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# Challenges and opportunities of 5G integration in Bangladesh: Impacts on education, research, business, and healthcare

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## ABSTRACT

**Background:** 5G has been officially launched in Bangladesh but remains limited to pilot zones (mainly Dhaka), while nationwide mobile broadband demand continues to grow. This study examines the prospects and constraints of 5G adoption in Bangladesh and maps likely sectoral implications for education, research, business, and healthcare.

**Methods**: An exploratory research design was employed using secondary datasets from the Bangladesh Telecommunication Regulatory Commission, the World Bank, and a University of Minnesota (Twin Cities) measurement dataset. IBM SPSS Statistics 25 and Python 3.6.9 were used for correlation analysis and feature-based visualizations to interpret relationships between key network features and performance indicators.

**Results:** Throughput shows a positive association with 5G radio type (Pearson 0.669; Kendall 0.492) and with web protocol (Pearson 0.758; Kendall 0.653). Throughput decreases with distance (Pearson −0.85), orientation (Pearson −0.782), NLOS effects (with multipath Pearson −0.533; without multipath Pearson −0.678), and server-type differences (Pearson −0.787), highlighting mmWave sensitivity to propagation and deployment conditions.

**Conclusion:** While 5G can enable high data rate and low-latency services relevant to key sectors, successful nationwide impact in Bangladesh depends on mitigating mmWave limitations, strengthening infrastructure readiness, and addressing cost, security, and policy coordination across stakeholders.

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## KEYWORDS

5G technology; Internet of Things; mobile communications; cellular network; TCP protocol

## Introduction

The introduction of 5G signifies a remarkable advancement in the telecommunications sector, featuring a plethora of enhanced capabilities compared to its predecessor [1]. Bangladesh witnessed a surge in mobile internet usage after the implementation of 4G in 2018, escalating from 100 Mb (3G) to 700 Mb (4G). This substantial improvement brought by 4G has greatly impacted the networking industry. In recent times, there has been exponential growth in the number of internet users in Bangladesh, as evidenced by the data presented in Table 4. Consequently, the existing channel bandwidth support provided by 4G has become inadequate to meet the escalating demands of consumers due to the rapid expansion of internet usage. The COVID-19 pandemic, beginning in late 2019 and extending into late 2020, highlighted the critical necessity for high and dependable data transmission, especially for online-based communication in Bangladesh [2]. Furthermore, with Bangladesh aiming to exit the Least Developed Countries category by 2026, the urgency for technological progress becomes more pronounced. Considering these significant factors, the Bangladesh Telecommunication Regulatory Commission (BTRC), in collaboration with Teletalk and Huawei Technology, unveiled 5G on December

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13, 2021, although 5G has been officially launched, it is not yet available nationwide. Teletalk initially deployed 5G on a trial basis in select areas of Dhaka and a few designated hotspots. No commercial operator has extended 5G services across the entire country. Coverage remains extremely limited, and the majority of Bangladesh still relies on 4G networks for mobile broadband access. While still maintaining the existence of 4G and 3G networks [3].

Table 1 shows the comparison of 3, 4, and 5g technologies. 5G, among its diverse services, plays a pivotal role in advancing various newer technologies such as Internet of Things (IoT), Artificial Intelligence (AI), Cloud Computing, Smart Grids, Industry Automation, Machine Communication, and Natural Language Processing (NLP) [3,4]. Aimed at achieving speeds 1,000 times faster than 4G, 5G accomplishes this feat through massive Massive multiple input multiple output (MIMO), Scalable modulation, and advanced channel coding [5]. Operating commercially at significantly higher frequencies ranging from 24 to 53 GHz, 5G benefits from ample free spectrum, enabling end-to-end connections for users [6]. Implementing the Transmission Control Protocol (TCP) Internet Protocol, 5G facilitates congestion-free networks, allowing Protocol Data Units (PDUs) to traverse seamlessly, ultimately boosting the overall channel bandwidth of 5G [7–9]. TCP, a widely used transport-layer protocol across all IP-based networks, plays an important role in optimizing end-to-end data delivery in 5G environments by reducing congestion, improving throughput, and ensuring reliable transmission, although it is not exclusive to 5G systems. However, Bangladesh's national frequency allocation plan currently spans from 9 to 275 GHz [10], necessitating the swift adoption of this frequency range for widespread consumer use of 5G. Looking ahead, 5G is envisioned to reach its limits by 2030, paving the way for the arrival of 6G globally. Despite Bangladesh's recent launch of 5G in the capital, there remains insufficient coverage for 3G and 4G networks, with only 52% coverage using 4G by the top four network operators and 28.2% internet penetration among the population [11]. The introduction of 5G marks a technological shift with its cutting-edge architecture and the potential for integrating value-added services into service companies [12,13]. However, implementing 5G poses challenges due to the integration of mm-wave technology, which operates at frequencies between 24 and 53 GHz. These high-frequency signals, despite offering high bandwidth, are susceptible to attenuation and exhibit limitations such as non-line-of-sight propagation, blockage by obstacles like pedestrians and vehicles, and orientation challenges with user equipment. To expedite 5G deployment, the Non-Standalone (NSA) Deployment model integrates 5G core network equipment with existing 4G LTE infrastructure. This approach, utilized by carriers for their initial commercial 5G deployment, aims to reduce time to market and seamlessly transition from legacy cellular infrastructure [14,15]. Considering the challenges posed by mm-wave technology and the current telecommunications landscape, this paper will delve into the present scenario, major impacts, and future prospects of 5G across various sectors.

The primary objectives of this paper are as follows:

- To comprehend the factors associated with 5G that influence various sectors in Bangladesh.
- To explore the prospective impacts of 5G on different sectors within Bangladesh in the future.
- To present models pertinent to these sectors in relation to 5G technology.

**Table 1.** Comparison of 3G, 4G, and 5G technologies.

| Parameter | 3G | 4G | 5G |
|---|---|---|---|
| Core standard | WCDMA/CDMA2000 | LTE/LTE-Advanced | 5G NR (NSA & SA) |
| Typical data rate | 384 kbps–2 Mbps | 20–200 Mbps (peak up to 1 Gbps) | 1–10 Gbps (expected) |
| Latency | 100–500 ms | 30–50 ms | <1–10 ms |
| Operating frequency | <2.1 GHz | 1–6 GHz | Sub-6 GHz & mmWave (24–53 GHz) |
| Bandwidth | 5–20 MHz | 20–100 MHz | Up to 1 GHz (mmWave) |
| Multiplexing technique | CDMA | OFDMA | OFDMA + mMIMO + NOMA |
| Network architecture | Circuit-switched + Packet | All-IP Packet Switched | Cloud-native, SDN, NFV |
| Device density support | ~100 K devices/km² | ~400 K devices/km² | 1 million devices/km² (IoT-optimized) |
| Use-case focus | Mobile internet & voice | Broadband multimedia | Massive IoT, URLLC, smart cities, automation |
| Peak throughput efficiency | Low | Moderate | Very High |
| Mobility support | Up to 120 km/h | Up to 350 km/h | Up to 500 km/h |

- To offer recommendations aimed at optimizing the utilization of 5G technology by proposing strategies for effective adaptation to the current state.

The paper is structured into four distinct sections. Section II provides an in-depth literature review encompassing the existing knowledge and research concerning 5G and its implications. Section III details the methodology employed in this study, outlining the approaches and strategies utilized to investigate the impact of 5G on various sectors in Bangladesh. Section IV presents the findings derived from the research and provides an evaluation of the results obtained. Section V constitutes the conclusion, summarizing the key insights gathered from the study and highlighting potential future directions in harnessing the potential of 5G technology in Bangladesh.

