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ORIGINAL RESEARCH

Prospects and setbacks for migrating towards 5G wireless access in developing Bangladesh: A comparative study

Pranto Halder[1] | Md. Mehedi Hassan[2] | A. K. Z. Rasel Rahman[2] | Laboni Akter[3] | Abu Shakil Ahmed[4] | Shakir Khan[5,6] | Sajib Chatterjee[2] | M. Raihan[3]

[1]Computer Science and Engineering, Khulna University of Engineering and Technology, Khulna, Bangladesh

[2]Computer Science and Engineering Discipline, Khulna University, Khulna, Bangladesh

[3]Department of Biomedical Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh

[4]Graduate Student Member, IEEE, Dublin, Ireland

[5]College of Computer and Information Sciences, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh, Saudi Arabia

[6]Department of Computer Science and Engineering, University Centre for Research and Development, Chandigarh University, Mohali, India

Correspondence
Md. Mehedi Hassan, Computer Science and Engineering Discipline, Khulna University, Khulna 9208, Bangladesh.
Email: mehedihassan@ieee.org

M. Raihan, Department of Computer Science and Engineering, North Western University, Khulna, Bangladesh.
Email: raihanbme@gmail.com

Abstract

As 4G technology served as a foundation, the emergence of 5G is now underway, ushering in a new era of connectivity. With the growing demand for seamless internet experiences, particularly in the face of escalating internet subscribers, the networking domain must evolve. Developing nations strive to align with this dynamic landscape, necessitating an upgrade that integrates internet of things (IoT), natural language processing (NLP), and artificial intelligence (AI) with network infrastructure. By enhancing networking systems with lower latency and improved scalability, 5G addresses congestion issues. This is achieved by coupling mm-wave technology with the 5G framework through the 3rd Generation Partnership Project, significantly amplifying channel bandwidth. However, the comprehensive analysis underscores challenges in 5G implementation, encompassing aspects like distance, orientation, non-line-of-sight conditions, protocol utilization, and server positioning. Drawing from a dataset provided by the University of Minnesota that illuminates the limitations of 5G implementation in select US cities, this paper extends its focus to densely populated regions in developing countries of the sub-continent. Employing a machine learning approach, the paper delves into the constraints of 5G deployment in such areas. Ultimately, this research aims to shed light on the intricacies of 5G's implementation challenges, contributing to the discourse on enhancing network infrastructure in the evolving landscape of global connectivity.

1 | INTRODUCTION

5G, the fifth generation of wireless technology, represents a transformation in communication networks with its unparalleled speed, responsiveness, and capacity. Building upon the foundations laid by its predecessors, 5G is poised to revolutionize various industries and enable innovations that were once deemed impractical. 5G aims to provide faster data speeds, lower latency, greater reliability, and the ability to connect a massive number of devices simultaneously [1, 2]. While 4G networks offer download speeds of up to 100 Mbps, 5G is designed to deliver speeds ranging from 1 to 10 Gbps [3]. This massive increase in bandwidth empowers users to download large files, stream high-definition content, and engage in real-time communication with virtually no lag [1]. This speed boost is essential for emerging technologies such as augmented reality (AR) and virtual reality (VR), as these applications demand seamless and high-quality experiences [3, 4]. Low latency is crucial for applications that require real-time interactivity, like remote surgery, autonomous vehicles, and industrial automation. With minimal delay, critical decisions can be made swiftly and accurately, enhancing safety and efficiency across various sectors [5, 6]. Moreover, 5G's capacity to connect a massive number of devices within a limited geographical area is a game-changer. This capability is achieved through advanced antenna technologies such as Massive Multiple Input Multiple Output (MIMO) and beamforming. These technologies allow the network to serve multiple devices simultaneously while maintaining high data speeds. The Internet of Things (IoT) ecosystem stands to benefit significantly from this, as it involves a multitude of interconnected devices, ranging from smart appliances to environmental sensors, that rely on constant communication [7, 8].

2019 is marked as the deployment year for 5G. Within 2025, 5G will satisfy 30% of the 8.9 billion communication devices including 7.5 billion smartphones [1]. By 2025, global usage of mobile traffic will reach 164 EB (Exabyte), among which 45% will be carried over 5G cellular networks [9, 10]. At the end of 2019, Switzerland had implemented 5G networks in over 90% of the area of the country, which is a significant share of this coverage [5, 6]. Since then, it has been showing better performance than 4G LTE (Long term evolution) [11]. A key component of 5G is mm-wave technology. 5G mm-wave gains a frequency of 24 to 53 GHz (according to 3GPP 38.101) in proper conditions [1]. Among the first commercial implementations of 5G, many companies implemented 5G with mm-wave technologies, and the others executed a mid-range band. The mid-range band was also used in 4G to gain better scalability [1, 11]. Compared to mm-wave 5G and mid-band 5G, mid-band 5G offers better dynamic performance due to its directional nature [12, 13]. The first commercial 5G is coupled with 4G LTE infrastructure, known as non-stand-alone architecture. NSA 5G speeds up the implementation of 5G [1]. Due to non-standalone architecture, 4 and 5G are both commercially available today. However, NSA 5G does not offer much improvement in latency [14, 15].

The low-band spectrum provides wide coverage, making it suitable for rural areas, while the high-band (millimetre wave) spectrum offers high data speeds but over shorter distances, making it ideal for densely populated urban areas [1, 5]. However, the deployment of 5G isn't without challenges. The high-frequency millimetre wave spectrum offers incredible speeds but it has limitations in terms of range, orientation, and obstruction. As a result, more cell sites and small cells are required to ensure coverage in urban environments. Considering all these limitations the authors of this paper mainly focus on the limitations of implementing 5G in densely populated countries in the sub-continent. Though the data set of this paper is based on the US cities. Researchers found limitations of 5G over the US cities where more areas are free from population [1]. So, the authors of this paper work on the limitations of implementing 5G in populated sub-continent area such as Bangladesh depending on the limitations found in US countries. This paper mainly focuses on,

- To review limitations and challenges faced by developing sub-continent countries, specifically Bangladesh, in implementing 5G based on the limitations found in the US.
- To investigate the impact of distance on the implementation of 5G in densely populated areas of the sub-continent.
- To analyze the effect of orientation and obstacles on the deployment of 5G in different regions of Bangladesh.
- To evaluate the influence of the selection of protocols on the successful implementation of 5G in developing sub-continent countries like Bangladesh.

In this manuscript, Sections 2 and 3 will talk about the literature review and methodology, respectively, Section 4 will talk about the results and evaluation, and Section 5 will talk about the conclusion and future scope.

2 | RELATED WORKS

This section provides an overview of existing research with references to 27 papers that contribute to the significance of the work. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart is depicted in Figure 1. Table 1 shows the findings and limitations of the recent papers.

In their study, Narayanan and colleagues [1] conducted smartphone-based 5G performance assessments in diverse U.S. locations and conditions, alongside a discussion on 5G advancement using cross-layer theory; despite the absence of advanced handoff monitoring tools, the researchers suggested the development of a 5G network incorporating transport protocols and interface selection among 5G, 4G, and Wi-Fi to enhance Quality of Experience (QoE) on 5G.In their work, Xu and collaborators [9] deployed 5G within an urban setting through the sub-6 GHz spectrum, employing specialized instruments to investigate 5G-supported functionalities; their measurements facilitated a comprehensive analysis of 5G versus 4G, spanning from the physical to application layers of the protocol. Though their study is mainly focused on urban areas of modern cities they do not discuss the condition of populated areas of sub-continent countries.

Jiang and colleagues [12] investigated the potential of user and environmental mapping within high-frequency 5G networks, utilizing simplified models of signal propagation and direct positioning algorithms to associate received waveforms with specific locations. Their research is based on the countries that are using 5G in specific areas but they do not describe the implementation conditions while implementing 5G initial stages. Addressing end-to-end communications, Poorzare and co-authors [21] examined the impact of TCP within 5G millimetre-wave networks, analyzing diverse parameters and 5G's performance; their research primarily centred on integrating the TCP protocol with 5G to establish improved end-to-end connections and enhance network efficiency, although they did not elaborate on TCP's significance in sub-continental regions. Taking into account parameters like rapid attenuation, sensitivity, and mobility, Arvind and collaborators [5] qualitatively forecasted throughput, devising a machine learning model for Lumos 5G to anticipate throughput in open spaces, yet their work does not elaborate on Lumos 5G's performance in congested areas. Making use of the 5G-LENA network simulator integrated with ns-3, Poorzare and colleagues [16] simulated and generated preliminary adoption scenarios for the 5G network, with a primary focus on exploring the implementation of 5G in contemporary urban environments, however, they do not discuss the constraints associated with implementing 5G in underdeveloped sub-continental regions. Wu et al. [13] conducted the first empirical evaluation of state-of-the-art multipath schedulers based on real 5G data in both static and mobile scenarios. Yu [2] described the architectural description of the Mobile Edge Computing (MEC) platform, focusing on the key

TABLE 1 Comparison table among the related works.

