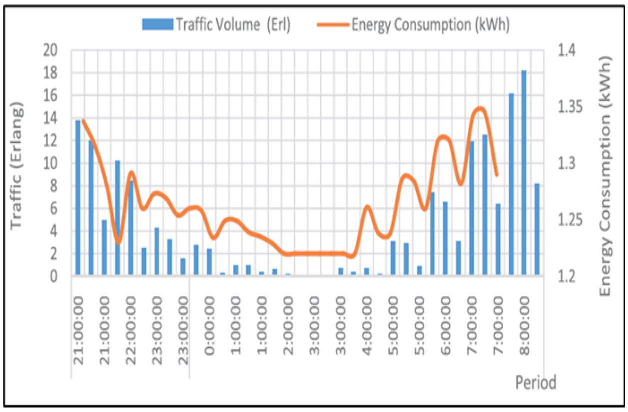

Figure 4. The quantity of energy consumption and traffic amount of base station No. 1 before employing the cell zooming technology

3.3 Other algorithms reducing power consumption and improve spectral efficiency

Alhumaima [13] conducted a study focusing on innovative methods and strategic approaches for reducing the power consumption (PC) of a Cloud Radio Access Network (C-RAN). Additionally, the research aimed to assess the energy efficiency of the C-RAN. The researcher found that while some authors have suggested new algorithms to decrease power usage and enhance energy efficiency, achieving these goals requires the development of new models and creative strategies, not just new algorithms to reduce power consumption. To evaluate the power cost of data transfer, diminish the power consumption (PC) of the 5G mobile network, and enhance energy efficiency, the author adopted a novel methodology.

The calculations and model analysis revealed that implementing their proposed model led to a significant 75% reduction in the size of the 5G mobile network, due to fewer active devices and user equipment being connected to the wireless network. Moreover, their research demonstrated that their new model offered more simplicity, cost-effectiveness, and flexibility than previous complex models used to estimate power usage and cost of 5G mobile networks.

In order to enhance energy efficiency and decrease power consumption (PC), another study investigated the significant roles and implications of employing the Zero-Forcing (ZF) algorithm and first-order techniques. This approach enabled an energy-efficient and optimal network power consumption (PC) related to Massive MIMO (MM) cell-free 5G mobile networks. The researchers proposed a simulation technique that considered hardware requirements, backhaul energy consumption, and the absence of channel condition information. They noted that due to the non-convex nature of the general energy efficiency optimization problem, it has typically been addressed within the framework of Second-Order Cone Programs (SOCPs) using the successive convex approximation paradigm. However, these methods are often time-consuming. As a result, they turned to simulation and numerical analysis in conjunction with the ZF algorithm [14]. Their findings indicated that the application of the ZF algorithm to estimate the optimal number of base stations, increase energy efficiency, and reduce power consumption (PC) in MM cell-free 5G mobile networks was more precise and effective than other standard methods.

4. PROPOSED METHODOLOGY

This paragraph presents an illustration and critical description associated with the major research phases, numerical analysis steps, and the comparative study procedure to validate the beneficial contributions and vital characteristics of the MMSE algorithm compared with the other four algorithms (which are (A) ZF, (B) Full-digital, (C) Kalman hybrid, and (D) Analog algorithms) in terms of accuracy and performance. Before introducing the illustration and vital contributions of the primary data collection process, it is worth mentioning that secondary data collection was employed in this work to identify and address critical contributions and substantial relevances of various state-of-the-art energy-saving techniques and novel beneficial methods that can be adopted in MM 5G mobile networks to help alleviate the amount of power consumption and improve the spectral and energy efficiencies (Figure 5).

This work is initiated by conducting a literature review through which critical contributions and major relevances of some AI intelligent algorithms were classified and determined to identify their role in predicting spectral efficiency and power consumption in 5G mobile networks. Thus, a comparative analysis is conducted in the fourth phase of this research to compare the values of spectral efficiency obtained from the numerical analysis and simulations between four DL algorithms, which include: The simulation results will give an indication regarding which intelligent algorithm would be the most appropriate one for providing the highest spectral efficiency Figure 6.

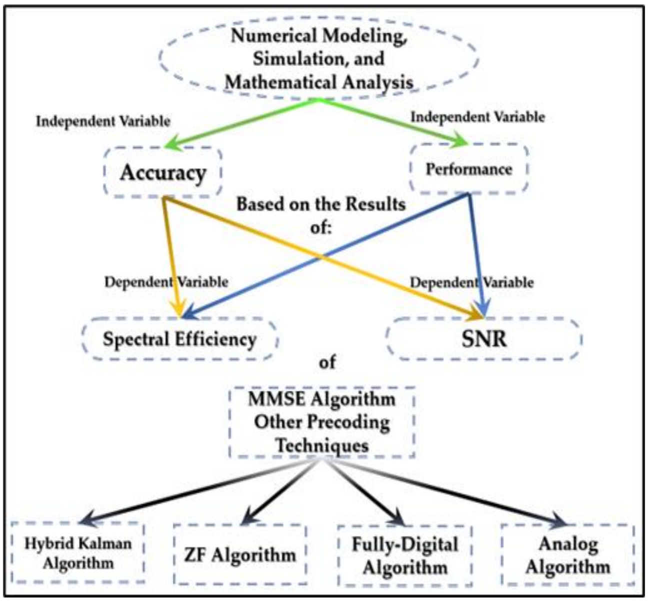

Figure 5. The research philosophy considering the dependent and independent variables of this work