### *Literature review*

Figure 1 illustrates the systematic literature review of this research work.

Halder et al. [1] emphasized the transformative impact of 5G technology in enhancing connectivity to address increasing demands for seamless internet experiences. By integrating IoT, NLP, and AI into network infrastructure, 5G delivers reduced latency and enhanced scalability, facilitating the widespread adoption of connected devices and innovative services. Despite these advancements, implementation challenges such as distance, orientation, and protocol utilization remain. Leveraging datasets and machine learning techniques, their research aims to address these challenges, particularly in densely populated regions of developing countries. However, the paper lacks emphasis on how various sectors can benefit from the performance enhancements offered by 5G. The first commercial use of 5G was tested by Arvind Narayanan and colleagues. They carried out their trials throughout several US states. In their experiment, four carriers were used (Verizon, AT&T, T-Mobile, and Sprint). In their studies, three carriers employed mm-wave 5G, and one used mid-band 5G. Their whole experiment focused on their mm-wave 5G experiences. They found several significant problems. Finally, they have shown how crucial NSA 5G for implementation is first step.

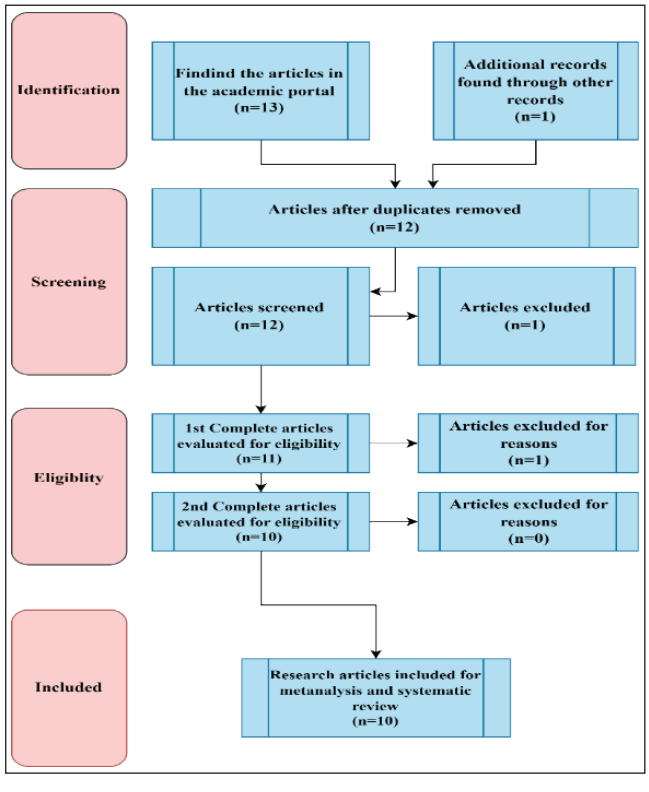



**Figure 1.** PLASMA analysis.

**Table 2.** List of abbreviations used in this study.

| Abbreviation | Full form |
|---|---|
| 1G | First generation mobile network |
| 2G | Second generation mobile network |
| 3G | Third generation mobile network |
| 4G | Fourth generation mobile network |
| 5G | Fifth generation mobile network |
| AI | Artificial intelligence |
| AR | Augmented reality |
| BTRC | Bangladesh Telecommunication Regulatory Commission |
| CDN | Content delivery network |
| COVID-19 | Coronavirus disease 2019 |
| FDM | Frequency-division multiplexing |
| GDP | Gross domestic product |
| GSM | Global system for mobile communications |
| HTTP | Hypertext transfer protocol |
| HTTPS | Hypertext transfer protocol secure |
| ICT | Information and Communication Technology |
| IoT | Internet of Things |
| ISP | Internet service provider |
| ITU | International Telecommunication Union |
| LTE | Long-term evolution |
| LTE-A | Long-term evolution advanced |
| MEC | Multi-access edge computing |
| MIMO | Multiple-input multiple-output |
| mMIMO | Massive multiple-input multiple-output |
| mmWave | Millimeter wave |
| NFV | Network function virtualization |
| NLOS | Non-line-of-sight |
| NLP | Natural language processing |

| Abbreviation | Full form |
|---|---|
| NSA | Non-standalone architecture |
| OFDMA | Orthogonal frequency-division multiple access |
| PDU | Protocol data unit |
| PSTN | Public Switched Telephone Network |
| QoS | Quality of service |
| SA | Standalone architecture |
| SDN | Software-defined networking |
| SWS | Static web server |
| TCP | Transmission control protocol |
| UE | User equipment |
| URLLC | Ultra-reliable low-latency communications |
| VR | Virtual reality |
| WB | World bank |
| Wi-Fi | Wireless fidelity |
| 3GPP | Third generation partnership project |

Table 2 discussed about the technological abbreviations used in the study. Table 3 described the comprehensive literature review. Swarna et al. [2] have first-hand knowledge of 5G and next-generation wireless networks in Bangladesh. She also discussed about trends, s5G in underdeveloped nations like Bangladesh. Gesneral population utilizes 4G as a 5G testbed. The experimental findings indicate that before 5G architecture is implemented, all parts of Bangladesh must be connected to the current connections (4G & 3G) [3]. The Aspects of Bangladesh's 5G Implementation by Deowan et al. [4] were described in this study. Here, the author provides an extensive analysis of all factors for improved efficiency with 5G technology. Additionally, the extent, security concerns, and difficulties of 5G technology were examined. Islam [5] talked about how 4G would affect business in Bangladesh in the future. The main goal of this research is to investigate the four aspects of 5G technology that have an impact on Bangladesh's business, to present a 4G-related business model, to make suggestions for the best way for an existing business to utilize 4G technology, and to investigate the potential future impact of 4G on Bangladesh's business. For 5G SLAM, Yu Ge et al. [7] explain how to employ clustering, assignment, and diffuse multipath. By breaking an issue down into simpler components, its complexity can be decreased. The end-to-end processing chain results in several operational drawbacks. By using the results of simulations, the effectiveness of the suggested technique is shown [6]. A study by Reza et al., [11] examined difficulties with TCP implementation over 5G networks. This study examines the robustness of end-to-end communications in 5G networks, focusing specifically on the implications of TCP in 5G mm-wave networks. The article addresses current challenges, proposes solutions, and offers recommendations for enhancing the reliability of 5G networks. Additionally, the researchers conducted a feasibility study on leveraging machine learning approaches to improve the dependability of end-to-end communication in these networks [7]. The Sufficient Deployment of TCP in 5G mm-Wave Networks across Urban Deployments was also proven by Reza et al. TCP was discovered to gain from these benefits as a result of the smaller control loop on edge servers and the increased maximum segment size. Furthermore, different TCP variations handle different RLC buffer widths in different ways. However, larger buffers are frequently linked to decreased latency, improving throughput [8]. Real-time mobile bandwidth and handoff forecasts for 4G and 5G networks were created by Meia et al. [10] They routinely outperform both univariate and multivariate bandwidth prediction algorithms. They suggest a novel handoff prediction challenge for 4G & 5G coexisting networks for low-latency 5G applications like self-driving. Based on classification and regression algorithms, a recent 5G dataset demonstrated more than 80% accuracy in predicting 4G and 5G handoffs [9]. Reza et al. spoke in her another study about FB-TCP, a 5G mm-Wave TCP protocol that is suitable for metropolitan areas. The protocol regulates the transmission rate following the current network circumstances to obtain the greatest performance. To accomplish this, it also makes an effort to reduce latency and average transmission rate to prevent buffer depletion. Based on comprehensive simulations, the new protocol outperformed BBR, High-speed, Cubic, and New Reno in the urban environment in terms of throughput, RTT, and sending rate adjustment [10].