No.	Authors	Published year	Findings	Limitations
01	Reza Poorzare et al. [16]	2021	They provided information that can streamline the validation of TCP behaviour in upcoming sections.	They do not discuss the constraints associated with implementing 5G in underdeveloped sub-continental regions.
02	Hongjia Wu et al. [13]	2021	The results effectively showcase the advantages of utilizing a learning-based multipath scheduler for 5G networks.	These approaches should exhibit enhanced adaptability to evolving path conditions and consider the evolving characteristics and demands of both 5G networks and those beyond.
03	Salman Mohebi et al. [17]	2021	It has been observed that beam overlaps primarily occur at the peripheries of the illuminated regions, resulting in interference issues.	This interference often contributes to frequent adjustments in beam configurations
04	Lifan Mei et al. [11]	2021	The study demonstrates that Recurrent Neural Network models excel in accurately predicting mobile bandwidth fluctuations, and introduces successful classification and regression-based models for anticipating handoffs between 4 and 5G networks,	Emphasizing their significance in maintaining high user Quality-of-Experience and supporting low-latency applications like self-driving strategies.
05	Aggarwal et al. [18]	2021	Their findings indicate that 802.11ad outperforms its 5 GHz counterparts in catering to the demands of emerging bandwidth-intensive smartphone applications	Simultaneously, they highlight several crucial avenues for further exploration to fully harness its potential.
06	Reza Poorzare et al. [14]	2021	The study introduces a novel TCP protocol based on Fuzzy logic to address challenges in high-speed, reliable communication within urban 5G networks.	Through intelligent sending rate adjustments during congestion, the protocol outperforms existing solutions in terms of throughput, RTT, and adaptive rate control, demonstrating enhanced performance and low latency in urban scenarios.
07	Tong Liu et al. [19]	2021	The study examines 5G's benefits and reveals a disparity between its advancements and existing wired networks and mobile apps.	The findings stress the need for improved Internet capacity and more 5G-friendly applications to fully leverage the capabilities of the evolving 5G era.
08	Josip Lorincz et al. [20]	2021	The paper presents an overview of TCP congestion control (CC) algorithms in the context of 5G networks, addressing the challenges posed by high user device density and mm Wave communications.	The paper emphasizes the need for reliable TCP CC in diverse 5G scenarios, providing insights and opportunities for future research in this domain.
09	Arvind Narayanan et al. [1]	2020	The study innovatively conducts an extensive analysis of commercial 5G performance on smartphones.	Yielding a substantial dataset that outlines research directions for improved user experience and serves as a foundational resource for subsequent investigations.
10	Dongzhu Xu et al. [9]	2020	The paper comprehensively examines 5G's transformative potential and uncertainties by conducting a cross-layer measurement study.	Though their study is mainly focused on urban areas of modern cities they don't discuss the condition of populated areas of sub-continent countries.
11	Yu Ge et.al. [12]	2020	The study explores 5G systems above 24 GHz for user localization and mapping. It introduces a phased approach involving downlink data transmission, multi-dimensional channel estimation, channel parameter clustering, and SLAM based on a novel likelihood function.	Their research is based on the countries that are using 5G in specific areas but they don't describe the implementation conditions while implementing 5G initial stages.
12	Reza Poorzare et al. [21]	2020	The paper explores the potential and challenges of 5G cellular communication, emphasizing the advantages of millimetre-wave bandwidth for high data rates and new use cases, while addressing obstacles such as non-line of sight states that impact performance and the reliability of transport protocols like TCP in 5G mmWave networks.	They did not elaborate on TCP's significance in sub-continental regions
13	Arvind Narayanan et al. [5]	2020	The research centres on emerging 5G services' potential for networked applications, examining mmWave 5G throughput predictability, machine learning model feasibility, user equipment (UE)-related performance factors, and introducing the Lumos5G framework.	Context-aware predictive model demonstrating reduced prediction error and paving the way for dynamic 5G throughput maps and future 5G-aware applications.

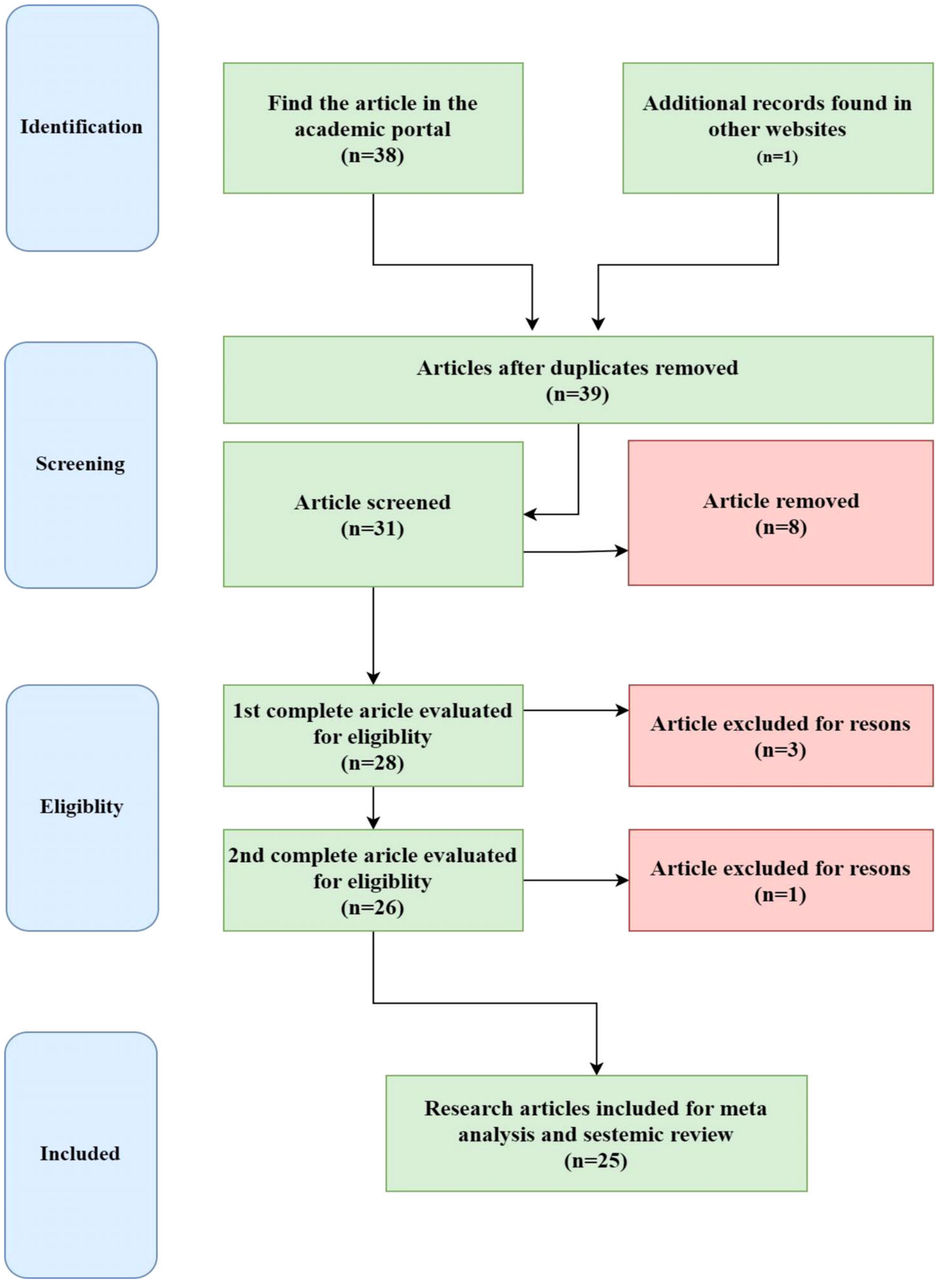


FIGURE 1 Preferred reporting items for systematic reviews and meta-analyses analysis.

functionalities that enable state-of-the-art research efforts. De Lara et al. [22] argued that the proliferation of devices, low latency requirements, digital infrastructure, high bandwidth, and data privacy continue to drive the need for edge computing research. Zhang et al. [4] developed a connection management scheme, policy framework, packet scheduling algorithm, and buffering strategy tailored to MPBond's architecture. Michelinakis et al. [17] conducted an experimental study to evaluate the performance of a commercial 5G mm Wave cell, considering various scenarios and end-to-end communication performance. Ai et al. [11] explored the feasibility and precision of handoff predictions and real-time mobile bandwidth using both 4G/LTE and 5G cellular networks. M. et al. [18] compared the performance of 802.11ad with 802.11ac and 802.11ax in the 5 GHz bands, examining power consumption in both communicating and non-communicating modes. To avoid performance degradation. Calaveras et al. [14] developed a Fuzzy Logic TCP for urban deployments. Fuzzy rules were implemented in the congestion avoidance phase of the protocol to prevent congestion impacts and achieve maximum performance. Varghese et al. [15] created the Scission Lite framework for accelerating distributed Deep Neural Network (DNN) inference using the Transfer Layer (T.L.). The TL was inserted between the optimal slicing point of a DNN model slice to decrease outbound network traffic without sacrificing accuracy. [23] performed global client-to-cloud latency measurements across 189 data centres from major cloud providers. They deployed up to 8500 probes in heterogeneous environments, including home and office settings. Kousias et al. [24] introduced HINDSIGHT++, an open-source framework based on R for bandwidth forecasting experimentation in MBB networks using Long Short-Term Memory (LSTM) networks. HINDSIGHT++ enhanced performance through Automatic Machine Learning (AutoML), relieving the burden of data preprocessing. W. et al. [25] developed Elf, a system that offloads video frames to multiple servers for parallel processing. This parallel offloading approach accelerates mobile deep vision applications with any server provisioning. N.B. et al. [26] investigated minimizing the age of information, focusing on recent developments in 5G mmWave technology and transmissions over unreliable but fast channels or slow reliable channels.

All of the aforementioned research revolves around the implementation scope and limitations of 5G, primarily concentrating on contemporary and advanced urban locales worldwide; however, as developing sub-continent regions endeavour to progress in the realm of networking and strive to adopt 5G technology, this paper specifically addresses the challenges associated with implementing 5G in such regions. Despite the insufficiency of dedicated datasets for these sub-continent areas, the authors draw from U.S.-based data to extrapolate issues and illustrate their relevance within the context of developing regions like Bangladesh.

3 | METHODOLOGY

Firstly, authors have measured the relationship between related features. Extracting seven features from the data defines the difficulties in implementing 5G, for example, distance, orientation, NLOS, obstruction, server location, and the implemented protocol. Then researchers use machine learning algorithms to determine the relationship with the features. Relationship among the features is shown based on visualization. Figure 2, shows the methodology of this paper.

3.1 | Dataset description

The dataset was collected by a research group at the University of Minnesota [1]. The dataset is created based on three cities such as, Minneapolis, Chicago, and Atlanta. Table 2, shows seven features that created difficulties in implementing mm-wave 5G. All of the values of the dataset are string and Numeric. This paper transfers string value to numeric for analysis.

3.2 | Algorithm

Correlation analysis and regression analysis are used to determine the relationships among features. Visualization of the correlated attributes is shown to describe the conditions.