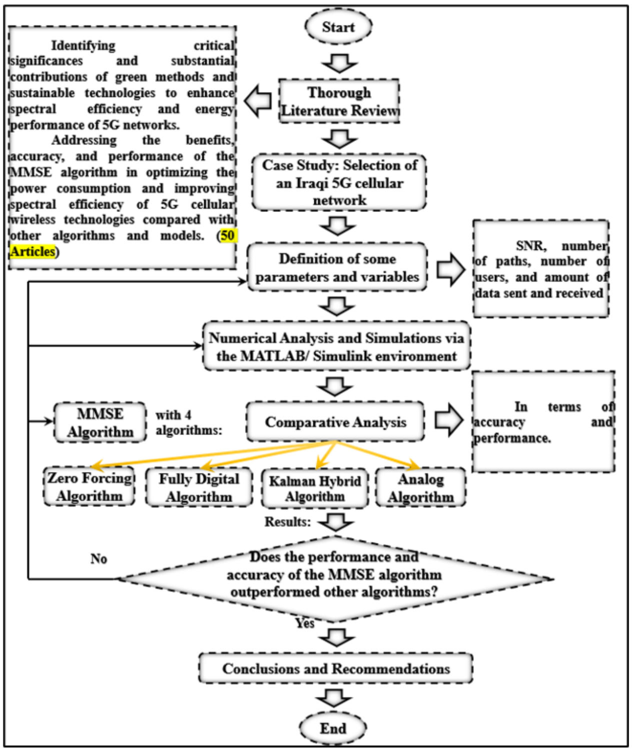

Figure 6. The research methodology flowchart

5. MMSE ALGORITHM

A Minimum mean square error (MMSE) estimator can be described as "an estimation technique employed in statistics and signal processing that reduces the Mean square error (MSE), a popular indicator of estimator quality, of the fitted values of a dependent variable" [15-18]. The MMSE estimator`s shape is typically restricted to fall within a particular class of functions since computing the posterior mean is laborious [19].

$$\text{MMSE Estimator} = E[X|Y] \tag{1}$$

where, X is the parameter or signal being estimated, Y is the observed data, and E [ ] represents the expectation operator.

In the case of linear MMSE estimation, where X and Y are related by a linear model, the formula is:

$$\text{MMSE Estimator} = a + bY \qquad (2)$$

where, a and b are constants that depend on the specific problem and can be determined using statistical methods such as least squares regression. The MMSE estimator in this case is the linear function of the observed data Y that minimizes the mean square error between the estimated parameter X and its true value.

In general, the calculation of the MMSE estimator involves computing the conditional expectation of the parameter X given the observed data Y, which can be done using various mathematical techniques depending on the specific problem.

$$\hat{\mathrm{x}} = \mathrm{K}^{-1}\mathrm{H}^{\mathrm{H}}\mathrm{r} = (\mathrm{H}\mathrm{H}^{\mathrm{H}} + \gamma^{-1}\mathrm{I})^{-1}H^{H}r \qquad (3)$$

where, $\gamma \triangleq \sigma_x^2/\sigma_w^2$. Also, σ_x^2 presents the signal power of the data input. At the same time, σ_w^2 indicates the noise variance. I is the identity matrix with a proper number of dimensions. It can be given by:

$$\mathrm{I} = \begin{bmatrix} \kappa & 0 & \beta & 0 \\ 0 & \kappa & 0 & \beta \\ \beta & 0 & \kappa & 0 \\ 0 & \beta & 0 & \kappa \end{bmatrix}, \qquad (4)$$

where, κ can be expressed by the following formula:

$$\kappa = \alpha + \gamma^{-1}, \qquad (5)$$

Additionally, Borges et al. [20] employed the MMSE algorithm and MMSE precoding technique to develop a formula through which alternative solutions can be provided to alleviate the average square error between the received signals and the actual transmitted data. They stated that the MMSE algorithm could be used to achieve this goal via the expression:

$$F_{BB}^{MMSE} = (H^H H + 2\sigma_n^2 I)^{-1} H^H, \qquad (6)$$

where,

F_{BB}^{MMSE}	The precoding matrix of the baseband (BB) matrix using the MMSE algorithm
σ_n^2	The noise variance
H	The propagation channel
I	The identity matrix

6. RESEARCH CRITICAL PARAMETERS

Six parameters are employed to conduct the simulations and numerical analysis in the MATLAB software package/ Simulink environment. The following paragraphs illustrate more details on each parameter.

(1) No. of users (1, 4, 8, 12, 16, 32, and 64),
(2) No. of paths, Figure 7.
(3) No. of transmitting antenna (1, 4, 16, and 64),
(4) No. of receiving antenna (1, 4, 16, and 64),
(5) No. of iteration, and
(6) SNR value (0, 5, 10, 20, 25, and 30).

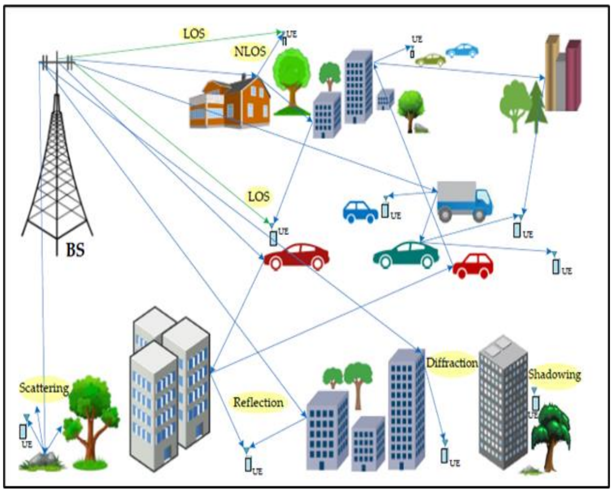

Figure 7. Multiple paths/ channels used to transfer data in a 5G wireless network between the base station and other user devices

Figure 8 illustrates the research steps and critical procedures followed in the employment of the MMSE precoding algorithm in the research by Said et al. [21], considering two implementation stages.