This study examines the effects and potential difficulties of adopting 5G in Bangladesh after taking into account all of the available research. This study investigates 5G and its effects on four distinct industries, especially focusing on Bangladesh's development.

Summary of previous research on 5G by year, technique, advantages, and disadvantages.

## Materials and Methods

The research has been conducted using an exploratory research design. The research's goals are to understand and investigate the 5G-related aspects

**Table 3.** Summary of previous research on 5G by year, technique, advantages, and disadvantages.

| Year | Authors | Techniques | Key contributions | Disadvantages |
|---|---|---|---|---|
| 2023 | Halder et al. [1] | Dataset-driven analysis integrating IoT, NLP, and AI for 5G performance | Identifies major factors affecting mmWave performance (distance, orientation, protocols); shows potential for developing countries | Lacks analysis of sector-wise impacts (education, business, healthcare) |
| 2020 | Narayanan et al. [2] | First commercial 5G performance trials across US carriers using mmWave & mid-band | Provides first real-world evaluation of mmWave 5G; highlights NSA as practical initial deployment | Findings limited to U.S. test environments; not generalizable to Bangladesh |
| 2022 | Swarna et al. [3] | Country-level assessment of 5G readiness in Bangladesh | Highlights trends, opportunities, and challenges in Bangladesh; emphasizes coverage gaps in 3G/4G | No empirical dataset; analysis remains descriptive |
| 2022 | Deowan et al. [4] | Analysis of key factors for 5G deployment including security, spectrum, coverage | Provides holistic overview of implementation challenges; identifies regulatory needs | Does not include technical throughput evaluation or mmWave performance data |
| 2019 | Islam [5] | Evaluation of 4G business impacts in Bangladesh | Identifies how improved mobile broadband influences business sector growth | Focus limited to 4G; does not address features of 5G |
| 2020 | Ge et al. [7] | 5G SLAM using clustering, assignment, diffuse multipath modeling | Reduces complexity of SLAM; validated through simulation results | Operational drawbacks due to end-to-end processing chain complexity |
| 2020 | Poorzare and Augé [8] | Evaluation of TCP behavior in 5G mmWave networks | Provides insights on TCP robustness over 5G; identifies key bottlenecks | Shows TCP instability under high signal variability; recommends further optimization |
| 2021 | Poorzare and Augé [9] | Performance of TCP variants across 5G urban deployments | Demonstrates performance differences under various RLC buffer sizes; identifies buffer impacts | Highlights risk of latency increases with larger buffers; limited to synthetic simulations |
| 2022 | Mei et al. [10] | Real-time bandwidth and handoff prediction using ML (4G/5G networks) | Achieves >80% accuracy in predicting handoff and bandwidth; improves reliability | Limited by dataset scope; only addresses mobility, not other 5G features |
| 2021 | Reza et al. | Development of FB-TCP for 5G mmWave (urban) | Outperforms BBR, Cubic, High-speed TCP in throughput and latency; adaptive rate control | Protocol still tested in simulation; lacks deployment validation |

that would affect Bangladesh's highlighted sectors in the future. The numerous aspects of 5G technology that affect development have been identified using secondary data and expert debate. The majority of the national and international research on the effects of 5G technology, particularly on Bangladesh's various industries, was also evaluated in this study. Figure 2 shows the work flow of this research.

The author of this research gathered the data. The dataset is made available through the websites of the BTRC [5], World Bank [16], and the University of Minnesota - Twin Cities [1]. To determine the future impact of 5G, the correlation (Table 5) and visualization of the features are shown.

### Dataset

This Research used a dataset of three organizations. Firstly, to evaluate the features of 5G the dataset that is used was collected by a research group from Minneapolis, Chicago, and Atlanta of the University of Minnesota - Twin Cities [2]. Secondly, to know the situation of internet users in Bangladesh a dataset from the BTRC is used [5]. Finally, to show the change in the economy in Bangladesh, the dataset of the WB is used [16].

### Code implementation

IBM SPSS Statistics 25 is used to analyze the data, and Python 3.6.9 is utilized to build the visualizations that are based on the correlation.

## Algorithm

### Correlation

A technique of analysis is a correlation. It describes how solid the connections are. It examines quantitative information gained via research techniques. For identifying trends in the datasets, correlation analyses are used. A rise in both variables is indicated by a positive correlation. As other variables rise, the one that is negative falls [17]. The bivariate correlation, sometimes referred to as Pearson's r or Pearson's correlation is a coefficient that assesses

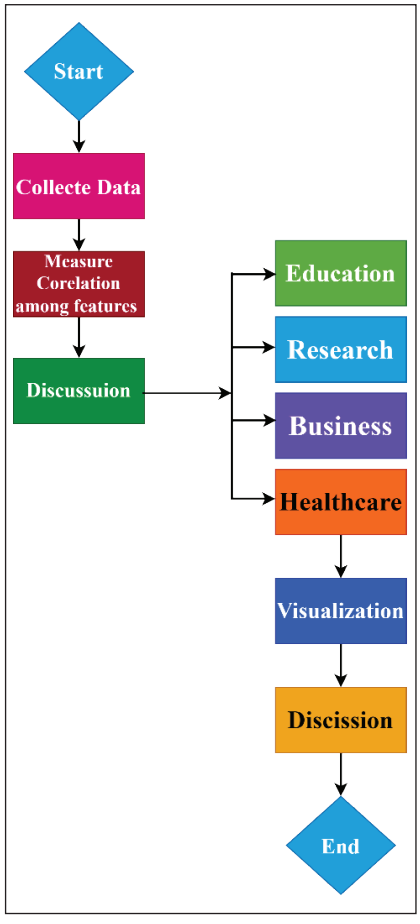



**Figure 2.** Flow chart of the research work.

the linear connection between two sets of variables in a dataset. So that the outcome will range from -1 to 1. The outcomes are positive (outcome 1) and negative (outcome -1) [18].

$$\rho\, X, Y = \frac{E[XY] - E[X]E[Y]}{\sqrt{E[X^2] - (E[X])^2}\sqrt{E[Y^2] - (E(Y)^2)}} \quad \text{(i)}$$

Kendall's *T* Coefficient, often known as the Kendal rank correlation, is a statistical indicator of the ordinal relationship between two items. A non-parametric statistics test for statistical dependency based on T coefficients is known as a *T*-test [7,15,19].

$$T = \frac{(\text{number of concordant pairs}) - (\text{numbers of discirdant pairs})}{(n\ 2)} \quad \text{(ii)}$$

where $(n\ 2) = \frac{n(n+1)}{2}$ is the binomial coefficient for the number of ways to choose two items to form *n* items [7,15].

## Results

This section thoroughly explains the 5G features and their potential future effects. Smartphones will consume data on a 5G cellular network in Bangladesh. The term "5G" refers to a next-generation cell system that, in theory, may provide lightning-fast data rates of around a gigabit per second [17,20]. Millimetre wave radio waves are a type of technology that can help make those high speeds a reality [2,7,21]. It has millimetre-scale wavelengths and extremely high frequencies of at least 30 gigahertz. Compared to the transmissions used by most cell phones today, such frequencies are far quicker. Naturally, cell towers will be necessary for users to receive these waves in the first place, but even then, a mobile phone will not be able to use them unless it has the appropriate antennas [12,21].