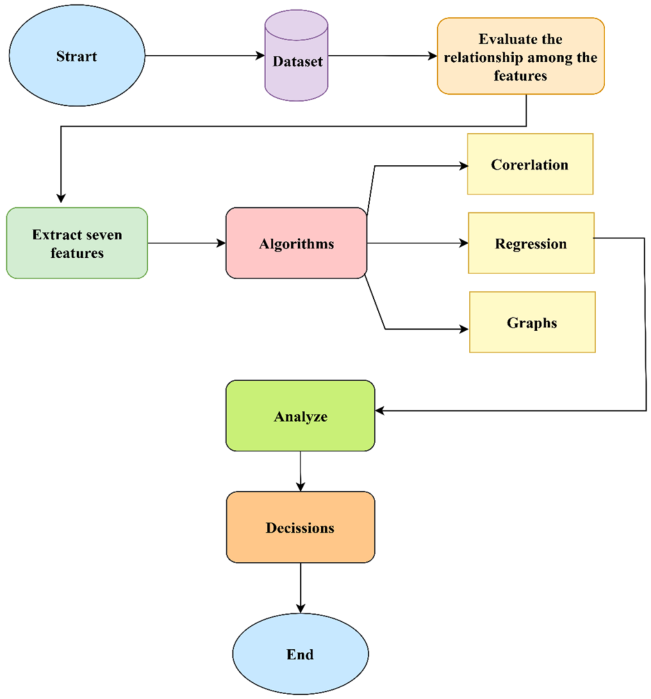


FIGURE 2 Workflow of the analysis.

TABLE 2 Features list of datasets.

Data set	Measurements	Maximum	Minimum
Radio type (4G/5G)	Radio type	2	1
	Throughput	954	0
Distance	Distance	160	25
	Throughput	2351.0549	10.491
Orientation	Orientation	90	0
	Throughput	2352.4593	897.423
NLOS (with multipath)	Obstruction	2	1
	Throughput	2076.182460	702.506
NLOS (without multipath)	Obstruction	2	1
	Throughput	717.965	12.390
Server (CDN/SWS)	Server	2	1
	Throughput	800.782	77.410
Web protocol (HTTP/HTTPS)	Web protocol	2	1
	Download time (s)	56.266	39.149

3.2.1 | Correlation

In the cited paper, the authors employed correlation analysis to elucidate the interrelationships among the featured variables. Correlation analysis is a valuable statistical technique utilized in the quantitative analysis of data. In cases where two variables exhibit a positive correlation, an increase in one variable accompanies a simultaneous increase in the other. Conversely, a negative correlation arises when an increase in one variable coincides with a decrease in the other. When there is no discernible connection exists, the correlation coefficient assumes a value of zero. Notably, Pearson's correlation coefficient is a pivotal metric enabling the measurement of linear relationships. This coefficient, denoted as '*r*', assumes values between −1 and 1. An *r* value of 1 signifies a perfect positive correlation, −1 indicates a perfect negative correlation, and 0 implies the absence of a linear relationship [5, 27].

$$\rho X, Y = \frac{E[XY] - E[X]E[Y]}{\sqrt{E[X^2] - (E[X])^2}\sqrt{E[Y^2] - \left(E(Y)^2\right)}} \tag{1}$$

Kendall's Tau coefficient, a non-parametric measure, quantifies association between ranked or ordinal variables. It exists in two forms: Tau-b accounts for tied ranks, while Tau-c doesn't. Ranging from −1 to 1, it denotes perfect negative to positive association, with 0 indicating no link. Unlike Pearson's correlation, Kendall's Tau suits non-linear data and does not demand normality. It's invaluable for revealing connections in situations where traditional methods fall short due to data type or distribution [28].

$$T = \frac{(number\ of\ concordant\ pairs) - (numbers\ of\ discirdant\ pairs)}{(x^2)} \tag{2}$$

Spearman's rank correlation coefficient evaluates relationships between ranked variables by measuring monotonic associations. It quantifies the strength and direction of this relationship, offering a non-parametric alternative to Pearson's correlation for non-linear data. Ranging from −1 to 1, it signifies perfect negative to positive monotonic association, with 0 denoting no correlation. Spearman's coefficient is robust against outliers and doesn't require assumptions of normality. It's a valuable tool when analyzing data with ranked or ordinal variables that might not adhere to linear relationships.

$$r = \rho R(X), R(Y) = \frac{cov(R(X), R(Y))}{\sigma R(X)\sigma R(Y)} \tag{3}$$

The covariance of ranked variables, cov(R(X), R(Y)), corresponds to the Pearson Correlation coefficient. However, this application is tailored to ranked variables.

3.2.2 | Regression analysis

Regression analysis is a powerful statistical method used to examine relationships between variables. It aims to understand how a dependent variable changes as one or more independent variables vary. By fitting a regression model to observed data, it estimates the nature and strength of these relationships. The process involves identifying the best-fitting line (or curve) that minimizes the differences between predicted values and actual data points. Linear regression is the most common form, modelling a linear relationship between variables. More complex models, like polynomial or multiple regression, consider non-linear or multiple influences, respectively. Regression analysis is widely used in various fields, including economics, biology, and social sciences, for prediction, explanation, and hypothesis testing [22].

3.2.3 | Linear regression

In statistics and structural modelling, linear regression is a crucial process for estimating relationships between a scalar variable and one or more related variables. When there's a single explanatory variable, it's known as simple linear regression, and when multiple variables are involved, it becomes multiple linear regression, akin to multivariate linear regression. The process involves analyzing standardized residual regression and utilizing tools like the Normal P-P plot of regression (standardized residual). Residuals are differences between predicted and observed values in statistical models. In the realm of regression analysis, these residuals serve as indicators of a model's accuracy in capturing the variance within the observed data. They help to evaluate the relationship between data points and perform analyses such as ANOVA. A probability–probability (P–P) plot, on the other hand, compares the cumulative distribution functions of two datasets, providing insights into their distribution characteristics. P–P plots are particularly useful for assessing the skewness of an analysis's distribution. In P–P plots, different probability distributions (represented as "F" and "G") can be employed to compare cumulative distribution functions (CDFs). The domain and range of these distributions lie within the unit square, making them suitable for representing comparisons as Z varies from 0 to 1. This intricate analysis of residuals and probability distributions plays a key role in understanding linear correlation and how well a regression model captures the underlying relationships within the data [5, 27, 13].

3.3 | Implementation environments and tools

This research investigates a system comprising an Intel Core i5 6th generation processor, 8 gigabytes of RAM, and a 256-gigabyte SSD. The study employs analytical techniques including correlation, regression, and residual analysis, executed through IBM SPSS Statistics version 23. Graphical representation is achieved using Python programming language version 3.6.9, with the Google Colab platform serving as the integrated development environment for Python coding.

4 | RESULT AND EVALUATION

4.1 | Dataset distribution analysis

In Figure 3a, the depiction showcases the increase in throughput comparing 4 and 5G. The notation "1" represents 4G, while "2" signifies 5G. Notably, 5G outperforms 4G in throughput, attributed to its utilization of mm-wave technology [1]. Furthermore, 5G employs the TCP protocol to ensure seamless end-to-end connections, contributing to the network's

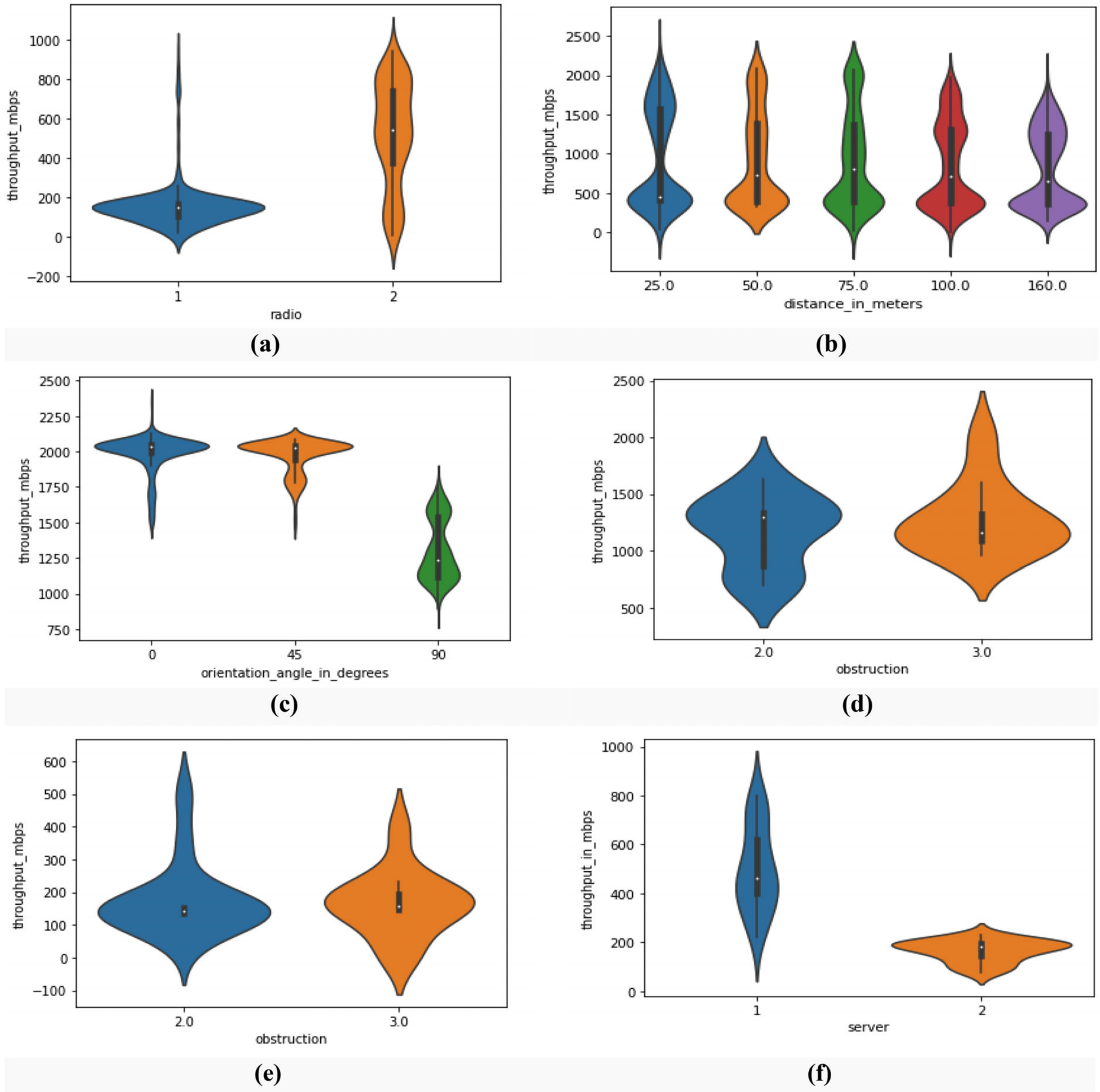


FIGURE 3 Visualization of the relationship between (a) radio type and throughput, (b) distance and throughput, (c) orientation and throughput, (d) obstruction and throughput, (e) obstruction (NLOS) and throughput, (f) server location and throughput.

enhanced performance [1, 5]. In Figure 3b, the portrayal illustrates a decline in throughput as distance increases. This phenomenon arises due to 5G's utilization of mm-wave technology, which faces limitations in serving devices distant from network antennas. Consequently, a larger number of 5G antennas must be deployed compared to 4G to cover expansive areas [1]. This proves to be a cost-intensive endeavour, especially in densely populated countries such as Bangladesh [1, 7].

