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IDENTIFYING QOS IMPACTS ON THE 4G LTE AND 5G FWA INTEGRATION USING 2300 TO 2400 MHZ BAND REALLOCATION FOR HIGH-SPEED INTERNET ALTERNATIVE TO TRADITIONAL FIBER

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Although 5G technology has been in development for a considerable time, significant challenges regarding its effective implementation still need to be addressed. A key issue lies in using frequency and ensuring coexistence with previous technologies that continue to serve existing users because users in many countries' late adoption of new technologies does not always progress smoothly. This research paper aims to evaluate 5G Fixed Wireless Access (FWA) utilizing the 2300 to 2400 MHz spectrum that is usually used in 4G LTE previous technology, positioned as a viable alternative to traditional fiber optic networks, and its impact on technology valuation in spectrum usage to solve high-speed alternative traditional fiber in rural and urban areas. The study focuses on Quality of Service (QoS) related to user experience with a standard wireless access service parameter while analyzing payload growth and revenue generation improvements compared to LTE technologies. Through rigorous trials, our results demonstrate that 5G FWA not only preserves the QoS experienced but significantly enhances it as a feasibility analysis of network productivity by combining 4G and 5G technology in one service area. The implementation trial of 5G FWA resulted in notable increases of 50 % in more than 20 Mbps data throughput, contributing to 27 % substantial growth in payload and revenue in an area using only 4G LTE before 5G FWA was implemented. By providing detailed performance metrics, the trials highlighted the potential for 5G FWA to deliver broadband services more efficiently and cost-effectively, particularly in regions where geographical or economic factors constrain the expansion of fiber optics

Keywords: broadband internet, fixed wireless access, fixed mobile convergence, FMC, rural-urban internet, fiber optic

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1. Introduction

The penetration of broadband as a percentage of households varies significantly worldwide, illustrating the digital divide between developed and developing countries and highlighting the impact of infrastructure and economic policies on broadband accessibility. High connectivity in developed areas promotes economic and educational advances, while many developing regions face low broadband access due to economic and geographical constraints, particularly in rural areas. The emergence of 5G technology offers new opportunities for broadband expansion where traditional fiber optics are unfeasible. The escalating demand for faster and more reliable internet access has catalyzed the exploration of innovative broadband solutions, especially in regions where traditional fiber optic deployment proves challenging or cost-prohibitive. Among the myriad solutions, implementing 5G Fixed Wireless Access (FWA) by freeing up 2300 to 2400 MHz spectrum or, specifically referred to as the 2300 MHz spectrum band only, still widely utilized by previous 4G LTE mobile technology in many countries, will be a pivotal advancement in telecommunications. This approach promises high-speed data services comparable to fiber optics. It offers a more rapid and flexible deployment model or a temporary solution for the fixed network part of Fixed Mobile Convergence (FMC) until the fiber optic network is ready, making it a compelling alternative for today's digital demands. The importance of researching the 2300 to 2400 MHz spectrum for co-existing 5G FWA and previous 4G LTE technology implementation in real live networks cannot be overstated. As the telecommunications industry continues to evolve, especially technology adoption and transition, the strategic reallocation and utilization of such spectrum are critical to addressing the increasing data traffic and the diverse needs of modern consumers and businesses, especially in urban and rural service areas.

Although 5G technology has been developed for a long time, the appropriate implementation strategy, especially regarding frequency usage and coexistence with previous technologies, requires comprehensive research. This is a crucial investment strategy to ensure its benefits can be realized by industries that influence management and academics for further study development. In this context, rigorous research is conducted on the operational feasibility of user experience viewed from the network service performance related to Quality of Service (QoS). Still, it specifically takes coverage, throughput parameters, and some other QoS parameters are used solely as controls against performance degradation during the execution process. Most internet users commonly use these parameters to measure their satisfaction. Meanwhile, the payload and revenue productivity parameters of 5G FWA in the 2300 to 2400 MHz band are used to view the economic aspects of the network when the network has been implemented with optimal service performance. This aims to explore the technical nuances and financial benefits of deploying 5G FWA technology in this spectrum. Therefore, the study on Quality of Service (QoS) related to internet user experiences, especially those devoted to using 5G Fixed Wireless Access (FWA) technology to bridge the digital divide, holds substantial scientific relevance. These studies are crucial for understanding how 5G technology can enhance connectivity in underserved areas and developing strategies to ensure equitable access to digital services.