In Tables 4 and 5, the increase of mobile phone internet users and ISP Users are increasing day by day. Especially after the spread of COVID-19, where remote management is necessary [3,16]. In the case of 4G, there will be congestion as it cannot make an end-to-end connection.

4G used OFDMA [22]. Wi-Fi 6 (802.11ax) incorporates orthogonal frequency-division multiple access (OFDMA), allowing access points to serve multiple clients simultaneously. In this method, each client is allocated specific time intervals to transmit data, ensuring efficient and uninterrupted communication [23,24]. OFDMA improves upon traditional frequency-division multiplexing (FDM) by dividing data packets into separate frequency bands, each carried by distinct subcarriers. This approach optimizes data transmission by using carrier signal waves for efficient transport of small information bits, akin to advancements seen in 4G and 5G LTE mobile networks and Wi-Fi 6 technology [25]. The growth of Internet subscribers in Bangladesh is seen in Table 5. The number of mobile internet users is shown in Figure 3a, and the increase in ISP and PSTN internet subscribers is shown in Figure 3b. The overall increase is seen in Figure 3c when both mobile internet users and ISP and PSTN internet users are taken into account [26].

The increase in mobile subscriber growth for the top four mobile operators in Bangladesh is seen in Table 4. As the number of mobile internet users rises, consumers purchase subscriber identification module (SIM) cards from various operators to join the growing number of mobile internet users. From the discussion above and the data in Table 4, it is clear that the usage of the internet is significantly rising, which were 28.2% the year before. The 4G network's channel bandwidth cannot sustain the growing number of customers as internet subscriptions increase [26]. As a consequence, Bangladesh's government implemented 5G to serve the country's expanding Internet subscriber base.

**Table 4.** Increasing internet subscriber in Bangladesh.

| Month | Mobile internet user (In million) | ISP & PSTN internet user (IN million) | Total |
|---|---|---|---|
| June 2022 | 115.07 | 11.14 | 126.21 |
| May 2022 | 114.53 | 10.99 | 125.52 |
| April 2022 | 113.21 | 10.99 | 124.20 |
| March 2022 | 113.90 | 10.99 | 124.89 |
| February 2022 | 112.69 | 10.10 | 122.79 |
| January 2022 | 111.77 | 10.10 | 121.87 |
| December 2021 | 113.73 | 10.09 | 123.82 |
| November 2021 | 116.53 | 10.07 | 126.60 |
| October 2021 | 119.11 | 10.07 | 129.18 |
| September 2021 | 118.71 | 10.07 | 128.78 |
| August 2021 | 115.41 | 10.05 | 125.46 |

***mm-wave***

mmWave technology enables multi-gigabit transmission using extremely high frequencies between 24 and 53 GHz. Its short wavelengths support dense small-cell deployments and high data capacity, making it suitable for 5G. However, mmWave signals are highly sensitive to distance, blockage, and non-line-of-sight conditions, requiring precise network planning and robust channel estimation to maintain stable connections. Despite these challenges, mmWave remains a key enabler of high-speed 5G services [2,26,27].

**(a) Beamforming:** Beamforming is a signal-processing technique that directs radio waves toward a specific user, strengthening the connection and reducing interference. By focusing energy in a targeted direction, beamforming improves link reliability, supports mobility, and enhances spectral efficiency—critical requirements for 5G mmWave systems [28].

**(b) Data Centric Architecture**: Data-centric architecture separates data storage from applications, enabling flexible access, efficient processing, and smoother system upgrades. In the context of 5G, this approach supports large-scale data movement and low-latency processing at the network edge. Vector Label Switching (VLS) complements this by improving routing efficiency in dense networks, reducing forwarding delays, and supporting faster packet delivery [14,29].

**(c) Massive multiple input multiple output (mMIMO)-** (mMIMO) increases network capacity by using large antenna arrays to transmit and receive multiple data streams simultaneously. For 5G, mMIMO improves spectral efficiency, enhances coverage in dense environments, and enables more users to connect with high throughput [28,29].

**(d) Ultra Reliable Low Latency Communication (URLLC)**- URLLC is designed for mission-critical applications requiring near-instantaneous response and extremely high reliability. By minimizing transmission delays and optimizing uplink and downlink coordination, URLLC supports industrial automation, remote healthcare, smart grids, and other time-sensitive systems [29].

**(e) Scalability-** Scalability of a network refers to its ability to efficiently and sustainably handle increasing workloads by enhancing bandwidth capacity and extending its physical reach into new development areas [1,14,28,29]. Low latency and fast data rates are made possible by all of the qualities. As was already noted, depending on several factors, the short wave length of mm-wave hinders the high data rate. The author of this research extract key characteristics from the data set that are extremely important for the deployment of 5G [30].

Seven features from the data collection are taken as mentioned in Table 5. There are radio types, distances, and orientations, NLOSs with and without Multipath, servers, and web protocols in this list. Here, “radio type” refers to 4G and 5G. (5G was denoted to 2 and 4G to 1) [1,29]. The distance covered in mm-waves is measured in meters. Orientation is the angle formed between the UE and

**Table 5.** Important Features to discuss the impact of 5G.

| Features | Measurements |
|---|---|
| Radio type(4G/5G) | Radio Type |
| | Throughput |
| Distance | Distance |
| | Throughput |
| Orientation | Orientation |
| | Throughput |
| NLOS (With multipath) | Obstruction |
| | Throughput |
| NLOS (Without Multipath) | Obstruction |
| | Throughput |
| Server (CDN/SWS) | Server |
| | Throughput |
| Web protocol (HTTP/HTTPS) | Web protocol |
| | Download time (Seconds) |

**Table 6.** Correlation of features compared with throughput.

| Features | Pearson correlation | Kendall's correlation |
|---|---|---|
| Radio type | 0.669 | 0.492 |
| Distance | −0.85 | −0.116 |
| Orientation | −0.782 | −0.562 |
| NLOS (With multi path) | −0.533 | −0.444 |
| NLOS (Without multipath) | −0.678 | −0.507 |
| Server | −0.787 | −0.708 |
| Web protocol | 0.758 | 0.653 |

the base station. Degrees are used to represent orientation values. There is a way for the mm-wave to go even when the UE and base station are obstructed in multipath. Without multipath, the mm-wave cannot travel between the UE and the base station. Content Delivery Network (CDN) and Static Web Server (SWS) are two functionalities of servers. Last but not least, two aspects of the Web protocol are Hypertext Transfer Protocol (HTTP) and HTTP Secure (HTTPS). Throughput is compared to all the parameters in this research. Everyone is aware that increasing bandwidth is 5G's primary objective [1,7,30]. The analysis took into account every factor that affects 5G's high-speed gaining.

The connection between two features of a dataset is explained by correlations. The connection between throughput and each of the seven features is depicted in Table 6. Depending on how the dataset responds, the author of this study has found two correlation coefficients, Kendall and Pearson. According to Table 6, there is a strong association between throughput and Radio type [0.669 (Pearson's) and 0.492 (Kendall's)]. Therefore, 5G has a better throughput than 4G. Throughput and orientation are related, although the relationship is unfavorably skewed. This implies that the throughput drops as the orientation (0°–90°) increases. Throughput and distance have a strong, but adverse, relationship. This implies that the throughput drops as the direction (0–160 m) increases [1,31]. Throughput and NLOS (non-line of sight) have a large but adversely skewed connection. The throughput reduces when there is a blockage in the way that mm-waves move, while another path is still open. The reduction, though, is less than the NLOS (With Multipath) condition. The server (CDN, SWS) and throughput have a considerable but inverse relationship. The bandwidth expands when a CDN is employed. The throughput is decreased when SWS is utilized. The TCP protocol can considerably boost throughput with web protocols [32].