In Figure 3c, the visualization depicts the impact of orientation on throughput. At a 0° orientation, there's a notable increase in throughput due to a direct end-to-end connection between the device and the base station. At 45°, the violin plot extends, though less than the previous orientation. This is attributed to the device's inability to achieve higher speeds and establish a consistent end-to-end connection with the base station. Subsequently, at extreme orientations, the throughput diminishes significantly due to the absence of an end-to-end connection. This is influenced by mm-wave technology, whose higher wavelength restricts its effectiveness for devices at varying orientations. This presents a challenge, particularly in densely populated subcontinental countries, where creating reliable end-to-end connections amidst high population density and limited space is intricate. Figure 3d displays the impact of obstruction on throughput for mm-wave. Obstacles are represented by labels "2" and "3," signifying hindrances like the human body and hand, respectively. The presence of obstructions hampers mm-wave speed, resulting in decreased throughput. Interestingly, variations in throughput are observed depending on the obstruction's thickness. Greater thickness corresponds to lower throughput, while reduced thickness leads to significantly improved throughput [1, 3]. This issue adds to the complexities of implementing 5G in densely populated residential areas of subcontinental countries. In such environments, where mm-waves encounter obstacles within populated regions, their performance is compromised, posing challenges to optimal functionality.

In Figure 3e, the graphical representation highlights the throughput's response to an obstruction along a single path. Obstacles are represented by labels "2" and "3," signifying the human body and human hand, respectively. Notably, whether it's the human body or hand causing the obstruction, the throughput experiences a significant reduction compared to the multipath scenario, where the signal can travel through diverse paths [8, 21]. This emphasizes the impact of obstacles on throughput, posing challenges to optimal performance, especially in densely populated regions. Moving to Figure 3f, we designate the CDN server as "1" and the SWS server as "2". The figure demonstrates that the CDN server achieves notably higher throughput. It ranges from almost 1000 Mbps at its peak to nearly 0 Mbps at its lowest point [1]. This observation underscores the effectiveness of implementing a CDN server with 5G, highlighting its potential for robust performance.

In practical scenarios, acquiring a pristine raw dataset proves to be a challenge. A reliable and refined dataset is imperative for robust analysis. With a dataset predominantly comprised of numerical and string values, the authors undertook the task of converting string values to numeric representations in various instances. During the analysis of the raw dataset, 4G was denoted as "1" and 5G as "2". Similarly, HTTP 1.1 (Hypertext Transfer Protocol) was represented as "1", and HTTPS 1.1 (Hypertext Transfer Protocol Secure) as "2" to evaluate webpage download speeds. Additionally, NLOS scenarios were distinguished by varying obstacle notations: no obstacle as "0", Human hand as "1", and Human body as "2". Figure 4, illustrates the data's classification into features and labels. Different correlation algorithms are applied to the components, followed by the analysis of correlated features using linear regression algorithms. The relationships among correlated features are visually presented.

The dataset encompasses seven extracted features: Radio type, Distance, Orientation, NLOS (with Multipath), NLOS (without Multipath), Server, and Web protocol. Radio type represents 4 and 5G (with 4G converted to 1 and 5G to 2). Distance signifies the travel path in meters concerning mm waves. Orientation pertains to the angle between the User Equipment (U.E.) and the base station, with values denominated in degrees. In scenarios with Multipath, a blockage exists between the U.E. and base station, yet an alternative path for the mm-wave is present. In the absence of Multipath, no such path exists. Server attributes encompass Content Delivery Network (CDN) and Static Web Server (SWS). Web protocol features consist of HTTP and HTTPS. Throughout the paper, throughput is juxtaposed with all these features, encompassing the myriad factors influencing the attainment of high-speed 5G capabilities.

Figure 5 provides an illustrative scatter plot depicting throughput in relation to six distinct features. In Figure 5a, the numerical labels 1 and 2 correspond to 4 and 5G radios respectively, where the implementation of mm-Wave technology in 5G leads to a substantially higher channel bandwidth than in 4G [1]. Leveraging the TCP protocol, 5G ensures end-to-end connections that result in enhanced bandwidth availability [5, 29]. This graph reveals that while 4G maintains stable data rates up to 200 Mbps, it falls short of reaching the 1000 Mbps threshold, a limitation overcome by the 5G configuration (Figure 5b) which grants consumers access to channel bandwidth up to 1000 Mbps.

Moving to Figure 5b, a clear trend emerges as throughput experiences a reduction with increasing distance. This phenomenon is attributed to the inherent nature of 5G mm-wave technology, characterized by a short wavelength that restricts signal propagation over long distances [1]. Consequently, user equipment (U.E.s) must remain in close proximity to base stations to capitalize on the broader bandwidth potential offered by the channel.

In Figure 5c, the X-axis corresponds to orientation in degrees, while the Y-axis represents throughput. An orientation of 0° facilitates an optimal end-to-end connection between the device and the base station, yielding elevated throughput. Nonetheless, as orientation increases (between 45° and 90°), the channel bandwidth experiences a reduction.

Transitioning to Figure 5(d), the plot elucidates how throughput fluctuates in a multipath context when encountering obstructions. Here, the designations 2 and 3 signify human body obstructions and human hands respectively. When mm-wave encounters an obstacle, it either passes through unobstructed or encounters hindrance. This scenario involves the exploration of multiple transmission paths. The presence of multipath configurations can result in augmented channel bandwidth [1, 5, 30], with throughput divergence contingent on the obstructing object's thickness. Notably, thicker obstructions lead to diminished throughput, while exceptional throughput is observed when obstructions are thin.

Figure 5e illustrates the dynamic alteration of throughput in response to obstruction within a single transmission path, denoted similarly as in Figure 5d. Notably, in this context, throughput experiences significant reduction when obstructions such as human body or hand are encountered, as opposed to the multipath system [21].

Identified as 1 in Figure 5f, the CDN server stands distinct from the SWS server, marked as 2. Specifically, the CDN server exhibits superior channel bandwidth potential [1, 9, 31], with a maximum attainable value of 1000 Mbps.

4.1.1 | Correlation analysis

A correlation heat map visualizes the 2D correlation matrix between two features using coloured pixels, conveying the relationship between discrete dimensions or event types. The matrix rows represent the first dimension, while the columns represent the second dimension. Colour intensity increases as more measurements align with dimensional values. The association between Table 2 and Figure 7a is significant. As indicated

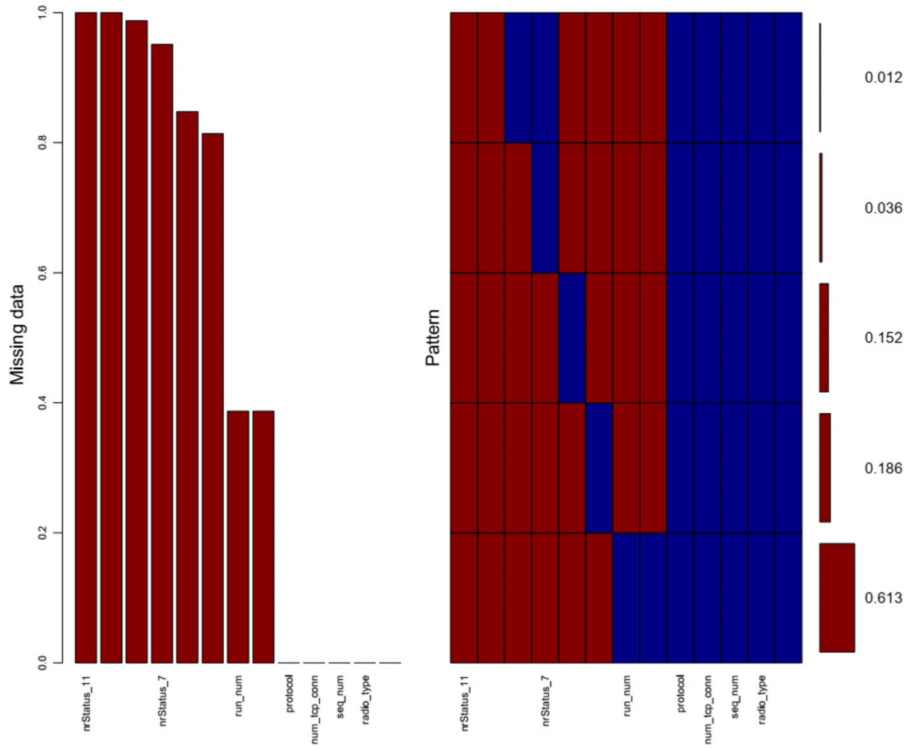


FIGURE 4 The visualization of incomplete data in dataset.

by Figure 6a, 5G's utilization of mm-wave technology results in considerably higher bandwidth compared to 4G [1]. The correlation coefficient of 0.669 underscores their substantial connection. Additionally, Kendall's rank correlation coefficient (Kendall's T) from Table 2 is 0.492, while Spearman's rank correlation coefficient is 0.595, both indicating significant positive relationships. For the attributes in Table 2 and Figure 6b, the correlation coefficient is 0.85, yet the correlation is negative, signifying a significant inverse relationship. Within the nonparametric context (Table 2), Kendall's rank correlation is −0.116, and Spearman's rank correlation is −0.160. Table 2 and Figure 6c illustrate a throughput decrease with increasing distance due to mm-wave's limited range compared to mid-band. Kendall's rank correlation coefficient in this case is −0.562, while Spearman's rank correlation coefficient is −0.717 [1, 9].

A correlation is a way to describe how datasets are related. Table 3, shows the correlation between throughput and different factors of 4 and 5G signals. Though various correlation coefficients are being used based on the behaviour of the dataset, in this study, those are Pearson Correlation, Kendall's Correlation, and Spearman's Correlation, respectively. From Table 3, based on the Pearson Correlation, the correlation of throughput has found a maximum (**0.85,** which indicates solid but inverse relation) relation with the distance feature [32].

