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Review Article

Comparative Analysis of 5G Technology in the Agriculture Sector of Bangladesh (Challenges and Potential Impact)

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Abstract

This study provides a thorough examination of the introduction of 5G technology in Bangladesh's agriculture sector, providing insights into the problems and potential implications related to its adoption. Focusing on the contextual landscape of Bangladesh, the study evaluates the effectiveness, efficiency, scalability, and ease of implementation of 5G technology concerning key challenges faced by the agricultural sector. Drawing comparisons with global perspectives, including countries such as China, Taiwan, Colombia, Netherlands, and India, the analysis provides a nuanced understanding of the diverse technological landscapes. The examination encompasses the evolution from 4G to 5G, emphasizing the commitment of major telecommunications providers in Bangladesh to advance technological capabilities. The challenges in rural adoption, limited technology literacy among farmers, and high smartphone costs are discussed, highlighting potential barriers to seamless integration. To address the creation of a more comprehensive technological infrastructure, the study also explores the efforts and regulatory support provided by the government and the Bangladesh Telecommunication Regulatory Commission (BTRC). Furthermore, the comparative analysis sheds light on the unique characteristics and advancements in other countries, contributing to a holistic understanding of 5G's role in transforming global agricultural practices. By exploring the anticipated socio-economic factors influencing the pace and success of 5G adoption in the agricultural sector, this paper emphasizes the need for collaborative efforts, infrastructure development, and addressing accessibility challenges to achieve widespread agricultural technology integration.

Keywords: 5g; 5g technology; 5g technology bangladesh; bangladesh agriculture

1. Introduction

Bangladesh is an agricultural country with a population of over 160 million people, and agriculture is the backbone of the country's economy. The sector contributes to 14.2% of the country's GDP and employs around 47% of the labor force (Discovery Bangladesh, n.d.). The importance of technology in agriculture cannot be overstated, as it can help increase productivity, reduce costs, and improve the quality of crops. The introduction of 5G technology in agriculture has the potential to revolutionize the sector by enabling faster and more efficient communication, data transfer, and automation of processes.

The purpose of this paper is to provide a comparative analysis of 5G technology in the agriculture sector of Bangladesh. The paper will review existing literature on the adoption of 5G technology in agriculture globally and, if available, specifically in Bangladesh. It will also detail the current state of 5G technology adoption in the agricultural sector of Bangladesh, compare different 5G technologies or implementations in the context of the agricultural sector in Bangladesh, identify and discuss challenges associated with the adoption of 5G technology in the agricultural sector of Bangladesh, and assess the potential impact of 5G technology on the agriculture sector in Bangladesh.

Background of 5G

5G, or the fifth generation of mobile networks, is the latest standard for cellular communication technology. It succeeds the fourth generation (4G) and brings improvements in terms of speed, latency, capacity, and connectivity to a wide range of devices, including smartphones, IoT devices, and other connected technologies. Some key features and aspects of 5G include higher data rates, lower latency, increased capacity, enhanced connectivity, network slicing, millimetre wave spectrum, etc.

5G implementation in Bangladesh began in 2018, with Robi Axiata Limited as the first telecom company to conduct a 5G trial in the country in 2018. Subsequently, Grameenphone (GP) conducted its trial run for 5G in 2022 with some use cases in Dhaka and Chattogram. Since then, the four major telecommunication giants (i.e., Grameenphone (GP), Banglalink, Robi and Teletalk) have been slowly rolling out 5G in all the major divisions of Bangladesh with state-owned telecom operator Teletalk planning to introduce 5G network services in Dhaka's key residential areas and government offices in 2024.

Implementation of Existing Technology in Bangladesh & Beyond

In this section, we will discuss how 5G technology is being used in the agriculture sector around the world including Bangladesh. First, we will review existing literature on how 5G technology is being used in the agricultural sector around the world, and then we will explore how 5G is currently being implemented or will be implemented in the future in Bangladesh, given that the technology has recently been launched in this nation.

How 5G Technology Is Being Used around the World in the Agricultural Sector?

The global narrative surrounding 5G in agriculture paints a vibrant picture of transformative potential. Numerous pilot projects and initiatives demonstrate its impact across diverse contexts, focusing on precision farming, livestock monitoring, irrigation automation, and remote agricultural management. For instance, the paper written by Hilten & Wolfert (2022) discusses a 5G-powered robot for autonomous weeding and harvesting, highlighting increased efficiency and labor reduction.

Tang et al. (2021) explore the intersection of 5G networks and agriculture, delineating the potential transformative impact on smart farming practices in China. The discussion encompasses various applications facilitated by 5G, including precision farming, livestock monitoring, smart irrigation, drone-based agriculture, and agricultural e-commerce. In addressing the challenges and opportunities associated with implementing 5G in agriculture, the paper highlights critical considerations such as spectrum allocation, network architecture, security, privacy, energy efficiency, and cost-effectiveness. Furthermore, including case studies underscores the practical implications of 5G network applications in agriculture, featuring examples like smart greenhouses, dairy farms, tea plantations, and rice fields. The paper not only elucidates current applications but also suggests future research directions for the synergy between 5G networks and agriculture, emphasizing the potential of edge computing, blockchain, artificial intelligence, and the Internet of Things to further revolutionize and enhance agricultural practices. This comprehensive review positions the paper as a valuable resource for understanding and advancing the integration of 5G technology in the agricultural domain.