Figure 3 displays the box plot of throughput with six different features. Figure 3a displays the throughput for 4G and 5G radio, denoted by 1 and 2, respectively. The use of mm-wave allows 5G to have a better throughput than 4G [1,9]. 5G uses the TCP protocol to ensure an end-to-end connection with faster throughput [1,7,8,10,33].

As shown in Figure 3b throughput decreases as distance increases because mm wave cannot travel over great distances due to its tiny web length [1,6,14,34].

Figure 3c shows when the device and base station connect end-to-end, the orientation is 0°. When the orientation is increasing bandwidth of the channel is decreasing. It needs to design an architecture that allows for a 0° orientation between the base station and UEs.

Figure 3d illustrates how throughput in a multipath scenario varies depending on blockage. The author refers to numbers 2 and 3 as a human body blockage and a human hand, respectively. The author can see that the speed of the mm-wave decreases when it reaches an obstruction. But when it comes to thickness, the throughput varies. The extended box suggests there is no obstacle and can fully utilize 5G. Because of this, deploying 5G in an urban environment is more difficult [35].

But Figure 3e shows how throughput changes when a barrier is present along a single channel. In contrast to the multipath system, where a single individual may travel along multiple pathways regardless of whether there is a mechanical or

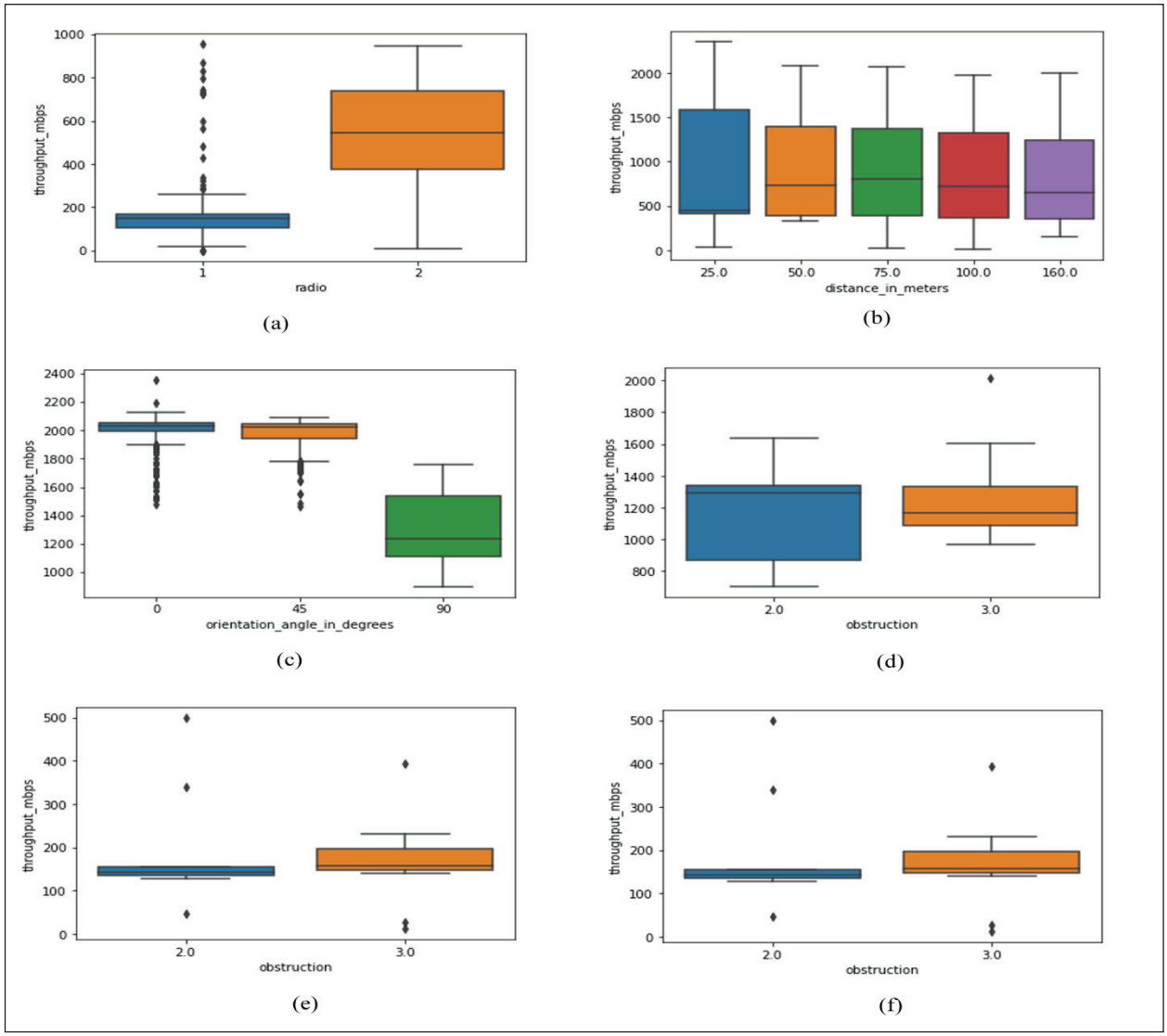



**Figure 3.** (a) Radio type versus throughput (box plot), (b) distance versus throughput, (c) orientation versus throughput, (d) NLOS (with multipath) versus throughput, (e) NLOS (without multipath) versus throughput, and (f) server versus throughput.

human obstruction, in this situation throughout is noticeably higher [36].

In Figure 3, the CDN server is represented by the number 1, while the SWS server is represented by the number 2. Figure 6(f) graph clearly shows the wide variation in throughput for the CDN server, with a maximum value of around 1000 Mbps and a minimum value of almost 0 Mbps. CDN can make an end-to-end connection, but in the case of SWS, it used PDU's header information for traveling towards the destination. In the case of SWS, the speed is quite low. To gain speed CDN server needs to be implemented with 5G.

The author briefly describes why consumers need 5G and the problem of 5G implementation. In the part above, where the author examines the difficulties with 5G millimeter wave. In the next section, the author will discuss the prospective impacts of 5G in Bangladesh across a variety of areas.

The results derived from the feature analysis, correlation study, and dataset interpretation highlight several technical and infrastructural constraints that directly influence the prospects of 5G deployment in Bangladesh. A central finding is that throughput performance in 5G is highly dependent on distance, orientation, server configuration, and line-of-sight factors, with mmWave signals demonstrating significant attenuation under non-ideal conditions. Additionally, the strong positive correlation between radio type and throughput confirms that 5G provides substantial performance improvements over 4G, although this advantage deteriorates rapidly under blockage or increased distance. These outcomes underscore an important