Kendall's Correlation measured Throughput's highest correlation value is 0.708, with the Server (CDN/SWS) feature indicating a relatively strong and negative association between the two. However, NLOS showed a minimum correlation (−0.116) with throughput.

Finally, according to Spearman's Correlation, the maximum correlation is 0.857 with the Server (CDN/SWS) dataset, illustrating an inverse and strong relation between throughput and the Server feature. Web protocol and orientation datasets also strongly relate to throughput, where calculated correlation values are 0.780 and −0.717, respectively.

This table shows that throughput is strongly affected by distance, server, and orientation as the correlation value is relatively high according to Pearson correlation.

In Figure 7, a graphical representation visually depicts the correlation between seven features, accounting for instances of missing data. Each cell showcases the correlation between two features. Notably, Run_num emerges with the highest positive correlation (1). Following closely is the second highest correlation (0.9) between num_tcp_conn and the throughput dataset. The correlation between the dataset run_num and num_tcp_conn stands at 0.2, while its correlation with the throughput dataset is 0.1. Solely, the correlation between distance and throughput is negative (−0.1), indicating an inverse relationship between throughput and the distance between the base station and the connected device. It's pertinent to mention that the correlations involving other feature combinations are observed to be zero.

Figure 8 depicts the correlation among seven datasets, with each cell denoting the magnitude and nature (positive or negative) of the relationship between the respective datasets. The analysis excludes missing values from the dataset. Among these correlations, the most significant is observed between the run_num and distance datasets. The second highest correlation of −0.8 is evident between the seq_num and

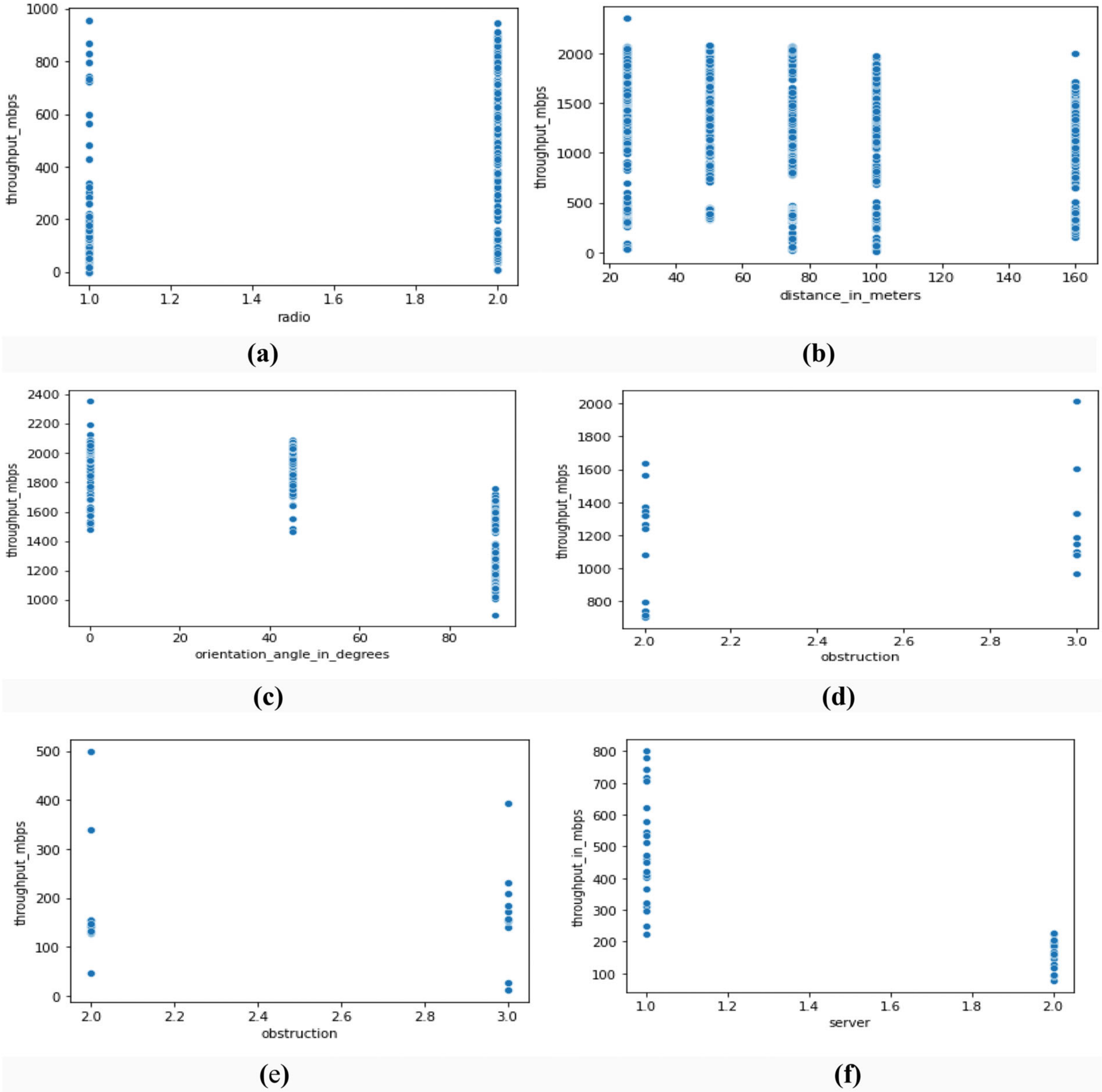


FIGURE 5 Scatter plot of (a) radio type and throughput, (b) distance and throughput, (c) orientation and throughput (d) NLOS (with Multipath) and throughput, (e) NLOS (Without Multipath) and throughput, (f) server and throughput.

radio_type datasets. Another noteworthy correlation exists between num_tcp_conn and throughput, with throughput exhibiting correlations of 0.4 and −0.4 with radio_type and seq_num, respectively. Notably, no correlation is identified between run_num and throughput, as indicated by a correlation value of zero. Other dataset combinations display correlations ranging from −0.2 to 0.2.

4.2 | Regression analysis

As depicted in Table 3, the regression analysis delves into the interrelation of features, all of which are assessed against throughput to elucidate the connection between bandwidth and these attributes [28, 27]. Notably, Table 3 highlights the most noteworthy dependence, primarily revolving around server attributes such as CDN and SWS. The server's geographical location indeed exerts a significant influence on 5G performance, given the inherent limitations of mm-wave's short propagation range. Consequently, if the server remains distant from the user equipment (U.E.), the resultant channel bandwidth would suffer limitations [1, 29, 33].

4.3 | Residual statistics

From insights gleaned from Table 4 and Figure 9, prognostications can be made regarding throughput metrics. With

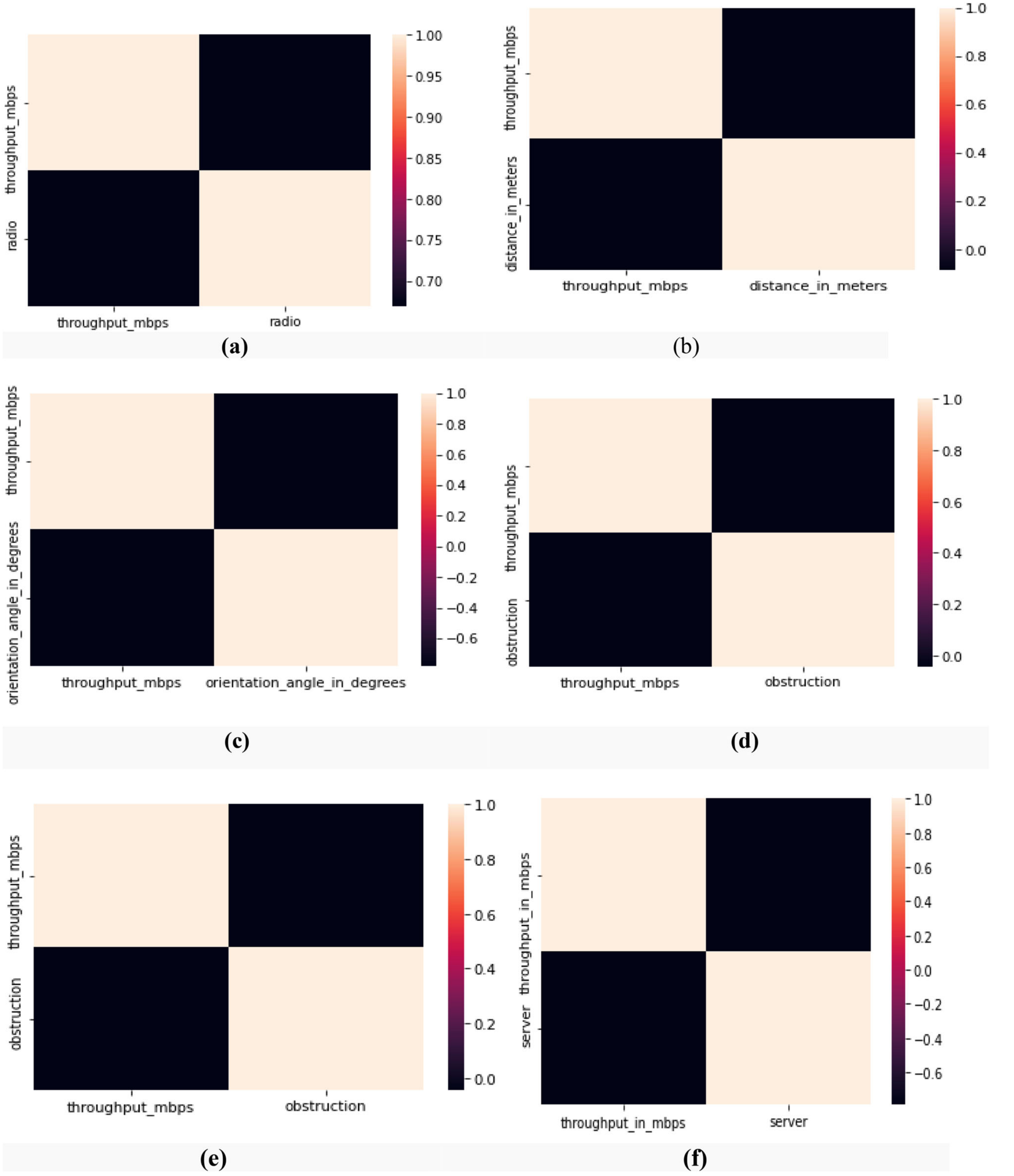


FIGURE 6 (a) Radio type Co-relation heat map against the throughput, (b) distance co-relation heat map against the throughput, co-relation heat map, (c) orientation co-relation heat map against the throughput, (d) NLOS (with multipath), (e) NLOS (without multipath) versus throughput, (f) server and throughput.