The paper written by Hoyos et al. (2022) delves into the transformative potential of 5G technology in the agricultural sector of Colombia, providing a comprehensive overview and proposing innovative applications. It categorizes crops based on factors like budget availability, population density, and regional development plans, offering a valuable resource for designing strategic 5G implementation plans tailored to the Colombian agricultural landscape.

The document also meticulously details the challenges and strategic approaches related to the radio spectrum, 5G pilots, business model development, digital security, and regulatory barriers to infrastructure deployment. It also provides a snapshot of Colombia's current radio spectrum frequency bands, including frequency bands, uplink and downlink information, usage status, availability, and operators with granted spectrum permits. Proposing future applications, the paper envisions 5G/IoT implementations in smart agriculture, such as monitoring, irrigation control, and smart farming systems. It emphasizes how deploying 5G/IoT in smart farms can enhance efficiency, productivity, and sustainability while addressing environmental impact and bridging the digital divide in rural areas. Technical considerations, including channel coding, power consumption, and waveform design, are also discussed, contributing to the broader discourse on the efficient deployment of 5G/IoT technologies in the agricultural domain.

Focused on China, the paper written by Li & Li (2020) delves into the specifics of 5G technology's impact on agricultural efficiency, quality, and sustainability, offering insights into the challenges and opportunities in China's rural development and providing valuable recommendations for policymakers and practitioners.

This paper explores the potential applications of 5G technology in agriculture, emphasizing its advantages such as high speed, low latency, reliability, and massive connectivity. With characteristics conducive to smart farming, precision agriculture, agricultural IoT, big data, and cloud computing, 5G is positioned to enhance agricultural production's efficiency, quality, and sustainability, contributing to the modernization and digitalization of rural areas. However, despite its promise, challenges persist, including insufficient signal coverage in rural areas, high device costs and power consumption, security vulnerabilities, and incomplete standardization and regulation. The paper underscores the need for comprehensive research on the integration and optimization of 5G technology in agricultural systems, emphasizing the evaluation of economic, social, and environmental impacts. To address challenges and capitalize on opportunities, future directions, and recommendations include enhancing 5G network infrastructure in rural areas, reducing device costs and energy consumption, improving data security and privacy, and establishing standards and regulations. Additionally, the paper advocates for interdisciplinary research on 5G-based agricultural applications and systems, exploring both benefits and risks.

The paper written by Tomaszewski & Kołakowski (2023) does not focus on a specific country, but rather on the challenges and opportunities for 5G and 6G mobile networks in the sectors of smart agriculture, forestry, biodiversity monitoring, and water management.

According to the paper, the integration of 5G technology holds immense potential for revolutionizing Smart Agriculture and Forestry, Biodiversity Monitoring, and Water Management. It is envisioned to enhance precise position sensing through Geographic Information Systems, aiding applications such as agricultural treatment planning, soil property mapping, and tracking spatial migrations of flora and fauna. Moreover, 5G's capabilities include supporting high-speed data transmission for field mapping and remote assessment of plants and crop properties, utilizing sensors, cameras, and drones. This technology ensures low latency and reliable communication for real-time analysis and feedback. Automation and teleoperation of various tasks, including harvesting, weed elimination, pest control, disease management, fire monitoring, and water quality assessment, are made possible through 5G's Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (URLLC), and massive Machine-Type Communication (mMTC) service slices. Notably, 5G addresses challenges in spatially conditioned sectors by guaranteeing the required Quality of Service (QoS) in expansive areas beyond urban and built-up land, leveraging integrated terrestrial/non-terrestrial networks, edge computing, and network slicing. This holistic integration of 5G technology is poised to significantly advance efficiency and innovation in agriculture and environmental monitoring.

Valecce et al. (2019) explore the transformative potential of 5G technology in advancing machine-to-machine (M2M) services for agricultural applications, particularly focusing on cellular- connected drones and robots. These technologies play a pivotal role in monitoring and managing various facets of agricultural production, including soil quality, water usage, pest control, and animal health. Notably, the paper introduces groundbreaking concepts, elucidating how 5G enhances the accuracy and efficiency of remote sensing. By providing higher data capacity, lower latency, greater device density, and improved reliability, 5G elevates the capabilities of remote sensing, enabling the integration of diverse data types such as optical, thermal, radar, and hyperspectral. Additionally, the paper highlights the facilitation of artificial intelligence (AI) and machine learning (ML) adoption in agriculture through 5G. By offering the necessary bandwidth and speed for data transmission and processing, 5G supports AI and ML applications. The integration of edge computing further reduces latency and enhances performance, as demonstrated in examples ranging from crop yield prediction and autonomous vehicles to weather forecasting and animal tracking.

5G technology is making significant strides in the agricultural sector, exemplified by Jio, an Indian telecommunications company, launching a program focused on Variable Rate Technologies (VRTs) (Jio, 2022). This initiative harnesses the power of 5G-powered sensors to measure crop and soil characteristics in real-time, facilitating optimal usage of fertilizers, pesticides, and water across diverse soil types. The integration of 5G-enabled solutions empowers farmers with real-time insights, enabling them to make predictive and proactive decisions in their farming practices. Such technologies not only contribute to increased agricultural efficiency but also align with sustainable practices, allowing farmers to produce more food with fewer resources. The utilization of smart farming technologies, including artificial intelligence, machine learning, robotics, drones, and 5G, underscores the sector's commitment to achieving cleaner and more efficient agricultural practices, which is crucial for meeting the demands of a growing global population. This innovative intersection of telecommunications and agriculture exemplifies the transformative impact of 5G technology in enhancing productivity and sustainability in farming operations.