2. Literature review and problem statement

The emergence of 5G technology represents a transformative shift in telecommunications, enhancing speed, connectivity, and network efficiency. Fixed Wireless Access (FWA) offers high-speed internet in areas where traditional broadband is inadequate or cost-prohibitive. This literature review assesses 5G FWA's technological progress, implementation challenges, and socio-economic effects. It synthesizes findings from scholarly articles, industry reports, and empirical studies to evaluate 5G FWA's performance, market potential, and user experience improvements. The review aims to provide a comprehensive understanding of 5G FWA's impact on the future of digital communication and its role in promoting a digitally inclusive society. First, previous research has highlighted a joint-optimization framework for planning cost-effective optical transport networks in 5G Fixed Wireless Access (FWA) systems, addressing the complexities of deployment while ensuring coverage and capacity requirements are met [1]. Although this study introduces the advantages of 5G FWA technology, the research focuses more on the 5G FWA transport solutions that support the need for wide bandwidth, low latency, increased connectivity, and cost efficiency. It may not fully account for the dynamic nature of user demand and network conditions, which could affect the long-term viability and adaptability of the proposed solutions. Furthermore, other research emphasizes the role of 5G FWA in bridging the digital divide and providing high-speed internet access to rural and semi-urban communities where fiber optic cables have not yet penetrated [2]. However, it may not provide sufficient detail on specific solutions or strategies to overcome the identified challenges in implementing 5G FWA in rural settings, leaving a gap in actionable insights for operators.

The literature on 5G FWA encompasses diverse studies that collectively highlight its potential as a transformative broadband solution. Much recent research has focused on 5G FWA's technical feasibility and performance assessment, especially in the context of 5G implementation. For instance, studies have detailed how using the concepts of fixed wireless access, network providers can use the new and upcoming 5G technology to deploy fixed broadband to homes, small enterprises, and medium enterprises with limited access [3]. There is limited discussion on FWA's technical challenges and potential limitations, such as the requirement for coverage and the impact of geographical factors on connectivity, which could affect its implementation in certain regions.

The following previous research talks about how the rapid deployment of 5G FWA technologies is reshaping the landscape of broadband internet services, offering a viable alternative to traditional wired connections. In this research, the new FWA opportunity, FWA spectrum, market segmentation, deployment scenarios, remote unit structure, and typical link performance are discussed, reinforcing the key role of 5G technology in FWA viability.5G FWA provides significantly higher data rates and lower latency than previous generations [4]. However, examples related to data from live network measurements have not been presented yet, leaving room for further research on these real network measurements connected with services, user experience, and productivity feasibility, often serving as concrete references for large-scale implementation. The other highlights the potential application of 5G FWA as a cost-effective solution to provide ultra-high-speed broadband connectivity in urban, suburban, and rural areas [5]. Besides the benefits of 5G FWA, this study mainly focuses on highlighting the current application scenarios and the network topology that can be proposed; however, its performance can be limited by factors such as signal interference, distance from base stations, and the availability of infrastructure in rural areas.

Furthermore, it has comprehensively discussed the fundamental architecture and characteristics of the 5G ecosystem and outlined the characteristics and layered architecture of the Internet of Things [6]. In addition to outlining the benefits of 5G technology, this study also explores the connection between 5G FWA and its future integration with Internet of Things technology, thus primarily discussing the potential for inter-technology integration in the future. Therefore, articles that utilize live network measurements are still necessary.

Differentiation schemes improve network performance and present a closed-form expression for the multiple-input, multiple-output scheme in which the PL and beamforming schemes are considered [7]. The paper analyzes the performance of 5G Fixed Wireless Access networks, highlighting their advantages over 4G, such as higher data rates, lower latency, and improved capacity, while addressing the technical challenges and solutions necessary for effective deployment with a specific channel model. This article would be much more interesting if it included actual references to model channels related to user experience. Studies with various deployment scenarios, business opportunities, and competition for the 5G FWA use case in many designs, development, migration, deployment challenges, and economic and financial options must be carefully explored [8]. The paper discusses the architectural, economic, and financial considerations for deploying 5G-based Fixed Wireless Access (FWA) networks. However, the user experience will also depend on factors such as network coverage and the quality of service provided.