consideration of four radio types (4G/5G), the analysis forecasts a potential maximum throughput of 522.848 Mbps, a minimum of 159.207 Mbps, an average of 332.886 Mbps, and a standard deviation of 181.7889 Mbps across 603 data points [34]. Examining distance attributes vis-à-vis throughput, the forecast anticipates a minimal throughput of 72.00 Mbps, reaching a maximum of 88.038 Mbps, with an average of 82.023 Mbps, and a standard deviation of 82.023 Mbps. The total data volume constitutes 738 instances, while the minimum throughput reads 1413.98 Mbps. Orientation-related

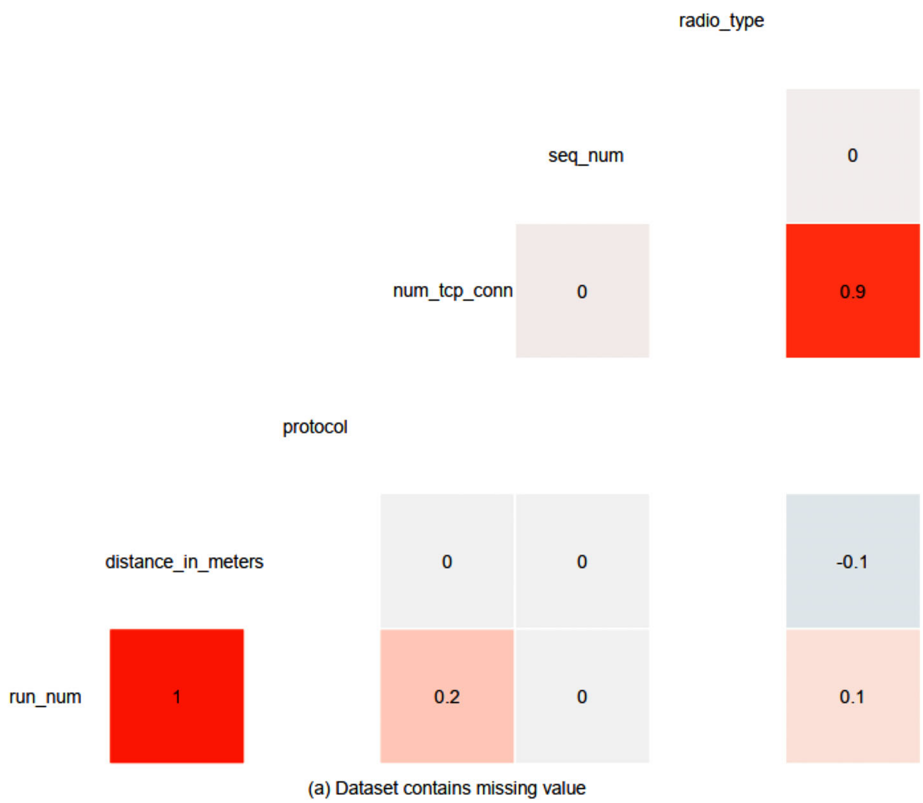


FIGURE 7 Heatmap before handling missing values in all datasets.

TABLE 3 Correlation analysis between throughput and other factors.

Correlation factors	Pearson correlation	Kendall's correlation	Spearman's correlation
Radio type(4G/5G)	0.669	0.492	0.595
Distance	**−0.85**	−0.116	−0.160
Orientation	−0.782	−0.562	−0.717
NLOS (with multipath)	−0.533	−0.444	−0.556
NLOS (wihout multipath)	−0.678	−0.507	−0.650
Server (CDN/SWS)	−0.787	**−0.708**	**−0.857**
Web protocol (HTTP/HTTPS)	0.758	0.653	0.780

features, when contrasted with throughput, yield projections of a minimum throughput at 1413.98 Mbps, a maximum at 2094.488 Mbps, a mean throughput of 1754.23 Mbps, and a standard deviation of 278.003 Mbps, with the peak throughput aligning at 2094.488 Mbps [35, 36].

For NLOS (multipath) attributes, forecasts based on 96 data points envisage a minimum throughput of 106.405 Mbps, a maximum of 433.115 Mbps, an average throughput of 371.857 Mbps, and a standard deviation of 111.80 Mbps. When focusing on NLOS (without multipath) characteristics, it is predicted that the throughput ranges from a minimum of 106.405 Mbps to a maximum of 443.315 Mbps, with a mean throughput of 371.857 Mbps, and a standard deviation of 111.80 Mbps. Analysis of server (CDN/SWS) data attributes and download speed points towards a minimum throughput of 166.791 Mbps, a maximum throughput of 498.987 Mbps, an average throughput of 351.345 Mbps, and a standard deviation of 130.825 Mbps, considering a total of 45 data instances. Lastly, examining web protocol (HTTP/HTTPS) compared to bandwidth with 20 data points, the forecasted figures encompass a minimum throughput of 45.602 Mbps, a maximum throughput of 53.979 Mbps, an average throughput of 49.7999 Mbps, and a standard deviation of 4.287 Mbps.

The R-squared ($R2$) statistic quantifies the extent to which an independent variable explains variance in a regression model, serving as a benchmark for evaluating regression models, but it alone does not determine a model's accuracy. To draw conclusions from the R-squared, it should be considered in conjunction with other variables within the statistical model. Figure 9 shows, adjusted R-squared, assessing model accuracy, is essential for linear models' goodness-of-fit; it reveals the portion of target field variance explained by input variables, correcting the tendency of R-squared to overestimate linear regression fits [37, 38]. The adjusted R-squared tends to decrease when a factor lacks positive impact, offering a more accurate representation of correlation between variables compared to the standard R-squared [34, 39].

Adding independent variables to the model and comparing them to the stock index allows the calculation of adjusted R-squared, offering insight into the relationship between orientation and throughput. The standard error of the estimate (S) represents the average discrepancy between observed values

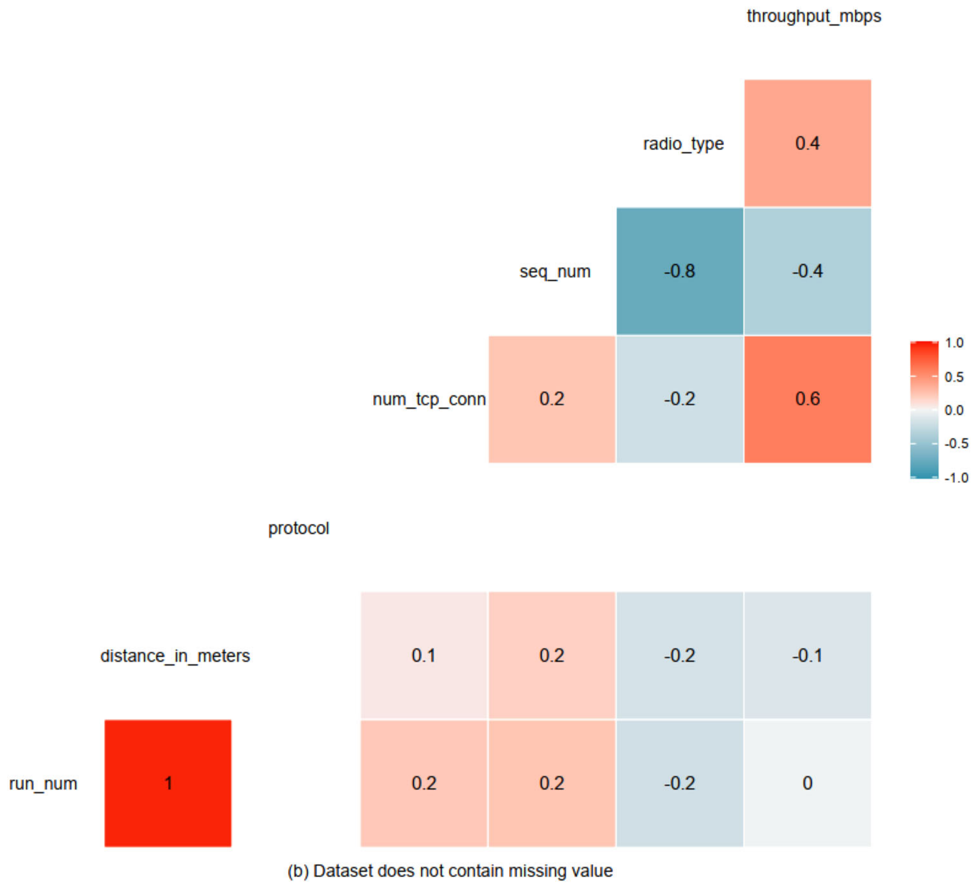


FIGURE 8 Heatmap after handling missing values in all datasets.

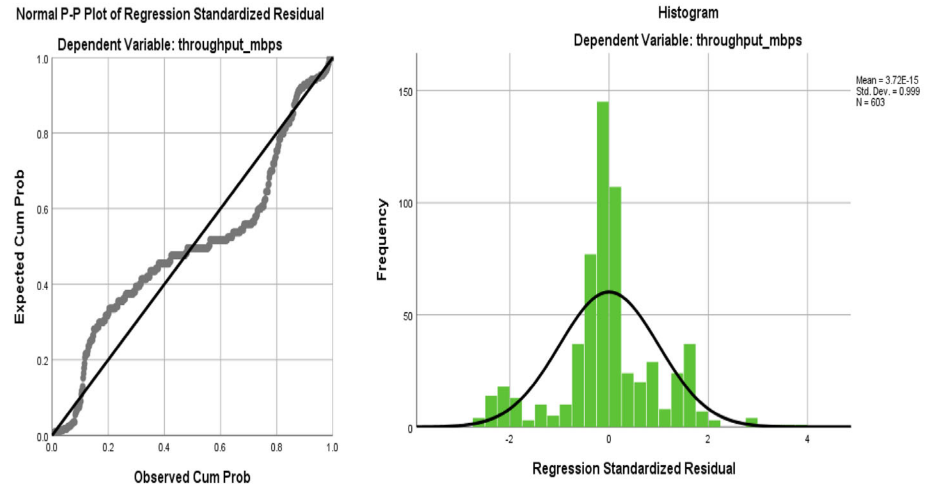
and the regression line, while *p*-values, derived from Table 5, indicate the significance of the connection between dependent and independent variables; low p-values signify significant relationships. The smallest f-change value (0.448) in Table 5 and Figure 9 underscores the significant link between Radio type and throughput, where 5G outperforms 4G due to its utilization of mm-wave technology for higher bandwidth channels [1, 9, 40].