The paper by Waaji et al. (2021) highlights the groundbreaking potential of fifth-generation (5G) technology in revolutionizing precision agriculture, particularly within the Netherlands, a global leader in agricultural innovation. With the world's population steadily increasing, the paper underscores the critical role of technology in meeting rising food demands and positions 5G as the next frontier. The Netherlands' high 4G coverage, expected to extend to 5G, serves as an optimal environment for testing and implementing innovative applications. The paper introduces transformative use cases, such as remote support tools, smart fencing, cow monitoring with GPS collars, crop inspection drones, and weeding robots, all leveraging 5G's high bandwidth, low latency, and mobile edge computing capabilities. However, the paper identifies a potential deadlock between the telecom and agriculture sectors due to global rural connectivity challenges. This presents a dilemma for global agricultural manufacturers, impeding 5G-enabled development. To address this, the paper proposes multifaceted solutions, including cooperative models, as-a-service business approaches, and learning from inclusive innovation perspectives in developing regions. The call to action encourages collaborative efforts and suggests a roundtable discussion to navigate this deadlock, stressing the need for cooperation to unlock the full potential of 5G in agriculture.

Hsu et al. (2019) introduced a pioneering application of fifth-generation (5G) technology in the agricultural sector through the implementation of an innovative Image Electronic Fence (IEF) system for smart farms in Taiwan. Leveraging the capabilities of 5G, this system enables real-time monitoring and control of livestock and crops, incorporating a network of cameras, a cloud server, and a mobile application. Demonstrating the distinct advantages of 5G, including high data rates, low latency, reliability, and extensive coverage, the paper highlights the superior performance of the IEF system compared to 4G and Wi-Fi technologies. The findings underscore that 5G significantly enhances the accuracy and efficiency of the IEF system, positioning it as a practical solution for smart farming. By addressing challenges and outlining future directions for utilizing 5G in smart farms, the paper makes a noteworthy contribution to the field of 5G technology in agriculture. Beyond its technological contributions, the paper imparts valuable insights and lessons learned from the design and implementation of the IEF system, serving as a source of inspiration and guidance for researchers and practitioners interested in the transformative applications of 5G technology in agriculture.

In their seminal work titled "AgriEdge: Edge Intelligent 5G Narrow Band Internet of Drone Things for Agriculture 4.0," Bhattacharya & De (2021) delve into the transformative potential of 5G technology in agriculture. The paper introduces the AgriEdge framework, a groundbreaking amalgamation of edge intelligence, 5G narrow-band IoT, and drone technology, designed to revolutionize precision farming and smart agriculture in real-time. The authors contend that this innovative framework has the potential to enhance efficiency, productivity, and sustainability in agriculture while concurrently reducing environmental impact and operational costs. Offering a comprehensive exploration of challenges and opportunities in applying 5G to agriculture, especially within the context of Industry 4.0 and Agriculture 4.0, the paper provides a thorough overview of the AgriEdge concept. The framework leverages edge computing, 5G communication, and drone technology to facilitate real-time data collection, analysis, and decision-making. Notably, the paper delves into the design, implementation aspects, and potential benefits of AgriEdge, offering valuable insights for the integration of 5G technology into the agricultural domain. Through simulations and experiments, Bhattacharya and De substantiate the feasibility and effectiveness of AgriEdge, underscoring its potential as a ubiquitous computing environment for agriculture, poised to usher in a new era of data-driven precision farming and smart agriculture.

Local Lens: 5G Tech Implementation in Bangladesh's Agricultural Sector

Despite being in its infancy, 5G adoption in Bangladesh showcases promising initiatives and pilot projects that harness the technology's potential for improved agricultural practices.

The paper by Haque et al. (2021a) reveals that the evolution of telecommunications technology in Bangladesh, with the introduction of 4G networks by major providers in 2018 was a pivotal step towards realizing the government's vision of a "Digital Bangladesh." The country's four major telecommunications service providers—Grameen Phone (GP), Banglalink, Robi, and Teletalk—have collectively facilitated a robust mobile network infrastructure, catering to a total of 158.438 million mobile subscribers, with 86.268 million engaging in mobile internet services. The ambition to launch 5G networks and services by 2021 reflects a commitment to advancing technological capabilities.

A survey conducted by Jannat (2019) in Bangladesh revealed that 83.2% of users have access to 4G networks, while 16.8% utilize 3G networks. Impressively, more than 80% of respondents reported enhanced internet speed compared to the previous 3G technology. Despite these advancements, challenges persist in remote villages where cellular networks may not support AI and IoT-based farming. In such scenarios, low-power wide area networks (LPWAN), notably the LoRaWAN standard developed by the LoRa Alliance, emerge as cost-effective alternatives, gaining popularity in Bangladesh for their long-range communication, low energy consumption, and support for smart technologies.

For 5G to work in the agricultural sector successfully, Haque et al. (2021b) suggest that responsible leadership is needed to implement smart farming in Bangladesh and to achieve sustainable agriculture goals. It argues that responsible leaders can manage the relationships among different stakeholders, such as farmers, policymakers, input suppliers, market linkages, and technology providers, ethically and inclusively.

The paper also highlights the potential benefits of smart farming for Bangladesh, such as increased crop yield and quality, reduced production cost and environmental impact, improved access to finance and market intelligence, and enhanced resilience to climate change and natural disasters.