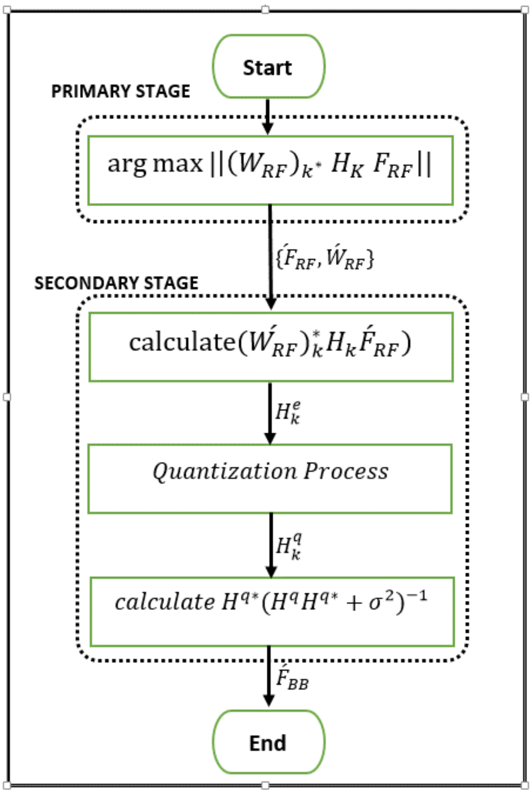

Figure 8. The employment of the MMSE precoding algorithm in the research [21], considering two implementation stages

7. RESEARCH RELIABILITY

The research results that will be obtained from the numerical analysis and simulations procedure using the

MATLAB software package/ Simulink environment will be validated, modified, and verified depending on two methods, as illustrated below:

(1) The first approach relies on MMSE, AI, and ANN professionals` and communications experts` points of view to check the validity and effectiveness of the results.

(2) The second technique depends on comparing the results attained by other scholars and communication researchers` findings with the research outputs obtained in this work to provide validity.

Therefore, they can help provide consultations regarding the validity and effectiveness of the results obtained from the numerical analysis and simulations in this work.

8. NUMERICAL ANALYSIS

The numerical analysis conducted in this work includes simulations using the MATLAB software package of version R2021a. Simulations are remarkably practical and beneficial to enable active monitoring and functional design and certification of the 5G components employed to transfer data (including sending and receiving processes). Here, simulations are implemented to determine the spectral efficiency related to some algorithms, which are (1) Analog, (2) Fully digital, (3) Zero forcing, (4) Kalman Hybrid and (5) MMSE algorithms. The aim is to identify which algorithm can provide a higher value of spectral efficiency compared with other algorithms.

9. RESULTS

It was discovered that changing those three factors would differentiate and variate the spectral efficiency of each algorithm. Thus, Figures 9 to 19 indicate a comparative analysis graphically based on the values of spectral efficiency under specific changes in those three factors. For instance, Figure 9 depicts the spectral efficiency of the five algorithms when: (1 user, 1 transmission antenna, 1 receiving antenna).

However, these conditions are considered for comparison purposes and validation of the spectral efficiency in some ideal situations to verify which algorithm would more effective and beneficial. This figure can indicate that at a simple number of users, receiving and transmission antennas. At less complicated communication configurations, all intelligent algorithms would provide excellent performance and higher and similar spectral efficiency. Nonetheless, the following figures will prove that complex communication schemes and the more complicated 5G mobile network situation in which a large number of those three indices would distinguish the performance of the five algorithms. Figure 10 indicates the spectral efficiency of the five algorithms, taking into account the following aspects: (1 user, 4 transmission antenna, 4 receiving antenna).

It can be inferred that increasing the number of transmission and receiving antennae into four (for each) would result in an outstanding performance related to the spectral efficiency of the MSE Fully Digital Precoding algorithm compared with MMSE and the three rest algorithms. Another situation is considered to interpret the performance of the five algorithms when the following conditions are taken into consideration: (4 user, 4 transmission antenna, 4 receiving antenna).

Based on the research outcomes described in Figure 11, it can be concluded that by elevating the number of users in the 5G mobile network, more traffic of data sending and transferring would be created, contributing to some challenges for some algorithms to provide higher spectral efficiency in serving all those users. For instance, a slight increase in the number of users in the 5G cellular communication scheme would contribute to enhanced performance of MMSE and MSE Fully Digital precoding techniques compared with other algorithms, (4 user, 16 transmission antenna, 16 receiving antenna).

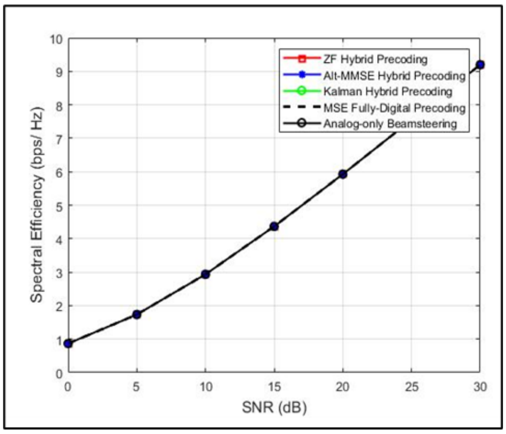

Figure 9. Spectral efficiency of the five algorithms considering one user, one transmission antenna, and one receiving antenna

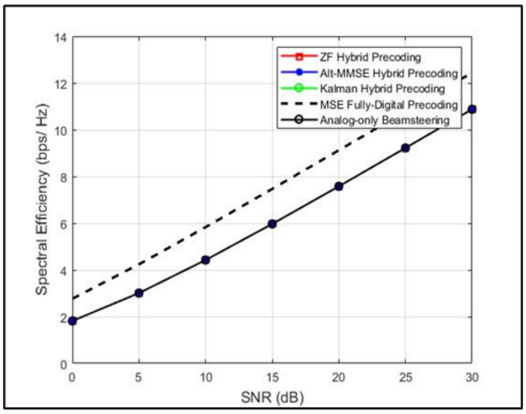

Figure 10. Spectral efficiency of the five algorithms considering one user, four transmission antennae, and four receiving antennae