Examining the use of meshing in a 5G FWA backhaul to determine if an optimal trade-off exists between deploying more nodes/links to provide multiple paths to the nearest Point of Presence (POP) and the network's performance.

Using an actual 5G NPN deployment as a basis, they have conducted a simulated analysis of increasing network densities to determine the optimal configuration [9]. The research analyzes the performance of meshing configurations in mmWave Fixed Wireless Access (FWA) 5G networks, emphasizing the trade-off between cost and reliability; however, it may lack comprehensive data on real-world deployment challenges and the long-term sustainability of the proposed solutions.

From an economic perspective, the literature reveals that 5G FWA presents economic impact analyses, which demonstrate the requirements and a first approach to a model to quantify the economic potential of 5G Technology in production. Therefore, existing methods and models to quantify the economic benefits of 5G Technology and digitalization in production in general are analyzed. Then, the model is derived. In the end, future research needs are given [10]. The document outlines a model for evaluating the economic potential of 5G technology in smart factories, emphasizing the need for quantifying key performance indicators (KPIs) to measure production improvements; however, it lacks a comprehensive analysis of existing economic evaluation methods tailored explicitly for 5G implementation, which may limit its applicability in real-world scenarios.

Collectively, the literature emphasizes the numerous benefits of 5G FWA, highlighting its potential to address broadband accessibility challenges while pointing out the technological, economic, and regulatory hurdles that must be overcome. This review sets the stage for a deeper exploration into how FWA can be strategically implemented to enhance global connectivity and support the burgeoning demand for high-speed internet services. This study's basis on trial testing in a live network sets it apart. It is hoped that the findings of this paper will provide a distinct contribution from previous studies, where the central issue of implementing new technology will be addressed to understand changes in customer experience from the previously dominant LTE technology and its impact on operator investment-related revenue productivity that is different from many previous researches.

In numerous developing countries, the deployment of 5G technology does not occur as swiftly or uniformly across the entire service area. The gradual introduction of user devices and a lack of specific business cases highlighting the advantages of 5G technology for a broad user base contributes to the generally sluggish pace of 5G implementation. Furthermore, internet service providers and telecommunications operators are compelled to continue supporting the quality of service for 4G devices, which remain predominant within their networks. The urgency and importance of this study are to ensure the effective utilization of the 2300 to 2400 MHz frequency spectrum, which is currently still employed by 4G LTE technology and will be used in conjunction with 5G FWA technology, has an impact that remains acceptable in terms of experience for users and feasible in term of revenue for internet service provider or telecommunication operator. The objective is to integrate these two technologies within the same coverage area while still providing optimal service to all users and laying the groundwork for a broader implementation of both 4G LTE and 5G FWA. The reallocation and application of the frequency spectrum is not a simple task, especially in countries with large populations of internet users where the settings for capacity and wireless capacity licensing are very limited and involve more than just switching frequencies. Significant effort and strategic implementation are required to maintain user experiences with both old and new technology through several activities related to frequency assignment strategy, proper capacity management, radio mobility management, etc. The issue of limited internet services in Alam Sutera, Indonesia, where fiber optic penetration is a major obstacle while the existing 4G LTE wireless network is insufficient to meet the growing data demands, represents a global problem in many countries where the adoption and transition from 4G to 5G technology are not progressing smoothly and quickly. Furthermore, the use of licensed spectrum bands is also limited. All of this allows to assert that conducting research on integrating 4G LTE and 5G FWA through reallocating the 2300 to 2400 MHz frequency band to replace traditional fiber optics is expedient.

3. The aim and objectives of the study

This study aims to evaluate the user experience from the perspectives of service performance and revenue feasibility of 5G Fixed Wireless Access (FWA) using the 2300 to 2400 MHz spectrum, which is typically used in previous 4G LTE technology, positioned as a viable alternative to traditional fiber optic networks. It will allow this study to provide practical strategies and references for integrating 4G LTE with 5G FWA through the limited reallocation of the 2300 to 2400 MHz frequency spectrum, which is commonly utilized in many countries. This approach aims to maintain service quality while offering an alternative broadband internet solution that could replace traditional fiber optics. By exploring the synergistic potential of combining existing 4G LTE infrastructure with emerging 5G FWA capabilities within the same spectral resources, the study seeks to optimize bandwidth utilization, enhance network efficiency, and ensure continuity of service. The results are expected to demonstrate the feasibility of this dual-technology approach, providing insights into how mixed-generation networks can be managed to meet growing data demands without the extensive infrastructural investments associated with fiber optic deployment.