From the insights in Table 3 and Figure 9, it becomes apparent that orientation profoundly affects channel bandwidth when employing mm-wave. A direct connection (0° orientation) between consumers and the base station translates to congestion-free 5G service, highlighting its importance in ensuring optimal user experience.

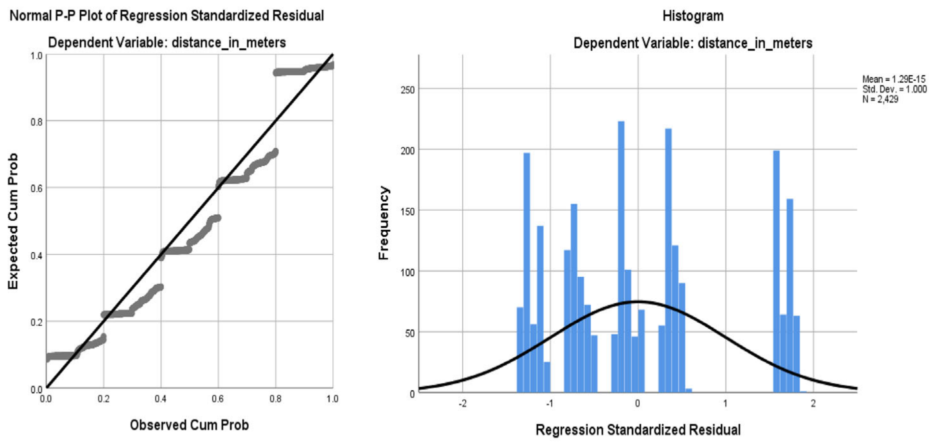
From Figure 10, The Elbow method is a widely adopted technique that employs K-Means clustering to identify the optimal number of clusters within a dataset. In our experimental dataset, we employed this method to determine the most suitable number of clusters. As the cluster count increases, the distance of "Within Cluster Sum of Squares (WCSS)" decreases [41, 20]. However, an excessive number of clusters can render clustering purposeless. Thus, pinpointing the optimal cluster count is crucial. Figure 10 illustrates the elbow method, showcasing the WCSS on the *Y*-axis against the Number of Clusters

TABLE 4 Linear Regression analysis.

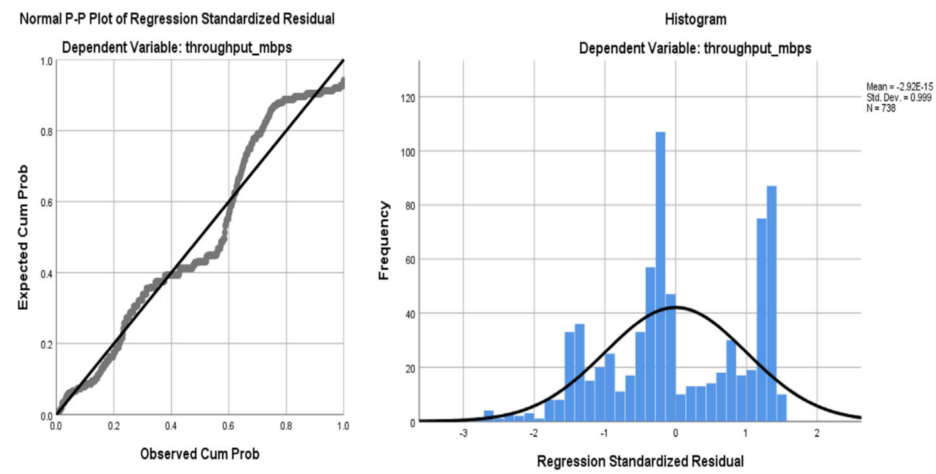
Data set	*R*	*R* square	Adjusted *R* square	Std. mistake of estimation	F change
Radio type(4G/5G)	0.669	0.448	0.447	202.0628	0.448
Distance	0.085	0.007	0.007	48.1698	-
Orientation	0.782	0.611	0.610	222.072	-
NLOS (with multipath)	0.678	0.460	0.454	121.835	79.998
NLOS (without multipath)	0.678	0.460	0.454	121.835	79.998
Server (CDN/SWS)	0.787	0.620	0.611	132.337	70.013
Web protocol (HTTP/HTTPS)	0.758	0.574	0.531	3.793	24.271



(a)



(b)



(c)

FIGURE 9 (a) Radio Type Residuals Statistics (to plot normal P–P plot of regression standardized residual and regression analysis normal P–P plot of regression standardized residual), (b) distance residuals statistics (to plot normal P–P plot of regression standardized residual and regression analysis normal P–P plot of regression standardized residual), (c) orientation residuals statistics (to plot normal P–P plot of regression standardized residual and regression analysis normal P–P plot of regression standardized residual), (d) NLOS(With multipath) residuals statistics (to plot normal P–P plot of regression standardized residual and regression analysis normal P–P plot of regression standardized residual), (e) NLOS (without multipath) residuals statistics (to plot normal P–P plot of regression standardized residual and regression analysis normal P–P plot of regression standardized residual), (f) server (without multipath) residuals statistics (to plot normal P–P plot of regression standardized residual and regression analysis normal P–P plot of regression standardized residual).

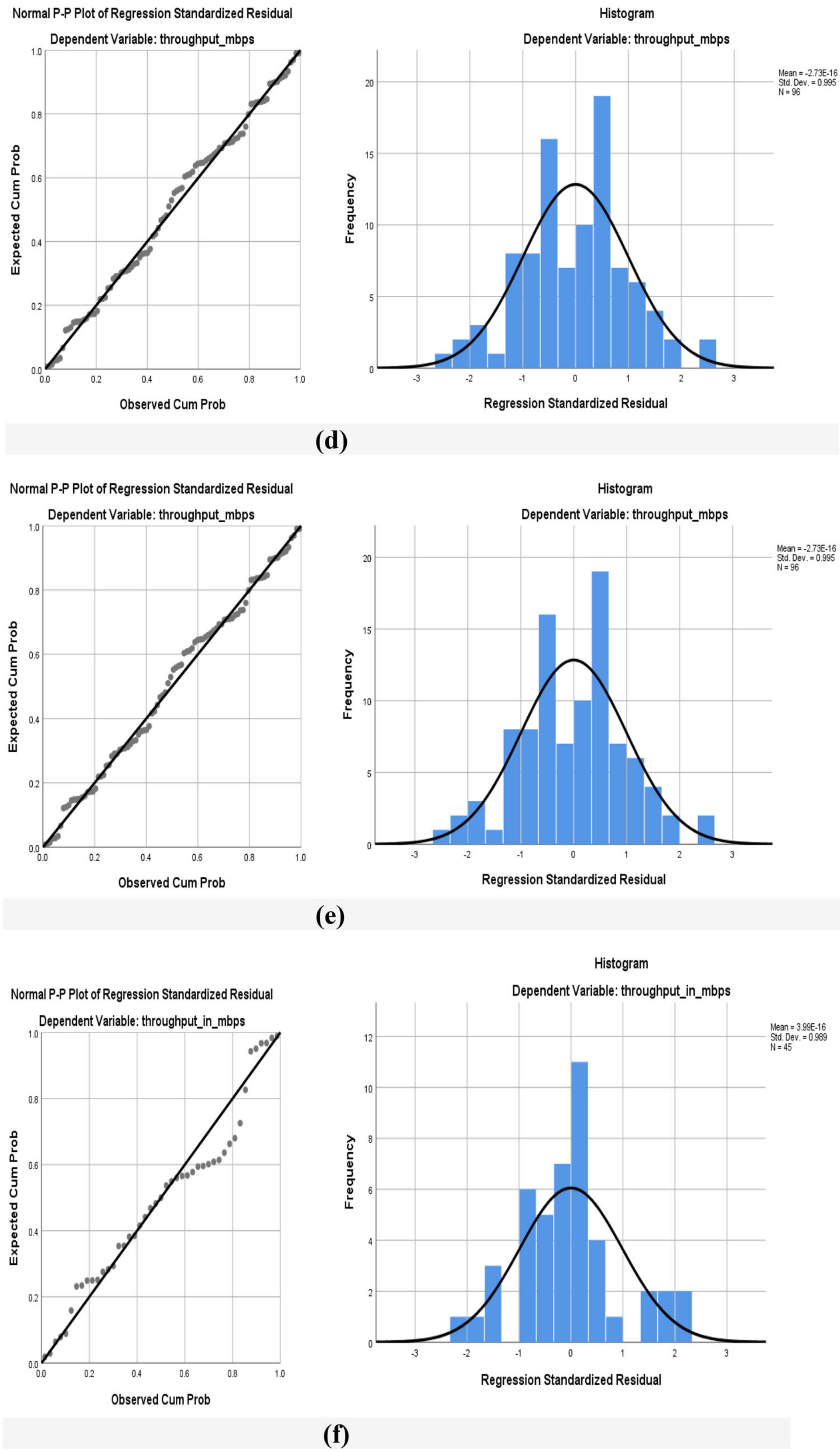


FIGURE 9 Continued

TABLE 5 Residuals Statistics (to plot Normal P–P plot of regression standardized residual and regression analysis normal P–P plot of regression standardized residual).