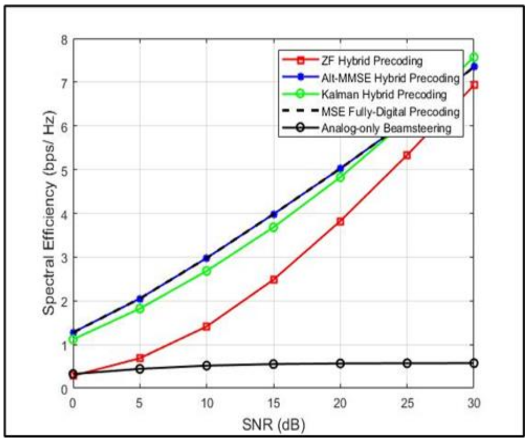

Figure 11. Spectral efficiency of the five algorithms considering four users, four transmission antennae, and four receiving antennae

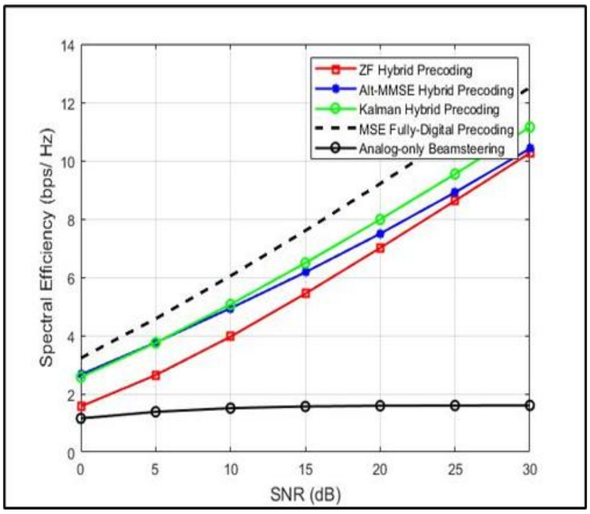

Figure 12. Spectral efficiency of the five algorithms considering four users, sixteen transmission antennae, and sixteen receiving antennae

Here, it is inferred from Figure 12 that a large number of transmission and receiving antennas compared with the number of users would help MSE Fully Digital and Kalman precoding algorithms outpace the spectral efficiency of Analog-only, ZF Hybrid, and MMSE precoding algorithms. However, these results may change if the following conditions exist in Figure 13: when (8 user, 16 transmission antenna, 16 receiving antenna).

It can be understood from the results in Figure 13 that increasing the number of users from four to eight, maintaining a constant number for both transmitting and receiving antennae as sixteen, would not result in significant improvements in the spectral efficiency and performance of the five algorithms that were analyzed in Figure 12. Thus, another situation was considered for comparison purposes in Figure 14, taking into consideration the following values of the three indices: (12 user, 16 transmission antenna, 16 receiving antenna).

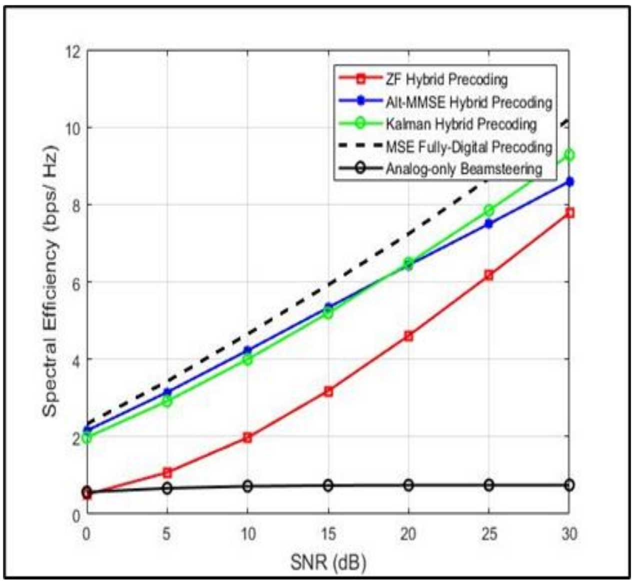

Figure 13. Spectral efficiency of the five algorithms considering eight users, sixteen transmission antennae, and sixteen receiving antennae

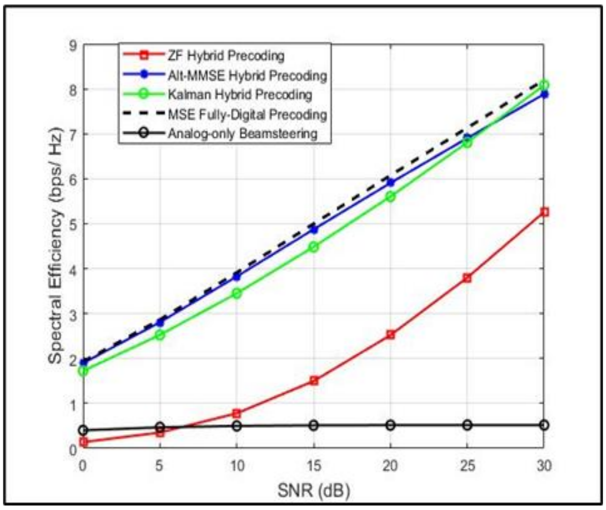

Figure 14. Spectral efficiency of the five algorithms considering twelve users, sixteen transmission antennae, and sixteen receiving antennae

By comparing the two scenarios addressed in Figures 13 and 14, it can be discovered that a higher number of users with a relatively higher number of transmitting and receiving antennae (sixteen for both) would result in closer values of spectral efficiency linked to the three algorithms: Fully Digital, Kalman, and MMSE. The spectral efficiency of those three algorithms is higher than the two algorithms (ZF Hybrid and Analog-only), knowing that the analog-only algorithm has the smallest performance compared with the other four algorithms in case the number of users rises. For example, Figure 15 explains the spectral efficiency for the same five algorithms, but the three indices were changed into some values including: (16 user, 16 transmission antenna, 16 receiving antenna).