To achieve this aim, the following objectives are accomplished:

– to assess the feasibility of reconfiguring the wireless network to allow simultaneous use of the 2300 to 2400 MHz spectrum for both 4G LTE and 5G FWA within a single service area (dual utilization);

– to develop, set a plan, and conduct pilot implementation trials for viable analysis of 5G FWA as an alternative broadband solution for areas with fiber optic challenges;

– to take necessary measurements and conduct service performance analysis of 5G FWA based on potential users, coverage, data throughput, and other QoS parameters, as well as data of usage as an alternative broadband internet solution to substitute fiber optics network;

– to conclude by techno-economic analysis of 5G FWA revenue feasibility as an alternative broadband internet solution to substitute fiber optics network.

4. Materials and Methods

The object of research in this study is the integration of 4G LTE and 5G Fixed Wireless Access (FWA) technologies through the strategic reallocation of the 2300 to 2400 MHz spectrum band. This integration evaluates the feasibility of using 5G FWA as a viable alternative to traditional fiber optic networks in urban and suburban settings. Integrating 5G FWA utilizing the 2300 to 2400 MHz spectrum band alongside existing 4G LTE technologies represents a transformative advancement in telecommunications. This spectrum allocation is particularly significant as it enables coexistence with 4G LTE, enhancing the overall network capacity and efficiency without requiring extensive infrastructural overhaul. Conducting pilot trials before a massive implementation is essential to fully capitalize on this integration. These trials should employ specific methodologies to assess the feasibility and performance of the combined technologies under real-world conditions. The dual-utilization of these bands facilitates a seamless transition and broader coverage, providing high-speed internet access that rivals traditional fiber optic connections. By leveraging this hybrid approach with thorough preliminary testing, telecommunications operators can deliver more robust and reliable services, meeting the ever-growing demand for faster internet and supporting many modern digital applications. This strategic spectrum usage optimizes existing resources and paves the way for a more connected and technologically advanced future.

This study comprises a thorough literature review and a case study of 5G FWA trial tests carried out by a specific telecommunications operator in Indonesia in collaboration with a global vendor. The literature review will initially delve into existing research on 5G FWA technology, emphasizing its development, deployment challenges, and influence on the broadband market. Sources will encompass peer-reviewed journals, industry reports, and academic publications, providing a theoretical basis and identifying current research gaps. The study employs an experimental methodology by observing pre- and post-intervention and evaluating its efficacy in modifying the variables or conditions under examination. The analysis will involve studying the data gathered over the trial period. This will include looking at changes in the overall distribution spread using specific QoS variable thresholds to understand how it affects user experience metrics and network efficiency. This analysis aims to illustrate the advantages of deploying 5G FWA technology. This study hypothesized that the deployment of 5G Fixed Wireless Access (FWA) technology utilizing the 2300 to 2400 MHz spectrum band would provide internet speeds and service quality that are equivalent to those of existing fiber optic networks in both urban and rural environments while concurrently maintaining the service levels of the pre-established 4G LTE networks.

In this research on integrating 5G Fixed Wireless Access (FWA) with existing 4G LTE infrastructure using the 2300 to 2400 MHz spectrum, the study framework is guided by several critical assumptions. It assumes that there are no auxiliary infrastructure issues, such as transport and power supply stability problems or other network unavailability issues, which could affect the Quality of Service (QoS) during the trial integration of 4G LTE and 5G FWA technologies. A feasibility comparison with traditional fiber optic networks references thresholds for internet service delivery related to video experience, assuming that video services are the highest bandwidth-consuming and most widely utilized internet services. The QoS parameters employed directly impact customers, namely coverage and downlink throughput speed, as the downlink is critical to user experience. Other QoS parameters are used as supports and controls throughout the study. Latency measurements are not conducted, given that the transport network more significantly influences latency than the access network itself.

This study employs a representative sample approach, which involves selecting urban and suburban clusters as sample areas to generalize the findings across a broader geographic region. These clusters are chosen based on their demographic and infrastructural characteristics, indicative of varied urbanization levels and technology adoption rates representing larger populations. By testing the integration of 4G LTE and 5G FWA in these distinct environments, the research can comprehensively assess the effectiveness of spectrum utilization, network performance, and service quality across different urban densities. This approach not only substantiates the scalability of the technology in diverse settings but also provides empirical data on the potential of 5G FWA to meet the high-speed internet demands typically served by fiber optics.