In 2020, the Bangladesh Telecommunication Regulatory Commission (BTRC) allocated a frequency band for 5G technology, which will enable the introduction of 5G technology in various sectors, including agriculture (Report, 2019). The government of Bangladesh has also launched several initiatives to promote the use of technology in agriculture, such as the "Krishi Call Center" and the "Krishi Gobeshona Foundation" (AIS, n.d.; Uddin, n.d.).

Some specific technologies or implementations being used in Bangladesh agriculture include the use of mobile phones by farmers to access market information and the use of drones to monitor crop health and detect diseases. Lastly, there is the potential for increased use of 5G technology due to the popularity of agri-fintech businesses like iFarmar or WeGro.

The use of mobile phones by farmers in Bangladesh has increased significantly in recent years and has helped improve communication between farmers and buyers. According to a study conducted in Mymensingh District in Bangladesh, the majority of the farmers had low cell phone contact while a good number of farmers had no cell phone contact, 1.82% had medium contact and no farmers had high cell phone contact with agricultural extension agents (Rahman et al., 2018). Another study revealed that most farmers used their mobile phones to obtain and secure various crop farming information, weather forecasts, access to agricultural inputs, pest and disease control, access to market information, consulting with extension workers, and financial transactions (Gopela, 2020).

Drones are being increasingly used in agriculture to monitor crop health and detect diseases. They can provide farmers with a bird's eye view of their crops, which can help them identify problems early on and take corrective measures. According to a recent article in the journal Agronomy, multispectral and thermal cameras aboard drones can detect diseases in the fields, monitor crop vigor, estimate biomass and yield, and detect symptoms of both abiotic and biotic stresses (Abbas et al., 2023).

In Bangladesh, the use of drones in agriculture is still in its early stages. However, there are some initiatives underway to promote the use of drones in agriculture. For example, the Bangladesh Agricultural Research Institute (BARI) has been conducting research on the use of drones for crop monitoring and management (Sarkar et al., 2023). Drones can be used to automatically obtain growth status, canopy height, crop health, disease level, nutrients, and water stress level, and predict the final yield. This technology can help increase crop production and monitor crop growth, providing real-time information on the farm that can be used at different stages throughout the cropping cycle.

The potential for increased use of 5G technology in Bangladesh is significant, particularly in the context of the rising popularity of agri-fintech businesses such as iFarmer and WeGro. These startups play a pivotal role in intertwining finance and agriculture, offering innovative digital platforms that connect individual sponsors or investors with farmers. iFarmer, for instance, enables individuals to sponsor farms, invest digitally, and engage with farmers. Notably, iFarmer provides the flexibility of Sharia-based financing in addition to conventional interest-based financing (iFarmar Asia, n.d.). Similarly, WeGro, another prominent agri-fintech startup in Bangladesh, focuses on leveraging technology to connect farmers with investors, markets, and essential data, thereby enhancing the efficiency and productivity of the agricultural supply chain (WeGro, 2023). As these agri-fintech platforms gain popularity and reshape the landscape of agricultural financing and management, the adoption of 5G technology becomes crucial for ensuring seamless connectivity, real-time data exchange, and efficient operations across the agricultural sector in Bangladesh. The potential synergy between 5G and agri-fintech holds promise for advancing digital agriculture, promoting financial inclusion, and contributing to the overall sustainability of the agricultural industry in the country.

The paper by Ashraf (2023) mentioned that Grameenphone, Robi, Airtel, and Banglalink are the four telecom operators that have launched 4G services in Bangladesh since February 2018. The paper also stated that Grameenphone is the best 4G sim in Bangladesh, according to 61.3% of the respondents, followed by Robi with 19.4% and Airtel with 9.7%. The paper also claimed that Grameenphone is the fastest sim in Bangladesh, with 50% of the respondents agreeing, and that Grameenphone has the best mobile internet, with 53.1% of the respondents choosing it.

As of December 2021, Teletalk Bangladesh Limited has launched the first commercial 5G network in Bangladesh with technical support from Huawei. The initial 5G network is available in 6 locations around the Bangladesh Secretariat, the National Parliament area, the Prime Minister's Office, the Bangabandhu Memorial Museum, the National Monument in Savar, and the mausoleum of the Father of the Nation in Tungipara, Gopalganj. Coverage will gradually expand to more regions of the country (Huawei, 2021).

In March 2022, GrameenPhone, Robi, and BanglaLink acquired 5G spectrum, and the Bangladesh Telecommunication Regulatory Commission (BTRC) instructed the providers to start test runs within six months (Freedom House, n.d.).

Bangladesh, while making strides in technological advancement, faces significant challenges in adopting and integrating 5G technology, especially in rural agricultural areas. Despite the recent launch of 5G networks in urban centers, the diffusion of this technology to remote villages, where the majority of agricultural activities occur, poses a considerable hurdle. Limited infrastructure, connectivity issues, and the need for extensive network expansion make the widespread implementation of 5G in rural areas a time-consuming process. The agricultural sector, integral to Bangladesh's economy, may experience delays in harnessing the full potential of 5G due to the lag in technology diffusion from urban to rural settings.

Another obstacle to the seamless integration of 5G technology in the agricultural sector lies in the low literacy rate among farmers and their limited smartphone usage. The disparity in technology literacy hampers the adoption of smartphones, which are essential for leveraging 5G capabilities. Many farmers may not possess the necessary digital skills to fully exploit the benefits of 5G technology, hindering its widespread application in precision farming, data-driven decision-making, and smart agriculture practices. Moreover, the high cost of smartphones, a prerequisite for 5G compatibility, serves as an additional barrier, worsening the digital divide among farmers and impeding the equitable adoption of advanced technologies.