Data set	Measurements	Minimum	Maximum	Mean	St. deviation	N
Radio type (4G/5G)	Predicated value	159.207	522.848	332.886	181.7889	603
	Residual	−512.3476	794.7933	0.000	201.8949	603
	Std. predicated value	−0.955	1.045	0.000	1.000	603
	Std. residual	−2.536	3.33	0.000	0.999	603
Distance	Predicated value	72.000	88.038	82.023	3.9572	2429
	Residual	−62.8944	85.5944	0.000	46.1603	2429
	Std. predicated value	−2.533	1.520	0.000	1.000	2429
	Std. residual	−1.362	1.854	0.000	1.000	2429
Orientation	Predicated value	1413.98266	2094.488	1754.2354	278.003	738
	Residual	−615.826	347.793	−0.000000000000606	221.921	738
	Std. predicated value	−1.224	1.224	0.000	1.000	738
	Std. residual	−2.773	1.566	0.000	0.999	738
NLOS (with multipath)	Predicated value	106.405	433.115	371.857	111.802	96
	Residual	−300.919	285.590	0.000	121.1922	96
	Std. predicated value	−2.374	0.548	0.000	1.000	96
	Std. residual	−2.470	2.344	0.000	0.995	96
NLOS (without multipath)	Predicated value	106.405	433.115	371.857	111.802	96
	Residual	−300.919	285.590	0.000	121.1922	96
	Std. predicated value	−2.374	0.548	0.000	1.000	96
	Std. residual	−2.470	2.344	0.000	0.995	96
Server (CDN/SWS)	Predicated value	166.791	498.987	351.345	166.934	45
	Residual	−276.367	301.794	0.000000000000056	130.825	45
	Std. predicated value	−1.106	0.884	0.000	1.000	45
	Std. residual	−2.088	2.280	0.000	0.989	45
Web protocol (HTTP/HTTPS)	Predicated value	45.620	53.979	49.7999	4.287	20
	Residual	−6.471	7.5711	0.000000000000001	3.692	20
	St. predicated value	−0.975	0.975	0.000	1.000	20
	Std. Residual	−1.706	1.996	0.000	0.973	20

on the X-axis. This graph delineates how the WCSS diminishes with an increase in the number of clusters [42]. According to this elbow method analysis, the dataset is optimally clustered into four groups. With four clusters, the WCSS distance will be approximately 7000. Additionally, for visualizing high-dimensional datasets, the t-Distributed Stochastic Neighbour Embedding (t-SNE) technique proves particularly effective [41].

In Figure 11, a t-SNE plot displays the distribution of the four clusters. These clusters are differentiated by distinct shapes and colours. The plot reveals that each cluster is distinctly segregated from the others, with some minor overlap observed between them [20].

5 | OBSERVATIONS

The objective of this paper is to provide a comprehensive overview of the major challenges associated with implementing 5G technology in developing subcontinent regions. The study draws upon a dataset collected by the University of Minnesota—Twin Cities, which gathered observations across various U.S. states, including Minneapolis, Chicago, and Atlanta. Although the dataset consists of 38 previous research works, it forms the foundation for investigating the obstacles that arise during the deployment of 5G technology. Given the lack of sufficient data from the subcontinent, the authors rely on observations from the U.S. dataset. This research holds significant potential for developing nations as they embark on their initial journey into the realm of 5G implementation. However, implementing 5G with an mm-wave has some problems. Mm-Waves with significant frequencies often face problems because they cannot travel more paths, orientation differently, experience blockages on their way, server location difficulties, protocol selection difficulties, and many other things. This research discusses the major features related to the implementation of 5G. With the help of different algorithms (co-relation,

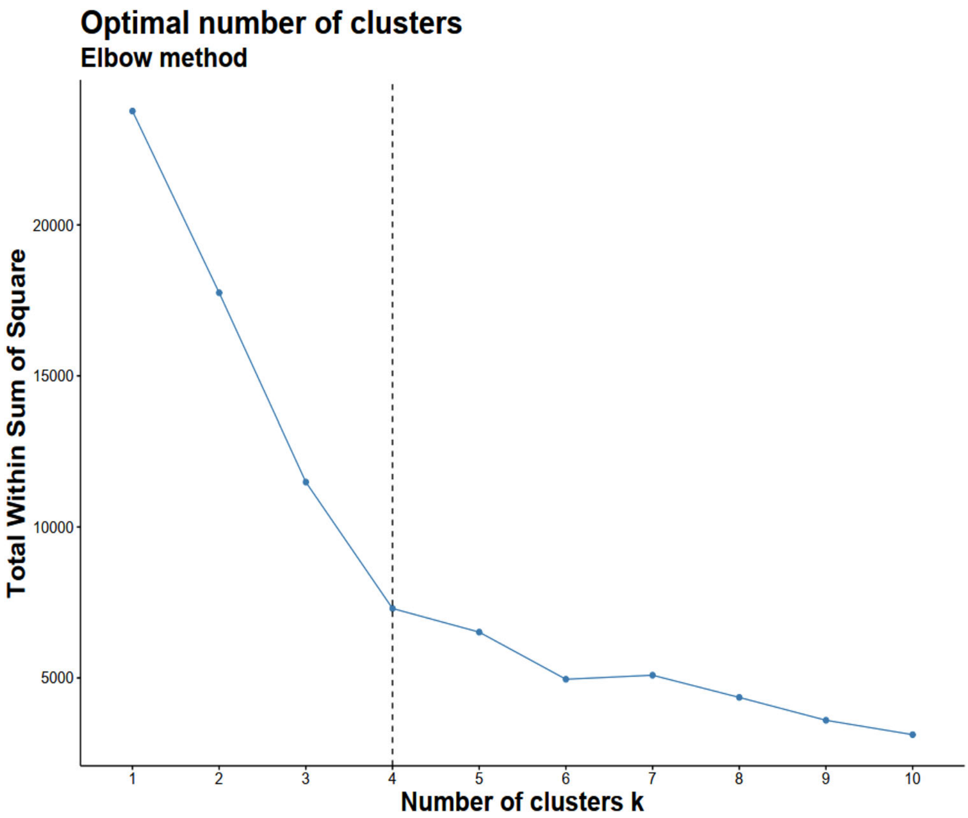


FIGURE 10 Determining the optimal number of clusters using the Elbow method.

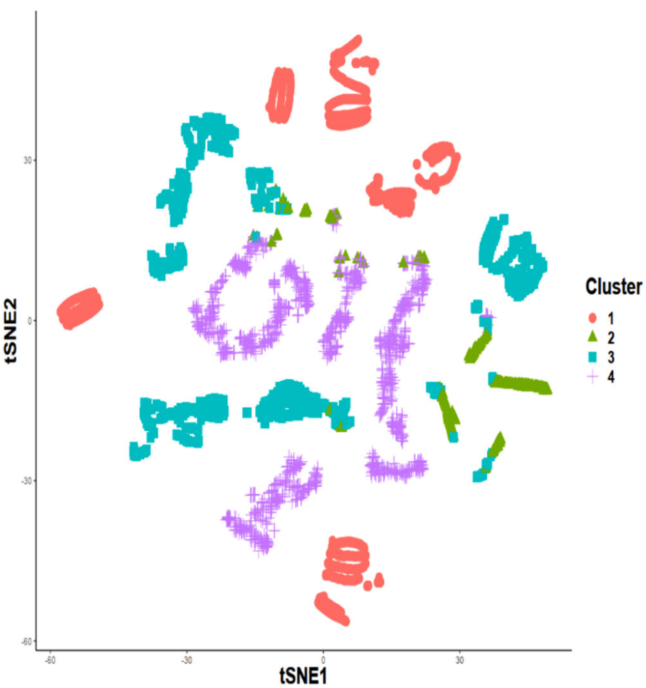


FIGURE 11 Visualization of tSNE plot of cluster analysis.

regression), the relationship of the features is evaluated and shown with other visualization (violin plot, scatter plot, and bar plot). The raw data have some null values.

The study initially delved into the motivations behind users' interest in 5G. Primarily, 5G is sought after due to its capacity for generating more bandwidth and scalability. Mm-wave technology is adopted to fulfil these demands. However, mm-wave-driven 5G implementation is not without challenges. Significant frequency mm-waves face obstacles such as limited path options, variable orientation responses, blockages, server location complexities, and protocol selection issues. This research extensively discusses these pivotal features concerning 5G implementation.

Employing various algorithms including correlation and regression, the study evaluates feature relationships, visualizing outcomes via violin plots and scatter plots. The research adeptly handles null values in the raw data and quantifies correlations among 5G's interconnected features. While theoretical 5G holds immense potential in terms of bandwidth, practical 5G is in its infancy. This is particularly evident in developing subcontinent nations, where widespread 4G connectivity is the norm. To address this gap, the research suggests a pragmatic approach: implementing 5G through a Non-Standalone Architecture (NSA) supplemented by mid-range 4G Long Term Evolution (LTE). This approach ensures 5G coverage in areas where it falters, preventing the loss of consumer interest due to unmet expectations. This study predominantly addresses the challenges associated with implementing 5G technology in developing subcontinent regions. While acknowledging the limitations of the available dataset, the authors made use of observations from a U.S. dataset. The research's future trajectory involves exploring 5G implementation across diverse conditions and devising solutions to overcome the identified challenges.

6 | CONCLUSION AND FUTURE SCOPES

This study explores the viability, challenges, architecture, and protocol suite associated with introducing 5G networks in developing subcontinent nations like Bangladesh. With a frequency range spanning 600 MHz to 100 GHz, internet users stand to benefit from wider bandwidth allocation, driving substantial enhancements in data rates. Leveraging mm-wave technology further enables improved scalability within the 5G framework. Additionally, the deployment of Reliable Low Latency Communications (URLLC) offers advanced interconnectivity features catering to IoT, advanced coding, and massive MIMO. The government's 2021–2023 initiative to roll out nationwide 5G services is also discussed. Despite highlighting significant challenges tied to 5G implementation in developing subcontinent nations, such as Bangladesh, the paper proposes various protocols and server placements. However, it acknowledges the current reliance on U.S. datasets, addressing the limitations and emphasizing the need for subcontinent-specific data for a more comprehensive analysis. The paper also looks ahead to the potential future scope, including solutions and the implementation of 5G using localized datasets within the subcontinent.

AUTHOR CONTRIBUTIONS

Pranto Halder: Conceptualization; Data curation; Formal analysis; Methodology; Visualization; Writing. Md. Mehedi Hassan: Formal analysis; Methodology; Visualization; Project Supervision and Investigation. A. K. Z. Rasel Rahman: Investigation; Validation; Writing. Laboni Akter: Investigation; Validation; Writing. Abu Shakil Ahmed: Supervision; Conceptualization; Validation; and Shakir Khan: Revised the manuscript; Sajib Chatterjee: Edited the final version of the manuscript; M. Raihan: Supervision; Administration; and Validation.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are available from the corresponding author upon request, Md. Mehedi Hassan

ORCID

Md. Mehedi Hassan https://orcid.org/0000-0002-9890-0968
Abu Shakil Ahmed https://orcid.org/0000-0001-8075-1733
M. Raihan https://orcid.org/0000-0003-1072-3555

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APPENDIX A

Acronym	Full Form
TCP	Transmission control protocol
ICMP	Internet control message protocol
MIMO	Multiple-input multiple-output
5G	Fifth-generation wireless
mm-wave	Millimetre wave
IoT	Internet of Things
AI	Artificial intelligence