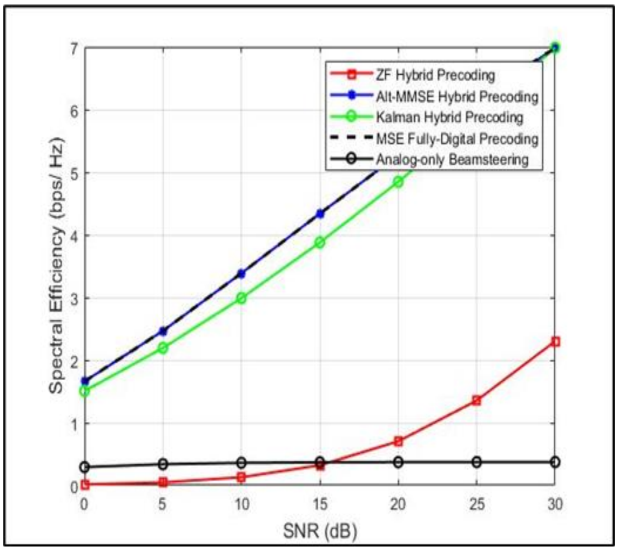

Figure 15. Spectral efficiency of the five algorithms considering sixteen users, sixteen transmission antennae, and sixteen receiving antennae

It can be indicated from Figure 15 that a similar number of users and receiving and transmitting antennas resulted in identical values of spectral efficiency for the two algorithms (MSE Fully Digital and MMSE Hybrid precoding). At the same time, the performance behavior of the other three algorithms is approximately similar in terms of spectral efficiency compared with the results represented in Figure 16. When (20 user, 16 transmission antenna, 16 receiving antenna).

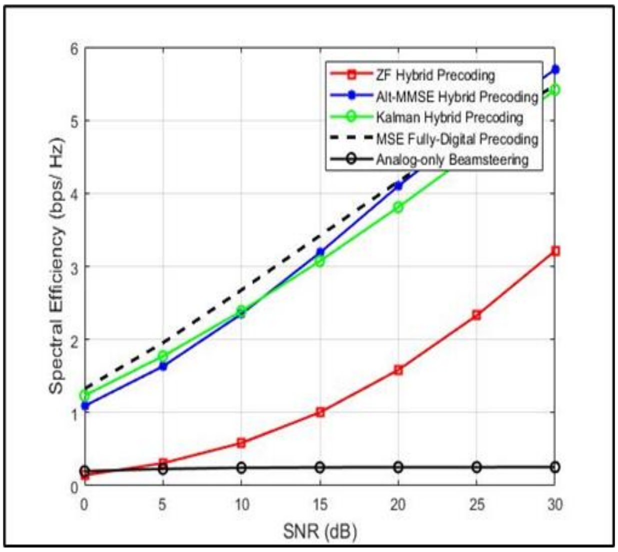

Figure 16. Spectral efficiency of the five algorithms considering twenty-four users, sixteen transmission antennae, and sixteen receiving antennae

It can be denoted from Figure 16 that increasing the number of users in this case to twenty-four compared with the previous scenario (represented in Figure 15) contributed to an outstanding spectral efficiency of the MSE Fully Digital algorithm compared with MMSE and Kalman precoding techniques. Figure 17 represents the spectral efficiency of the five investigated algorithms when the following aspects are taken into account: (32 user, 16 transmission antenna, 16 receiving antenna).

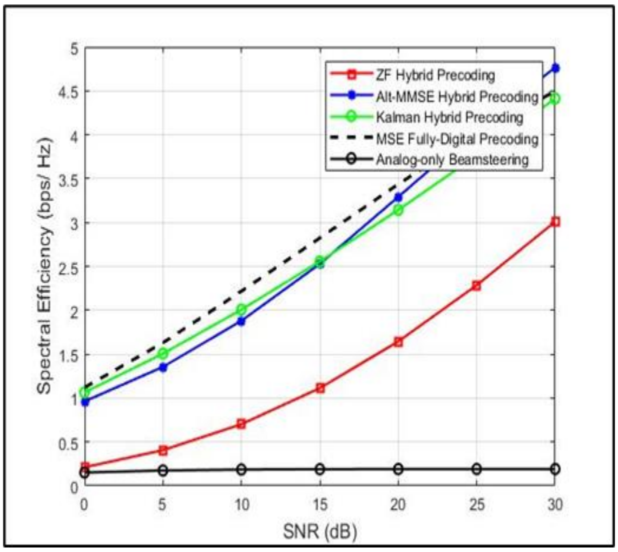

Figure 17. Spectral efficiency of the five algorithms considering thirty-two users, sixteen transmission antennae, and sixteen receiving antennae

Comparing the numerical outcomes attained in Figure 17 with previous schemes would demonstrate two observations.

Secondly, it can be inferred that the spectral efficiency of the algorithms (MMSE, MSE Fully Digital, and Kalman) stays closer to each other. Nonetheless, MSE Fully Digital still has the maximum communication performance and effectiveness in terms of spectral efficiency compared with the four different algorithms. Another situation is investigated in Figure 18 when the three indices are changed into the following quantities; (32 user, 64 transmission antenna, 64 receiving antenna).