The smooth and efficient nationwide rollout of 5G technology in Bangladesh faces challenges related to infrastructure development, regulatory processes, and financial considerations. While major telecom operators have acquired 5G spectrum and initiated test runs, achieving comprehensive coverage across the country demands substantial investments and strategic planning. The efficiency of the rollout will hinge on overcoming logistical hurdles, ensuring affordability, and addressing the technological literacy gap. The competition among telecom companies, including GrameenPhone, Robi, and BanglaLink, will play a crucial role in determining the pace of 5G adoption. The eventual success and speed of 5G technology integration into the agricultural sector depend on comprehensive planning, collaborative efforts, and addressing the socioeconomic factors influencing technology access and adoption. The timeline for farmers to benefit from widespread 5G adoption remains contingent on the resolution of these challenges.

2. Comparative Analysis

In this part, we will first compare 5G to existing technologies in Bangladeshi agriculture, followed by another comparison of 5G in Bangladeshi agriculture vs. global implementations. Finally, we will discuss the scope of improvement of 5G technology in the agricultural sector of Bangladesh.

2.1. Comparative Analysis: 5G vs. Existing Technology in Bangladeshi Agriculture

The Bangladeshi agricultural sector stands at a pivotal juncture, poised to leverage technological advancements for enhanced productivity, sustainability, and resilience. While 5G technology emerges as a transformative force, it is crucial to evaluate its efficacy against existing technologies within the context of specific challenges and limitations. This analysis delves into a comparative examination of 5G alongside prominent existing technologies, such as 4G mobile networks, drones, and LoRaWAN, focusing on four key aspects:

• Effectiveness: To what extent does each technology address critical agricultural challenges and contribute to improved outcomes?

• Efficiency: How cost-effective is each technology, considering initial investments, operational costs, and return on investment (ROI)?

• Scalability: Can the technology be readily scaled up and adapted to diverse agricultural contexts and geographies within Bangladesh?

• Ease of Implementation: How complex is the technology to implement, taking into account existing infrastructure limitations in rural areas?

Comparative Analysis Table:

Aspects	5G Technology	4G Mobile Networks	Drones	LoRaWAN
Efectiveness	*High potential for precision agriculture,real-time monitoring, and automation, leading to increased yields and resource efficiency * Can support advanced applications like smart farming and pest control.	* Enables access to market information, weather updates, and extension services, improving decision-making. * Supports basic data collection and communication.	* Provides aerial insights for crop health monitoring, disease detection, and precision spraying. * Effective for targeted interventions and rapid data acquisition.	* Suitable for long-range, low-power monitoring of environmental conditions and remote assets. * Supports basic data transmission for irrigation management and soil analysis.
Efficiency	* High initial infrastructure investment and device costs. * Operational costs may be higher due to increased data usage. * Long-term ROI depends on adoption rate and application development.	* Relatively lower infrastructure and device costs compared to 5G. * Operational costs depend on data usage but are generally lower than 5G. * ROI dependent on specific applications and user base.	* High initial investment for drone purchase and training. * Operational costs vary based on flight time and maintenance. * ROI can be high for targeted interventions and precision spraying.	* Low infrastructure and device costs. * Operational costs are minimal due to low power consumption. * ROI mainly depends on the value of collected data and its economic impact.
Scalability	* Requires extensive network infrastructure rollout, particularly in rural areas. * Initial scalability may be limited due to high costs and the digital literacy gap. * Long-term scalability potential is high due to its versatility and network advancements.	* Relatively good scalability due to existing 4G infrastructure. * Adaptable to diverse contexts but may require network applications.	* Scalability is limited by the operational range and battery life of individual drones. * Requires trained personnel for operation and data analysis.	* Highly scalable due to low-power and long-range communication capabilities. * Suitable for large-scale deployments in remote areas with
Ease of Implementation	* Requires significant infrastructural development and technical expertise. * Integration with existing agriculture practices may require training and adaptation. * Digital literacy among farmers needs to be addressed.	* Relatively easier to implement due to existing infrastructure and user familiarity. * Integration with existing practices may be straightforward. * Requires basic digital literacy for accessing information and services.	* Requires trained personnel for safe and effective operation. * Data analysis and interpretation may require technical expertise. * Integration with existing systems may require additional equipment and software.	* Easier to implement due to minimal infrastructure requirements. * Low power consumption makes it suitable for remote areas with limited power access. * Integration with existing systems may require data conversion and compatibility adjustments.

Each technology offers unique advantages and challenges within the Bangladeshi agricultural context. 5G boasts immense potential for transformative breakthroughs, particularly in precision agriculture and automation. However, its success hinges on overcoming infrastructure limitations, and digital literacy gaps, and ensuring cost-effectiveness. Existing technologies like 4G and LoRaWAN provide readily available and cost-effective solutions for information access, basic monitoring, and resource management. Drones offer targeted interventions and rapid data acquisition but require significant investment and expertise. Ultimately, the optimal technological mix will likely involve a hybrid approach, leveraging the strengths of each technology to address specific needs and contexts within the diverse Bangladeshi agricultural landscape.

2.2. Comparative Analysis: 5G in Bangladeshi Agriculture vs. Global Perspective

5G technology promises a revolution in agriculture across the globe, and Bangladesh is actively exploring its potential. However, understanding how Bangladesh's specific context and challenges influence its 5G implementation compared to other countries is crucial. This analysis delves into a comparative examination of 5G in Bangladeshi agriculture against prominent examples of countries discussed in the literature review above like China, Taiwan, Colombia, Netherlands, and India, focusing on the following key aspects:

• Deployment Stage: At what stage is 5G adoption in agriculture for each country?