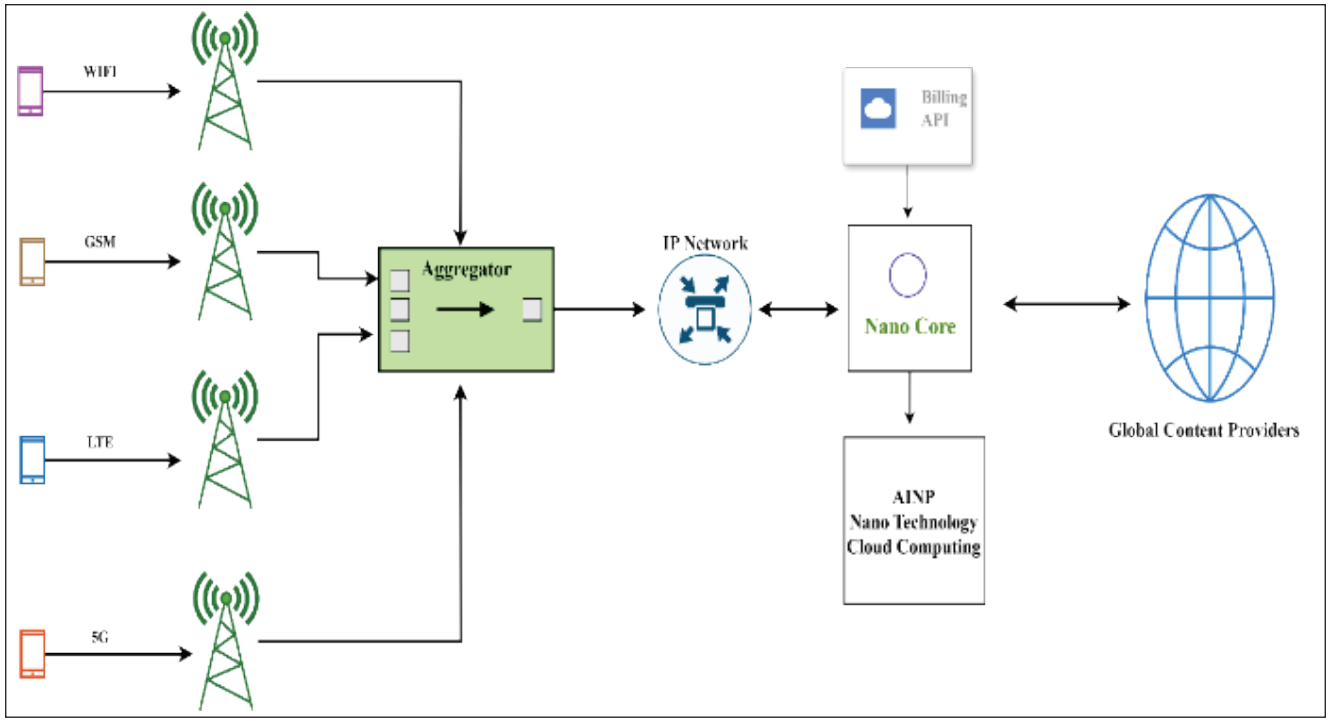



**Figure 4.** Network structure of 5G in Bangladesh.

national context: 5G is not yet available nationwide in Bangladesh. At present, 5G services are limited to small, operator-selected pilot zones, primarily within Dhaka, and remain unavailable across most urban and rural regions. This restricted deployment means that the immediate benefits of 5G cannot yet be realized on a national scale. As such, any projection of sectoral impacts must consider that the current nationwide digital infrastructure is still dominated by 4G, with significant service gaps in several districts.

Considering these realities, the discussion on future impacts is organized into four major sectors—education, research, business, and healthcare—as illustrated. The technical constraints identified in the dataset directly shape how each sector can realistically adopt 5G. For example, the sensitivity of throughput to obstruction has major implications for dense educational campuses; distance-based degradation affects real-time research applications; server-dependent variations influence business-level content delivery; and reliability requirements are critical for healthcare. To address these sectoral needs under existing constraints, this study proposes adopting the NSA 5G architecture as an intermediate solution, as shown in Figure 4. NSA allows 5G radios to operate on top of the existing 4G LTE core, enabling faster rollout, lower infrastructure cost, and backward compatibility for regions not yet supported by fiber backhaul. Given that a substantial portion of Bangladesh still operates on basic 4G coverage, NSA deployment is a more feasible transitional model compared to an immediate migration to Standalone (SA) 5G.

Overall, the observations confirm that while 5G introduces transformative capabilities—high bandwidth, low latency, massive device connectivity, and enhanced reliability—its full potential in Bangladesh will only be realized once infrastructure limitations, coverage gaps, and mmWave propagation constraints are adequately addressed. The following subsections, therefore, explore the future prospects and sector-specific implications of 5G based on both technical insights and the current deployment landscape.

### *Prospects of 5G in education*

The rapid digitalization of education, especially after COVID-19, has highlighted both the benefits and challenges of virtual learning. While many classes now depend on video conferencing and online tools, technological barriers—especially in less connected regions—have widened the digital divide. The introduction of 5G networks offers a promising solution by providing faster, more reliable connectivity, enabling immersive learning experiences like virtual reality (VR), and improving access to quality education. In Bangladesh, 5G can

play a transformative role in bridging gaps, enhancing teaching methods, and strengthening the overall education system, which is vital for national development. The key features of 5G technology—such as high data rates, low latency, mMIMO, enhanced scalability, Voice over Internet Protocol (VoIP) services, neural network integration, and reliable connectivity—hold significant potential to transform the education sector High data rates ensure rapid content delivery, enhancing user experience by minimizing wait times and increasing overall throughput and channel capacity [37]. Scalability supports a larger number of devices without latency, enabling seamless access for all users. VoIP plays a vital role in real-time communication; however, its efficiency depends on sufficient bandwidth, which is effectively managed by 5G networks. mMIMO technology increases bandwidth and supports the robust infrastructure required for 5G deployment. Additionally, the integration of neural networks enhances network security, while TCP ensures end-to-end reliability in data transmission. In the context of Bangladesh, these features can be effectively utilized to provide secure, uninterrupted, and inclusive learning experiences for students across the country.

The integration of 5G technology into education presents transformative benefits that can significantly enhance teaching and learning experiences. First, **5G enables improved collaboration and interaction** between educators and students by providing stable, high-quality video conferencing with minimal lag, especially in remote regions, thereby fostering more effective communication and engagement [38]. Second, **immersive learning experiences** such as augmented reality (AR) and VR become more feasible with 5G's high bandwidth and low latency, supporting interactive, tactile learning environments and enhancing the understanding of complex concepts [17]. Third, **personalized education** is facilitated through intelligent systems that adapt content to individual learning needs, enabling customized course delivery and virtual teaching assistants, particularly beneficial in technical and vocational education [17]. Fourth, **mobile learning** is greatly improved, offering seamless access to educational content across various devices, which supports flexible learning for students and professionals alike. Finally, **5G promotes educational equity** by expanding access to high-quality digital resources in underserved regions, helping bridge the digital divide and create more inclusive learning environments [39]. These advancements collectively position 5G as a key enabler in the evolution of future-ready education systems.

### *Prospects of 5G in research*

The expansion of 5G networks offers capabilities that extend far beyond enhanced mobile experiences, presenting significant opportunities for scientific research and innovation. With superior bandwidth, ultra-low latency, and high device density, 5G enables real-time data transmission and supports up to 100 times more devices within a given area compared to 4G networks [1,3,40]. These attributes are particularly beneficial for researchers operating in data-intensive fields or remote and harsh environments, where reliable wireless connectivity is critical. Recognizing this potential, the U.S. Department of Energy's Office of Science launched the 5G Initiative in 2021, allocating $6 million to projects aimed at leveraging 5G for fundamental scientific research, following recommendations from the "5G-Enabled Energy Innovation" workshop in 2020 [41]. A key feature of 5G is **network slicing**, which allows the creation of customized virtual networks tailored to specific device requirements—such as low latency for experiment control or high bandwidth for data transmission—while also reducing energy consumption by disabling unnecessary services [18,42]. These advancements position 5G as a critical enabler for cutting-edge applications in artificial intelligence, robotics, quantum information science, and real-time edge computing.