It is concluded from Figure 18 that the MSE Fully Digital precoding scheme returned to be the leading according to the spectral efficiency compared with the four investigated algorithms. In addition, when thirty-two users, sixty-four transmission antennae, and sixty-four receiving antennae exist, the spectral efficiency of ZF hybrid precoding declined and retreated to lower values compared with analog-only algorithms at lower rates of SNR. (64 user, 64 transmission antenna, 64 receiving antenna).

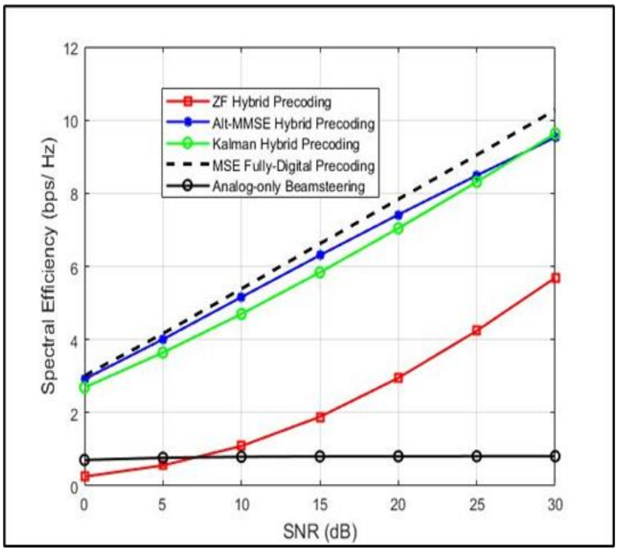

Figure 18. Spectral efficiency of the five algorithms considering thirty-two users, sixty-four transmission antennae, and sixty-four receiving antennae

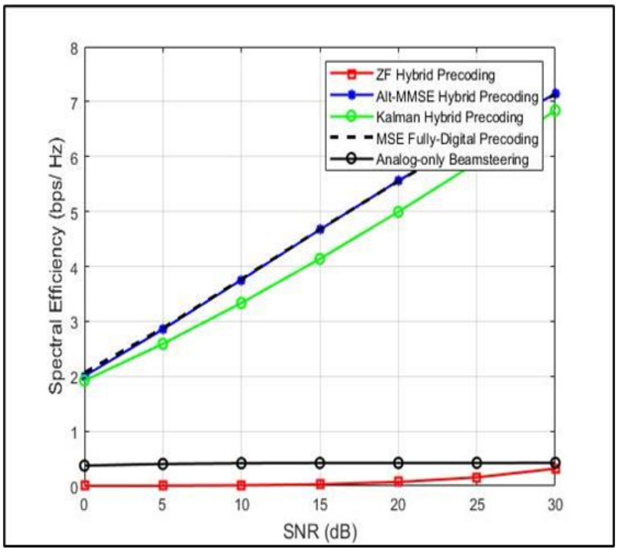

Figure 19. Spectral efficiency of the five algorithms considering sixty-four users, sixty-four transmission antennae, and sixty-four receiving antennae

In the scenario addressed in Figure 19, it can be inferred that increasing the number of users from 32 to 64 and maintaining a fixed quantity of transmitting and receiving antennas would result in identical performance and spectral efficiency of the two algorithms (MMSE and MSE Fully Digital). Furthermore, based on all cases represented in Figures 9 to 19, it is vital to note that MMSE provided the optimum and best spectral efficiency for both analog and digital precoding schemes.

Simulation Outputs of all five Precoding Schemes as will mentioned in Tables 1-5.

Table 6 is presenting a summary of all mentioned previous studies.

Table 1. Simulation outputs of MMSE precoding algorithm

#	Data Input											Data Output					
	A	**B**	**C**	**D**	**E**	**SNR (dB)**						**Spectral Efficiency (bites per second)/Hz**					
1	1	1	1	10	200	0	5	10	20	25	30	0.9	1.7	2.9	5.9	7.54	9.19
2	1	4	4	10	200	0	5	10	20	25	30	1.8	3	4.4	7.6	9.22	10.9
3	4	4	4	10	200	0	5	10	20	25	30	1.3	2.1	3	5	6.11	7.34
4	4	16	16	10	200	0	5	10	20	25	30	2.6	3.7	5.1	7	8.9	10.4
5	8	16	16	10	200	0	5	10	20	25	30	2	3.1	4.2	6.5	7.49	8.59
6	12	16	16	10	200	0	5	10	20	25	30	1.9	2.9	3.8	5.9	6.9	7.88
7	16	16	16	10	200	0	5	10	20	25	30	1.7	2.5	3.4	5.3	6.16	7
8	24	16	16	10	200	0	5	10	20	25	30	1.1	1.6	2.3	4.2	4.93	5.69
9	32	16	16	10	200	0	5	10	20	25	30	1	1.4	1.9	3.3	4.06	4.76
10	32	64	64	10	200	0	5	10	20	25	30	3	4	5.2	7.4	8.48	9.62
11	64	64	64	10	200	0	5	10	20	25	30	2	2.8	3.7	5.5	6.33	7.09

A: Number of users who send or receive data; B: Number of Transmission Antenna; C: Number of Receiving Antenna; D: Number of Channels (Path); E: Iterations