• Target Applications: What are the primary areas where 5G is being applied in agriculture for each country?

• Challenges: What are the unique challenges each country faces in implementing 5G for agriculture?

• Scalability & Affordability: Can the current solutions be readily scaled up and how does cost- effectiveness compare across countries?

Comparative Analysis Table:

Country	**Deployment Stage**	**Target Applications**	**Challenges**	**Scalability &Affordability**
Bangladesh	Early Pilot Stage	* Precision agriculture (soil sensors, weather forecasting) * Livestock monitoring (GPS collars, smart fencing) * Drone-based monitoring & spraying	* Limited rural infrastructure & network coverage * Low digital literacy among farmers * High cost of 5G smartphone devices & data plans	Focus on implementing 5G technology around the country and decrease data plan price, partnerships for infrastructure development, government subsidies for devices and training
China	Advanced Pilot & Commercial Rollout	* Smart greenhouses & farms (climate control, automation) * AI-powered disease detection & crop yield prediction * Agricultural e-commerce & market platforms	* Vast rural areas with varying infrastructure gaps * Concerns about data privacy & security * Regulatory complexities	Leveraging existing 4G network for rural reach, government- backed infrastructure projects, data security regulations & farmer training programs
Taiwan	Advanced Pilot Stage	* Image Recognition for livestock & crop monitoring * Smart irrigation systems & remote water management * Autonomous weed removal robots	* Limited agricultural land area * High initial investment for advanced applications * Skilled workforce requirement for technology maintenance	Collaborations with technology companies for pilot projects, focus on cost-effective AI models & open- source platforms, upskilling programs for farmers
Colombia	Early Pilot Stage	* Improved market access & information services for rural farmers * Precision agriculture for coffee & other cash crops * Remote sensing & disease control with drones	* Fragmented land holdings & diverse landscapes * Lack of technical expertise & digital infrastructure * High cost of 5G spectrum & devices	Public-private partnerships for infrastructure development, tailored 5G applications for specific crops & regions, financial incentives for early adopters
Netherlands	Advanced Pilot & Commercial Rollout	* Precision agriculture with robots & automated machinery * Remote cow monitoring with GPS collars & data analysis * Smart fencing & automated pest control systems	* Densely populated & intensively farmed land * Balancing technology adoption with environmental sustainability * Integration with existing advanced agricultural practices	Strong public-private collaboration, focus on knowledge sharing & farmer training, development of interoperable & sustainable technology solutions

India	Early Commercial Rollout	* Variable Rate Technologies (VRT) for fertilizer & water management * Drone-based crop health monitoring & pest control * AI-powered market prediction & advisory services	* Vast agricultural landscap with diverse needs & challenges * Inequality in access to technology & resources * Balancing Privacy Concerns with Data-Driver Agriculture	Government pilot projects & subsidies for VRT adoption, public-private partnerships for rural infrastructure & digital literacy programs, focus on affordable & inclusive technologysolutions

The comparative analysis reveals that while Bangladesh is still in the early stages of 5G adoption for agriculture, several key learnings can be gleaned from other countries. Leveraging partnerships, focusing on cost-effective solutions, prioritizing rural infrastructure development, and addressing digital literacy gaps are crucial for Bangladesh to accelerate its progress. Learning from China's extensive pilot programs, Taiwan's focus on AI and open-source solutions, Colombia's tailored applications for specific crops, and India's emphasis on inclusivity can prove valuable. Ultimately, Bangladesh's path forward lies in tailoring global experiences to its unique context, fostering collaboration, and prioritizing affordability and sustainability to empower its agricultural sector through the transformative potential of 5G technology.

2.3. Scope for Improvement: Unlocking 5G's Potential in Bangladeshi Agriculture

While the prospects of 5G technology revolutionizing Bangladeshi agriculture are undeniable, significant gaps remain between potential and reality. Analyzing the comparative landscapes explored earlier, a clear scope for improvement emerges, paving the way for optimized 5G implementation and maximized impact on the sector.

Bridging the Infrastructure Gap: The primary hurdle preventing widespread 5G adoption in rural Bangladesh is the limited infrastructure in these areas. Unlike denser urban landscapes, rural regions lack the necessary fiber optic networks and cell towers crucial for sustained 5G coverage (Murtuza, 2019). To bridge this gap, partnerships between public and private sectors are essential. Government initiatives targeting infrastructure development in rural areas, coupled with collaborations with telecommunication companies offering incentives for network expansion, can play a pivotal role in bringing 5G closer to the majority of Bangladesh's farmers.

Addressing Affordability and Accessibility: Cost remains a significant barrier for farmers seeking to leverage 5G technology. The initial investment in 5G-enabled devices and data plans can be prohibitive for many, particularly smallholder farmers. Following the example of India's government subsidies for VRT adoption, Bangladesh can explore similar initiatives to make 5G- powered solutions more accessible. Additionally, developing cost-effective and locally adapted technology tailored to the specific needs of Bangladeshi farmers is crucial for ensuring affordability and inclusivity.

Nurturing Digital Literacy and Skills: The success of 5G hinges on the ability of farmers to utilize its capabilities effectively. Bridging the digital literacy gap among the agricultural workforce is critical. Government programs providing basic digital literacy training and awareness campaigns tailored to rural communities can empower farmers to embrace technology and unlock its benefits. Furthermore, collaborating with universities and research institutions to develop targeted training programs in 5G-related applications like precision agriculture and data analysis can equip farmers with the necessary skills to actively participate in this digital transformation.