5G technology is expected to consume up to 90% less energy than previous generations, enabling long-term, remote scientific research with minimal maintenance. This is particularly beneficial for studies involving sensors and devices deployed in inaccessible environments, such as arctic regions or dense forests, where extended operation without battery replacement enhances both efficiency and safety [1,43]. The transformative impact of 5G derives from its ultra-high data transmission rates and low latency. With providers like Verizon achieving speeds up to 1 Gbps, 5G surpasses traditional fiber-optic and cellular connections, unlocking innovations across various sectors [44].

In e-health, 5G minimizes latency in telemedicine, enabling seamless communication between healthcare providers and patients, thereby enhancing the quality of virtual consultations. The increased mobility and faster cloud access allow healthcare professionals to operate across regions and respond rapidly, especially vital in pandemic

contexts [2,45]. In the energy sector, 5G supports the development of smart power grids that integrate renewable energy sources and optimize electricity distribution and storage, improving efficiency and sustainability [1,46]. In agriculture, the high-speed data transmission facilitated by 5G accelerates the application of artificial intelligence in both urban and rural settings, enabling real-time data analysis and smarter farming practices [1,2,47]. These advancements underscore 5G's potential as a foundational technology driving progress in scientific research and essential industries.

### *Prospects of 5G in business*

The introduction of 5G technology is expected to have a profound impact on Bangladesh's ICT sector. With potential data transmission rates reaching up to 10 Gbps, 5G can significantly enhance digital connectivity and service delivery across the country [1,48]. According to a Qualcomm study, 5G-enabled products and services are projected to generate approximately USD 13.2 trillion in global economic output and create 22.3 million new jobs by 2035. As of 2020, over 500 million 5G devices had been shipped globally, with projections indicating 750 million 5G smartphones deployed by 2022 and 2.8 billion 5G connections by 2025 [49].

In the context of Bangladesh, mobile internet plays a critical role, with 105.62 million of the country's 115.43 million internet users accessing services via mobile devices as of April 2021. Despite the launch of 4G services in February 2018, coverage remains inconsistent, and many regions still lack reliable 4G connectivity or experience substandard speeds. To address these challenges and align with global technological advancements, the adoption of 5G is essential. It offers the potential to overcome existing infrastructure limitations, enhance internet accessibility, and support the country's digital transformation goals [50].

The aim for mobile phone manufacturers is shown in Table 7 for 2022. As the majority of older citizens are unaware of technology, 2G smartphone production is on the rise in this country. Other manufacturers of 3G, 4G, and 5G smartphones are developing products to meet consumer demand.

Figure 5 visualizes the growth of producing smartphones.

The demand for feature phones and smartphones is rising, as seen in. It discusses the impact of 5G in Bangladesh. Consumers want to interact with technology. Thus, they also desire the 5G smartphones shown in [51]. But because 5G is not yet fully implemented, 4G manufacturing is not any less. Still, 52% of Bangladesh is covered with 4G internet. All of these factors contribute to the business sector's growth.

Figure shows some recent condition of mobile sim subscribers in Bangladesh. As shown, it is increasing day by day. Consumers want to be a part of upgrading technology. But the govt. operator Teletalk has less consumers than others as shown in Figure 6. But after their implementation of 5G their consumer also increased. If all of the operator can implement 5G their business can also flourish.

The deployment of 5G technology is anticipated to significantly enhance business performance and economic output, as depicted in Figure 6. Key features such as high-speed connectivity, ultra-low latency, increased device capacity, and network slicing offer substantial advantages across sectors. First, faster data transmission—up to 10 Gbps—will reduce processing times for large files and improve the efficiency of data-intensive industries, including media and IoT-based enterprises [18,20,52]. Second, lower latency, potentially under one millisecond, will minimize delays, enhance responsiveness, and support real-time decision-making in business operations [19,53]. Third, greater network capacity will enable seamless communication among a large number of devices, improving remote collaboration and customer interaction [20,54]. Lastly, network slicing will allow businesses to create tailored virtual networks, optimizing resource allocation and

**Table 7.** Bangladesh phone manufacturing target.

| Month | 2G | 3G | 4G | 5G | Total | Feature phone | Smart phone |
|---|---|---|---|---|---|---|---|
| **June 2022** | 20.15 | 0 | 8.48 | 0.32 | 28.95 | 69.60% | 30.40% |
| **May 2022** | 16.70 | 0.04 | 6.15 | 0.45 | 23.34 | 71.53% | 28.47% |
| **April 2022** | 22.66 | 0 | 12.63 | 0.52 | 33.81 | 61.10% | 38.90% |
| **March 2022** | 18.34 | 0 | 12.03 | 0.32 | 30.69 | 59.76% | 40.24% |
| **February 2022** | 16.60 | 0 | 10.68 | 0.14 | 27.42 | 60.55% | 39.45% |
| **January 2022** | 27.54 | 0 | 13.68 | 0.23 | 41.45 | 66.45% | 33.55% |

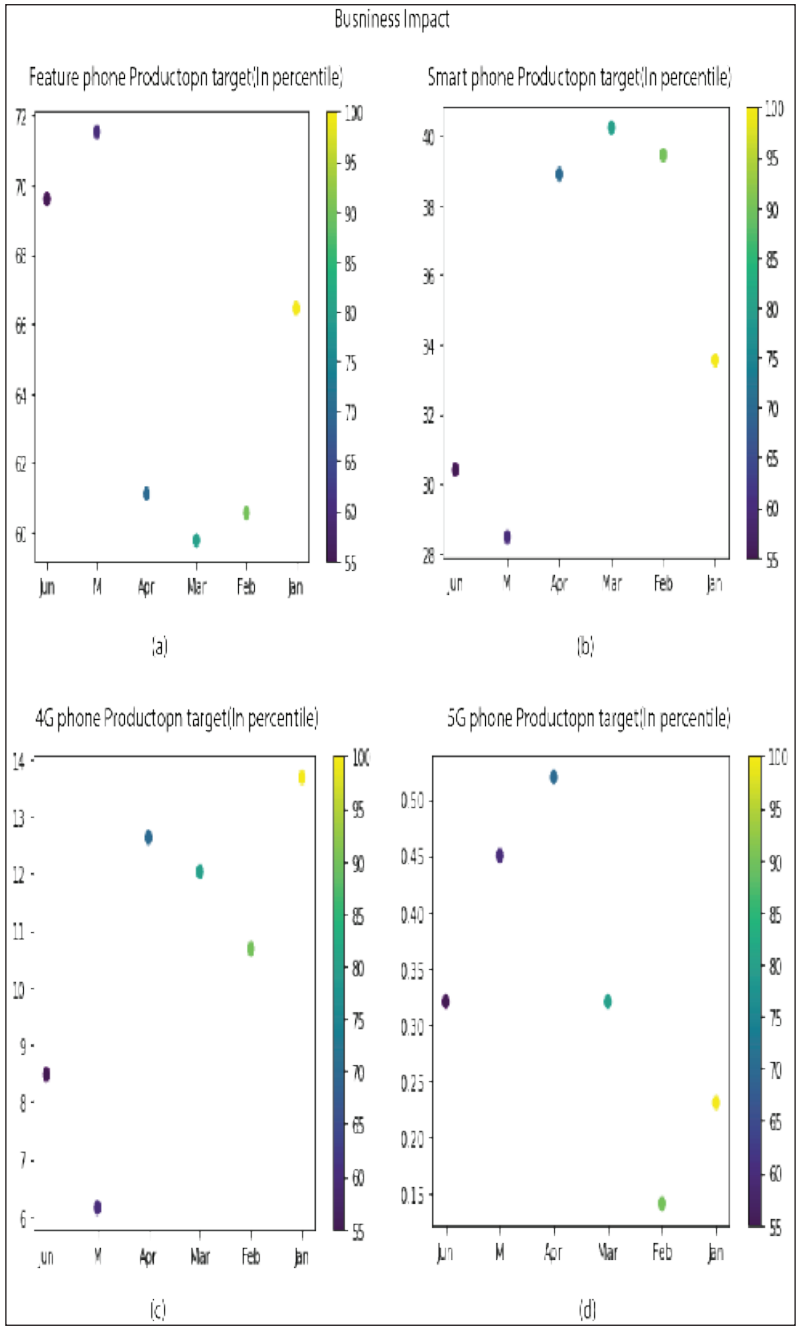



**Figure 5.** Bangladesh phone manufacturing target.

operational efficiency across diverse applications [17,20,55]. Collectively, these capabilities position 5G as a catalyst for accelerating business processes and contributing to sustained economic growth.