Table 2. Simulation outputs of MSE fully digital precoding algorithm

#	Data Input											Data Output					
	A	**B**	**C**	**D**	**E**	**SNR (dB)**						**Spectral Efficiency (bites per second)/Hz**					
1	1	1	1	10	200	0	5	10	20	25	30	0.9	1.7	2.9	5.9	7.54	9.19
2	1	4	4	10	200	0	5	10	20	25	30	2.7	4.1	5.7	9	10.7	12.3
3	4	4	4	10	200	0	5	10	20	25	30	1.3	2.1	3	5	6.03	7.25
4	4	16	16	10	200	0	5	10	20	25	30	3.3	4.5	6	9.2	10.8	12.46
5	8	16	16	10	200	0	5	10	20	25	30	2.4	3.5	4.7	7.3	8.71	10.3
6	12	16	16	10	200	0	5	10	20	25	30	2	2.9	3.9	6.1	7.13	8.19
7	16	16	16	10	200	0	5	10	20	25	30	1.6	2.5	3.4	5.3	6.14	7
8	24	16	16	10	200	0	5	10	20	25	30	1.3	2	2.7	4.2	4.86	5.47
9	32	16	16	10	200	0	5	10	20	25	30	1.2	1.6	2.2	3.4	4.01	4.49
10	32	64	64	10	200	0	5	10	20	25	30	3	4.2	5.4	7.8	9.04	10.3
11	64	64	64	10	200	0	5	10	20	25	30	2	2.8	3.3	5.5	6.33	7.09

A: Number of users who send or receive data; B: Number of Transmission Antenna; C: Number of Receiving Antenna; D: Number of Channels (Path); E: Iterations

Table 3. Simulation outputs of Kalman Hybrid precoding algorithm

#	Data Input											Data Output					
	A	**B**	**C**	**D**	**E**	**SNR (dB)**						**Spectral Efficiency (bites per second)/Hz**					
1	1	1	1	10	200	0	5	10	20	25	30	0	0	0	0	0	0
2	1	4	4	10	200	0	5	10	20	25	30	0	0	0	0	0	0
3	4	4	4	10	200	0	5	10	20	25	30	1.1	1.8	2.7	4.8	6.13	7.56
4	4	16	16	10	200	0	5	10	20	25	30	2.6	3.7	5.1	8	9.53	11.1
5	8	16	16	10	200	0	5	10	20	25	30	2	2.9	4	6.5	7.84	9.27
6	12	16	16	10	200	0	5	10	20	25	30	1.7	2.5	3.5	5.6	6.8	8.08
7	16	16	16	10	200	0	5	10	20	25	30	1.5	2.2	3	4.8	5.88	6.98
8	24	16	16	10	200	0	5	10	20	25	30	1.2	1.8	2.4	3.8	4.59	5.41
9	32	16	16	10	200	0	5	10	20	25	30	1.1	1.5	2	3.1	3.76	4.41
10	32	64	64	10	200	0	5	10	20	25	30	2.7	3.6	4.7	7	8.3	9.62
11	64	64	64	10	200	0	5	10	20	25	30	1.9	2.6	3.3	5	5.89	6.84

A: Number of users who send or receive data; B: Number of Transmission Antenna; C: Number of Receiving Antenna; D: Number of Channels (Path); E: Iterations

Table 4. Simulation outputs of zero-forcing precoding algorithm

#	Data Input											Data Output					
	A	**B**	**C**	**D**	**E**	**SNR (dB)**						**Spectral Efficiency (bites per second)/Hz**					
1	1	1	1	10	200	0	5	10	20	25	30	0	0	0	0	0	0
2	1	4	4	10	200	0	5	10	20	25	30	0	0	0	0	0	0
3	4	4	4	10	200	0	5	10	20	25	30	0.32	0.68	1.41	3.82	5.33	6.92
4	4	16	16	10	200	0	5	10	20	25	30	1.56	2.64	3.95	7	8.62	10.26
5	8	16	16	10	200	0	5	10	20	25	30	0.56	1.07	1.97	4.6	6.16	7.78

#	Data Input											Data Output					
	A	B	C	D	E	SNR (dB)						Spectral Efficiency (bites per second)/Hz					
6	12	16	16	10	200	0	5	10	20	25	30	0.14	0.35	0.78	2.25	3.8	5.26
7	16	16	16	10	200	0	5	10	20	25	30	0	0.04	0.13	0.7	1.35	2.3
8	24	16	16	10	200	0	5	10	20	25	30	0.19	0.3	0.58	1.58	2.32	3.21
9	32	16	16	10	200	0	5	10	20	25	30	0.21	0.4	0.7	1.64	2.85	3
10	32	64	64	10	200	0	5	10	20	25	30	0.25	0.56	1.08	2.95	4.23	5.68
11	64	64	64	10	200	0	5	10	20	25	30	0	0	0.01	0.08	0.17	0.34

A: Number of users who send or receive data
B: Number of Transmission Antenna
C: Number of Receiving Antenna
D: Number of Channels (Path)
E: Iterations

Table 5. Simulation outputs of analog only precoding algorithm

#	Data Input											Data Output					
	A	B	C	D	E	SNR (dB)						Spectral Efficiency (bites per second)/Hz					
1	1	1	1	10	200	0	5	10	20	25	30	0.9	1.7	2.9	5.9	7.54	9.19
2	1	4	4	10	200	0	5	10	20	25	30	1.8	3	4.4	7.6	9.22	10.87
3	4	4	4	10	200	0	5	10	20	25	30	0.3	0.4	0.5	0.6	0.57	0.57
4	4	16	16	10	200	0	5	10	20	25	30	1.2	1.4	1.5	1.6	1.59	1.6
5	8	16	16	10	200	0	5	10	20	25	30	0.6	0.7	0.7	0.7	0.74	0.74
6	12	16	16	10	200	0	5	10	20	25	30	0.4	0.5	0.5	0.5	0.51	0.51
7	16	16	16	10	200	0	5	10	20	25	30	0.3	0.3	0.4	0.4	0.37	0.37
8	24	16	16	10	200	0	5	10	20	25	30	0.2	0.2	0.2	0.3	0.25	0.25
9	32	16	16	10	200	0	5	10	20	25	30	0.2	0.2	0.2	0.2	0.19	0.19
10	32	64	64	10	200	0	5	10	20	25	30	0.7	0.8	0.8	0.8	0.81	0.81
11	64	64	64	10	200	0	5	10	20	25	30	0.4	0.4	0.4	0.4	0.42	0.42