Prioritizing Scalability and Sustainability: While initial pilot projects focusing on specific applications are valuable, ensuring scalability is crucial for maximizing 5G's impact. By learning from countries like Taiwan and the Netherlands, where open-source platforms and collaboration with technology companies drive scaling efforts, Bangladesh can foster similar partnerships to create interoperable and adaptable solutions. Additionally, integrating 5G with existing agricultural practices and infrastructure, as seen in countries like Colombia and India, can ensure smooth integration and avoid redundancy. Ultimately, prioritizing sustainability should be at the forefront of 5G adoption. Balancing technology advancement with environmental concerns, by exploring energy-efficient solutions and promoting responsible data management practices, is crucial for ensuring long-term benefits for both farmers and the environment.

Strengthening the Institutional Framework: A robust institutional framework is necessary to guide and regulate 5G implementation in the agricultural sector. Learning from China's data security regulations and India's focus on privacy concerns, Bangladesh can develop legal frameworks to safeguard farmer data and promote responsible data governance. Additionally, establishing dedicated government agencies or task forces focused on 5G in agriculture can streamline policy formulation, resource allocation, and monitoring of progress.

2.4. Challenges of Implementing 5G Technology in the Agricultural Sector of BD

While 5G technology promises a transformative leap for Bangladesh's agricultural sector, translating aspirations into reality demands a clear understanding of the challenges that lie ahead. By examining the comparative landscapes and scope for improvement outlined earlier, we can identify and dissect the key hurdles that need to be overcome for 5G to unleash its full potential in Bangladeshi agriculture.

The existing network coverage in the country is reported to be suboptimal, with a peak data rate of 7Mbps per device, significantly below the desired 1Gbps. The deployment of 5G is hindered by poor infrastructure and the need for costly new towers. This infrastructure deficit can particularly affect rural areas where agricultural activities are prevalent. Security concerns also pose obstacles to the introduction of advanced network systems. Swarna (2022) emphasizes the need for improved networking infrastructure and suggests that addressing these challenges could unlock significant opportunities, ushering in a new era for Bangladesh. The experimental findings reveal that the mean 4G network coverage of major mobile operators in Bangladesh is only 52%, indicating a need for enhanced connectivity across the country before implementing 5G architecture.

Islam et al. (2023) discussed that adopting 5G introduces security challenges, particularly in Software Defined Networking (SDN), Network Function Virtualization (NFV), and IoT, with potential difficulties for developing countries like Bangladesh. These security challenges of 5G pose obstacles to the introduction of advanced network systems in the agricultural sector. The transformative potential of 5G extends to smart cities and agriculture, offering applications like smart parking, smart farming, trash management, streetlights, and public safety, enhancing urban living. Nonetheless, infrastructure constraints, including tower availability and fiber networks, remain critical for ensuring widespread 5G coverage and capacity, necessitating potential reforms in infrastructure sharing guidelines for seamless access.

Halder et al. (2023) conducted a comparative study of the difficulties and potentials of deploying 5G wireless access in densely populated regions of the sub-continent, such as Bangladesh, based on the limitations observed in US cities. They used correlation and regression analysis to examine the relationships between 5G throughput and various factors, such as distance, orientation, obstruction, server location, and protocol selection. They also employed machine learning algorithms to predict the impact of these factors on 5G performance, using a dataset collected by the University of Minnesota. They found that 5G faces significant challenges regarding range, orientation, and obstruction, especially in urban environments with high population density and limited space. This suggests that predictive analysis is necessary to understand and address challenges in deploying 5G technology in agricultural settings. They also identified the advantages of using CDN servers and HTTPS protocols for improving the 5G user experience. Their study contributes to the discourse on enhancing network infrastructure in the evolving landscape of global connectivity.

Rahman (2020) explored the prospects and challenges of implementing 5G mobile technology in Bangladesh, a densely populated country with a growing digital economy. The paper discussed how 5G could enhance the productivity and connectivity of various sectors, such as agriculture, education, health, e-commerce, and gaming. The paper also examined the health effects of electromagnetic radiation from cell phones and base stations, based on a survey and measurements in Rajshahi district. Although not directly tied to the agricultural sector, health concerns related to radiation may impact the workforce in the agricultural sector if they are exposed to such radiation in rural areas where farming activities take place. The paper found that more than half of the existing 4G base stations emitted radiation above the permissible limits and that most people were unaware of the health risks. This lack of awareness could extend to rural areas, including agricultural communities, where individuals may not be fully informed about the potential health impacts of 5G technology.

The finding that more than half of the existing 4G base stations emitted radiation above permissible limits suggests a regulatory and compliance challenge. This issue may need to be addressed before implementing 5G in the agricultural sector to ensure that radiation levels adhere to safety standards.

Rahman et al. (2021) examine the feasibility and challenges of deploying 5G networks in least- developed countries (LDCs), emphasizing technical and security obstacles. LDCs encounter hurdles in spectrum allocation, high spectrum costs, limited infrastructure development, low network density, and the complexity of dynamic spectrum sharing. Security concerns loom large, as LDCs lack the requisite expertise, resources, and infrastructure to effectively counter various 5G network vulnerabilities, including denial-of-service, man-in-the-middle, spoofing, and data leakage attacks. The applicability of 5G use cases in LDCs is constrained, with most advanced applications such as autonomous vehicles and smart cities being unsuitable for the current context. The paper identifies narrow-band IoT as the sole promising use case, offering support for low-power and low-cost devices across various applications. This could be relevant for the agricultural sector in Bangladesh, indicating that low-power and low-cost devices supporting narrow-band IoT could find applications in agriculture, potentially for monitoring and data collection purposes. However, in implementing this many challenges may occur.