### *Prospects of 5G in healthcare*

At the height of the COVID-19 pandemic in Wuhan, China, the city that served as the focal point for the worldwide epidemic, 12 robots slid across the floor of a medical ward. Their main responsibilities include checking patient temperatures, bringing meals, and cleaning the facilities. These robots were not only a step forward in automation; they were also saving lives. Patients got much-needed care, and healthcare staff had access to a safer ward and distance from the outbreak. The telecommunications innovation that enabled this mind-blowing, one-of-a-kind healthcare automation feasible [8,16] specifically, a 5G network, the newest generation of wireless communication technology—is easily overlooked in the intricacies of the tale. The enormous improvements in 5G's speed, dependability, and quality make managing a fleet of robots impossible [5,7,56].5G technology marks a substantial

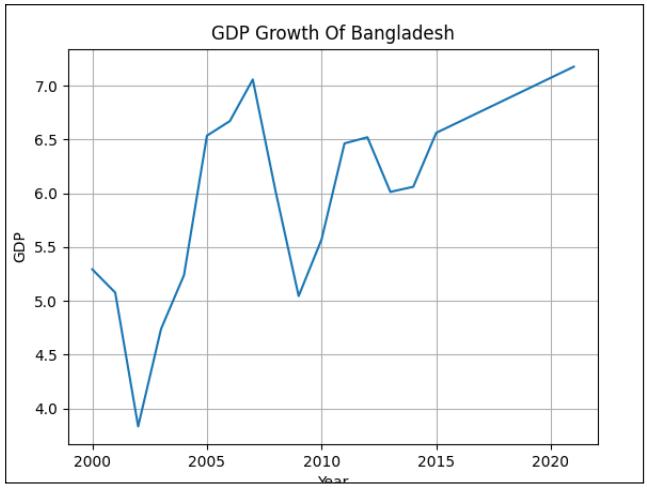



**Figure 6.** GDP growth of Bangladesh (2000–2021).

advancement over 4G, offering speeds up to 100 times faster, ultra-low latency, and the capacity to support massive device connectivity. While full-scale adoption, particularly in healthcare, is projected around 2025 in developed countries [1,21,57], several challenges remain, including concerns over data privacy and security in public network environments [58]. Despite these limitations, 5G holds considerable promise for transforming the delivery of healthcare.

The technology enables real-time data access, which can streamline clinical trials, reduce administrative costs, and accelerate drug development by allowing faster decision-making and early trial adjustments [59]. Continuous monitoring through 5G networks enhances patient care by enabling early detection of health issues based on real-time vital signs and behavioral data [60]. Moreover, applications such as geolocation tracking and diagnostic profiling, as demonstrated during the COVID-19 response in South Korea, underscore the role of 5 G in effective public health interventions [61].

Additionally, 5G supports personalized healthcare, enabling remote examinations and continuous patient engagement through wearable devices and the tactile Internet. This shift empowers individuals to manage their health proactively, potentially improving outcomes and reducing healthcare expenditures [22,38,62].

### *5G adoption barriers in Bangladesh*

The nationwide adoption of 5G in Bangladesh faces several significant challenges stemming from infrastructural, economic, and human-resource limitations. Despite recent progress, the current telecommunications infrastructure remains inadequate for large-scale 5G deployment, as mmWave technology requires dense small-cell networks, extensive fiber backhaul, and stable power systems, whereas much of the country still experiences incomplete 4G coverage and limited fiber availability. These infrastructural gaps constrain the feasibility of both non-SA and future SA 5G architectures. In addition to technical constraints, the high cost of deployment and operation poses substantial barriers; operators must invest heavily in spectrum licensing, equipment acquisition, and network upgrades, while consumers face the burden of purchasing relatively expensive 5G-enabled devices. Furthermore, the broader population exhibits varying levels of digital literacy, and the national workforce lacks sufficient expertise in advanced areas such as network virtualization, cybersecurity, and cloud-native 5G operations. This shortage of digital skills affects not only network deployment but also the ability of industries, educational institutions, and public services to integrate 5G-based solutions effectively. Together, these constraints underscore the need for strategic infrastructure investment, affordable device policies, and comprehensive digital-skill development to ensure equitable and sustainable 5G adoption across Bangladesh.

## Discussion

The results derived from the feature analysis, correlation study, and dataset interpretation highlight several technical and infrastructural constraints that directly influence the prospects of 5G deployment in Bangladesh. A central finding is that throughput performance in 5G is highly dependent on distance, orientation, server configuration, and line-of-sight factors, with mmWave signals demonstrating significant attenuation under non-ideal conditions. Additionally, the strong positive correlation between radio type and throughput confirms that 5G provides substantial performance improvements over 4G, although this advantage deteriorates rapidly under blockage or increased distance.

These outcomes underscore an important national context: 5G is not yet available nationwide in Bangladesh. At present, 5G services are limited to small, operator-selected pilot zones, primarily within Dhaka, and remain unavailable across most urban and rural regions. This restricted deployment means that the immediate benefits of 5G cannot yet be realized on a national scale. As such, any projection of sectoral impacts must consider that the current nationwide digital infrastructure is still dominated by 4G, with significant service gaps in several districts.

Considering these realities, the discussion on future impacts is organized into four major sectors—education, research, business, and healthcare. The technical constraints identified in the dataset directly shape how each sector can realistically adopt 5G. For example, the sensitivity of throughput to obstruction has major implications for dense educational campuses; distance-based degradation affects real-time research applications; server-dependent variations influence business-level content delivery; and reliability requirements are critical for healthcare.

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Overall, the observations confirm that while 5G introduces transformative capabilities—high bandwidth, low latency, massive device connectivity, and enhanced reliability—its full potential in Bangladesh will only be realized once infrastructure limitations, coverage gaps, and mmWave propagation constraints are adequately addressed. The following subsections, therefore, explore the future prospects and sector-specific implications of 5G based on both technical insights and the current deployment landscape.

## Conclusion

This paper reviews the scope, challenges, architecture, and protocols for implementing 5G in developing Bangladesh. With spectrum ranging from 600 to 100 GHz, 5G promises higher data rates and improved scalability through mm-wave technology and URLLCs for IoT. However, mm-wave integration poses significant challenges. The government plans nationwide 5G rollout by 2021–2023. Key challenges include signal issues, cost-effective rural deployment, security, and privacy. Future research should focus on optimizing mm-wave use, dynamic spectrum allocation, environmental and economic impacts, and enhancing URLLC for IoT. Collaboration among academia, industry, and government is essential to ensure equitable 5G access across Bangladesh.

### Conflicts of interest

The author declares no Conflicts of Interest.

### Funding

Not Applicable.

### Declarations

The author declares that this manuscript has not been submitted to other journals for consideration.

### Availability of data and materials

Not applicable.

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