A: Number of users who send or receive data
B: Number of Transmission Antenna
C: Number of Receiving Antenna
D: Number of Channels (Path)
E: Iterations

Table 6. Summary of studies

Author(s)	Study Technique	Illustration
Höyhtyä et al. [6]	Investigating critical advances	The comprehensive review indicated that critical factors that could influence the power consumption (PC) in 5G mobile networks comprise the number of users who depends on the 5G mobile network, relaying of UE, throughput energy, nodes number, cell size, and the electrical power requirements of the base station.
Gandotra et al. [22]	Examining substantial factors and vital elements	Their comprehensive review confirmed that critical factors which affect the power consumption (PC) in MM - 5G mobile networks include mobile terminals` battery lifespan, the number of subscribers (users) connected to 5G networks, cellular networks` overall operational costs, energy efficiency, and Specific Aspect Ratio (SAR).
Bulashenko et al. [10]	Advantageous ways and active strategies	Their software simulations and numerical analyses showed that software simulations and solutions were more effective than LTE systems at reducing power consumption (PC) and fostering energy efficiency.
Javaid et al. [11]	Examine crucial software solutions	Their in-depth analysis revealed that adopting software solutions that integrate AI and IoT is incredibly practical and advantageous in helping to monitor the performance of the 5G network, lower its power consumption (PC), and boost its energy efficiency.
Dahal [12]	Investigating software solutions and environmentally friendly techniques	Using MATLAB simulations, the researcher presented a cell zooming technique and verified the power usage and energy efficiency. The student also used cell zooming and turned off low-traffic base stations, compensating for nearby base stations by increasing transmit power, allowing them to increase their coverage area.
Alhumaima [13]	Cutting-edge methods and clever strategies	Authors suggested brand-new algorithms to aid lower power usage and improve energy efficiency. In order to quantify the power cost of data transfer, lower the power consumption (PC) of the 5G mobile network, and increase energy efficiency, the author chose a novel methodology.
Mai et al. [14]	Exploring the positive roles and relevance of using the ZF algorithm and first-order techniques	This enabled energy-efficient and optimal network power consumption (PC) related to MM cell-free 5G mobile networks. Their findings showed that applying the ZF algorithm to approximate the optimal number of base channels, increase energy efficiency, and reduce power consumption (PC) in MM cell-free 5G mobile networks was more accurate and effective than using other standard methods.

10. Conclusion

The results of this research revealed that the performance and accuracy of the MMSE algorithm outpace other conventional algorithms. Moreover, the research results confirmed that the spectral efficiency of MMSE ranges between 4.76 bps/Hz and 10.87 bps/Hz for a fixed number of channels (paths) which amounted to 10.

These results are consistent with the results of other studies who conducted an analysis investigating the critical role of some intelligent algorithms, including ZF, MMSE, Regularized ZF, and Water Filling (WF), in achieving signal detection, energy efficiency, user scheduling, precoding, channel estimation, and pilot contamination for the 5G mobile network and found that using MMSE can offer optimal performance and accuracy, with less computational time, compared with other algorithms. Chataut and Akl [23] who carried out research analyzing the critical relevances and significance of the MMSE algorithm to estimate the spectral efficiency in the 5G network. They found that using a modified MMSE algorithm can offer higher performance and less computational complexity compared with different state-of-the-art algorithms.

Also, this result is consistent with the findings [24], who found that using the MMSE algorithm provided higher performance than the Least Square channel estimation that is integrated with Compressive Sensing (LS-CS).

Furthermore, the results of this study revealed that increasing the number of antennas would increase the number of paths. This result is consistent with the research outputs [25], who found that increasing the number of antennas would require more energy and cost demands.

Moreover, the research findings indicated that increasing the number of channels can increase the spectral efficiency when the users` number is increased.

This study is conducted to investigate and identify the critical contribution and beneficial role of the MMSE algorithm in providing less power consumption and higher spectral efficiency under a given number of users, channels, and data transfer capacity. Thus, the 5G network can serve a further number of users and transfer data to far distances and distant zones. To validate the critical relevance of the MMSE algorithm, a comparison was carried out in terms of performance and accuracy between the MMSE algorithm and other conventional algorithms.

The performance and accuracy of the MMSE algorithm outpace other conventional algorithms. The spectral efficiency of MMSE ranges between 4.76 bps/Hz and 10.87 bps/Hz for a fixed number of channels (paths) which amounted to 10. Increasing the number of users would reduce the spectral efficiency under a fixed number of channels, also, increasing the number of channels can increase the spectral efficiency when the users` number is increased. Power consumption will increase if the number of users and data capacity increases.

11 RECOMMENDATIONS

These concrete recommendations include:

(1) To change the SNG (gain) data input and expand its range and predict the impact of using new values on the spectral efficiency.

(2) To investigate other parameters related to the 5G network, such as power consumption and energy efficiency.

(3) To variate the number of users and expand its range and predict its new values on the spectral efficiency.

(4) To use different values of data transfer volume (including data sent and data received) and see the new amounts of spectral efficiency.

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NOMENCLATURE

m, n	Dimensions of cell
X	the parameter or signal being estimated
Y	the observed data
E	the expectation operator
a, b	constants that depend on the specific problem and can be determined using statistical methods such as least squares regression
I	The identity matrix
H	The channel matrix of the ZF transmission and receiving processes
$\hat{x}$	The ZF precoding index
r	The received signal matrix related to antenna system arrays
k	The sample time
F_{BB}^{MMSE}	The precoding matrix of the baseband matrix via the MMSE algorithm
α	The channel gain