The paper mentions that LDCs face challenges in infrastructure development. In the context of Bangladesh's agricultural sector, this could mean that the existing infrastructure may not be robust enough to support the deployment of 5G technology. Agricultural areas may require significant improvements in terms of network infrastructure to fully benefit from 5G applications. In the paper, LDCs are noted to have low network density. This could translate to challenges in providing widespread and reliable 5G coverage in rural and remote agricultural areas. Farmers and stakeholders in the agricultural sector might face connectivity issues if the network density is insufficient.

The hurdles in spectrum allocation and high spectrum costs highlighted in the paper could impact the availability and affordability of 5G infrastructure. This may be a barrier for the agricultural sector in Bangladesh, especially if the costs associated with acquiring and deploying 5G technology are prohibitive. Security concerns are emphasized in the paper, particularly in the context of LDCs lacking expertise, resources, and infrastructure to counter various 5G network vulnerabilities. In the agricultural sector, where data security is crucial, these concerns could hinder the adoption of 5G technologies unless robust security measures are in place.

The paper also suggests that advanced 5G applications such as autonomous vehicles and smart cities may be unsuitable for the current context of LDCs. In the agricultural sector of Bangladesh, this limitation could mean that certain advanced applications may not be immediately applicable, and the focus might need to be on more basic and practical use cases.

Other challenges in implementing 5G technology in the Agri tech sector in Bangladesh are Affordability and Accessibility for farmers, Digital Literacy and Skill Gap, Scalability and Integration concerns, Sustainability and Environmental considerations, and lastly, Institutional framework and Regulatory landscape.

The initial investment in 5G-enabled devices and data plans can be prohibitive for many farmers, particularly smallholders who constitute a significant portion of the agricultural workforce. This creates a digital divide, excluding those who could benefit most from the technology's precision agriculture capabilities and real-time information access. Bridging this affordability gap requires a multi-pronged approach. Government subsidies for 5G-powered solutions, as seen in India's VRT adoption program, can offer immediate relief. Additionally, developing cost-effective, locally adapted technologies specifically tailored to the needs of smallholder farmers is crucial for ensuring inclusivity and maximizing impact.

The success of 5G hinges on the ability of farmers to leverage its capabilities effectively. Unfortunately, a significant digital literacy gap exists among the agricultural workforce in Bangladesh. Many farmers lack the basic skills required to operate 5G-enabled devices or utilize the data generated by these technologies. To address this, comprehensive digital literacy training programs must be implemented, targeting rural communities and tailored to their specific needs. Collaborating with educational institutions and research bodies can contribute to developing targeted training modules in 5G applications like precision agriculture and data analysis, equipping farmers with the necessary skills to actively participate in this technological transformation.

While initial pilot projects exploring specific 5G applications are valuable, ensuring scalability is critical for maximizing impact across the wider agricultural landscape. Scaling up solutions often requires significant investments and robust institutional frameworks. Bangladesh can learn from the approaches of countries like Taiwan, where open-source platforms and partnerships with technology companies drive scaling efforts, and the Netherlands, where integration with existing agricultural practices ensures smooth adoption. Addressing issues of interoperability and adaptability throughout the scaling process is key to avoid creating technology silos and maximizing resource utilization.

While 5G technology can improve resource efficiency and reduce waste, responsible implementation is crucial to ensure long-term environmental sustainability. Prioritizing energy- efficient solutions and promoting responsible data management practices are essential. Learning from the Netherlands' focus on integrating technology with environmental sustainability can provide valuable insights. Additionally, establishing clear regulations and best practices for data security and privacy, as seen in China's approach, can build trust and encourage wider adoption among farmers. Implementing 5G successfully requires a robust institutional framework that can guide, regulate, and monitor its application in the agricultural sector. Establishing dedicated government agencies or task forces focused on 5G in agriculture can streamline policy formulation, resource allocation, and progress monitoring. Furthermore, learning from India's efforts to address privacy concerns and China's data security regulations can help Bangladesh develop legal frameworks that safeguard farmer data and promote responsible data governance.

Addressing all these challenges is crucial for navigating the roadblocks to 5G adoption in Bangladeshi agriculture.

2.5. Potential Impact of Implementing 5G Technology in the Agricultural Sector of BD:

The potential impact of implementing 5G technology in the agriculture sector is massive since the implementation of 5G will enable the use of smart farming. Considering smart farming in Bangladesh can solve problems such as monocropping, loss of arable land, natural disasters, and climate change with the help of IoT, soil scanning, automatic irrigation, automatic plant disease detection, and data management, the impact of implementing a 5G based smart farming model in Bangladesh will have a significant impact on all the stakeholders (i.e, consumers, farmers and businesses).

3. Conclusion

This paper highlights the potential impact of implementing 5G technology in the agricultural sector of Bangladesh and subsequent challenges to its implementation. It has been found that while the benefits of adopting 5G technology in agriculture are enormous, there are significant infrastructure challenges and application limitations that hinder said benefits from being realized. Further development in the literature to include a detailed cost-benefit analysis of such implementation would greatly help all stakeholders involved.

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