After the literature review, the research will focus on trial planning, which includes determining the area or cluster where the trial will be conducted, the measurements to be used, and the hardware, software, and technology licenses required for 4G, 5G, and FWA. This will then be followed by field implementation based on the planned design and a one-week stability test to ensure the expected measurements are achieved. After the planning and implementation are completed, the research will focus on collecting measurement data and analyzing relevant data for the feasibility test of 5G technology for FWA. These trials are critical as they provide insights into 5G FWA technology's operational capabilities and limitations under observed clusters with standard operational conditions and configurations. The data collected from these trials, including performance metrics such as speed represented by data throughput, coverage changes to ensure network stability, payload improvement, and Data of Usage (DoU) increment serve as the empirical foundation for assessing the feasibility of 5G FWA compared to 4G LTE solutions. The analyzed data will conclude the network performance and productivity of 5G FWA. This stage is crucial for understanding the specific challenges and advantages encountered during the trial phases, providing a grounded perspective on the operational readiness of 5G FWA technology in various settings.

The trial phase necessitates a tuning process encompassing configuration, capacity changes, and quality adjustments within the wireless parameter setting. This meticulous tuning is crucial to ensure the network operates optimally under varying conditions and user demands. By fine-tuning these parameters, the trial aims to evaluate the robustness of the network infrastructure and its capability to handle different traffic loads and service requirements effectively. This stage is integral to identifying potential areas for improvement and ensuring that the network can deliver a consistent and high-quality user experience.

Lessons learned from the study and then proposed additional solutions to overcome further massive implementation challenges observed based on insights gained from the trial tests. These proposals are based on trial results and aim to enhance the deployment strategies of 5G FWA systems, technological frameworks, network configurations, and investment feasibility based on revenue estimation methods. This segment addresses urgent technical-related performance and business aspects related to competition and acquisition issues. It suggests innovative approaches for integration and optimization that could further improve the adoption and efficiency of 5G FWA.

By integrating these diverse research components, literature review, empirical data analysis, and solution formulation, the methodology provides a robust framework for understanding 5G FWA's present capabilities and prospects in the broadband internet sector. This approach captures a snapshot of current 5G FWA deployments. It frames them within a broader technological and market-oriented context, offering comprehensive insights into the strategic positioning of 5G FWA technologies moving forward.

5. Result of 5 Generation Fixed Wireless Access Trial Test

5. 1. Possibility of wireless network reconfiguration

Using the 2300 to 2400 MHz spectrum band to enable 5G FWA represents a strategic decision, as this band is partially occupied by existing 4G LTE technology. The result ensures that the existing resources, including hardware, software, licenses, and new requirements, are feasible and fully supportive to realize this trial. Specific configuration changes are required to activate 5G FWA on this shared spectrum, including massive mimo technology to perform frequency reallocation to ensure coexistence between 4G LTE and 5G services as shown in Fig. 1 below by adding 10Mhz idle frequency. The process involves careful planning of both software and hardware components. On the software side, updates to network management systems are essential to optimize bandwidth allocation and reduce interference between technologies. Hardware planning includes upgrading base stations to support 5G capabilities, particularly antenna systems and radio frequency (RF) components that can handle the dual operation of 4G and 5G within the same spectrum band. These changes must be carefully tested and validated to ensure a seamless transition and optimal network performance, allowing for efficient spectrum utilization and enhanced user experience in urban and rural environments.

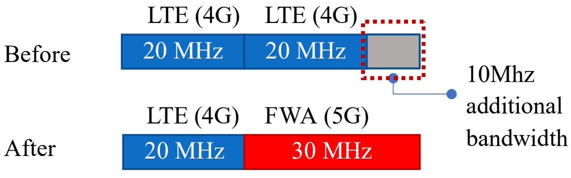


Fig. 1. Frequency band reallocation

Fig. 1 also explains that with the current spectrum allocation, in areas with low base station 4G LTE traffic utilization, 5G technology can be implemented for FWA needs, enhancing the network's traffic throughput. From the 4G LTE technology that initially occupied a 40 MHz spectrum, with low utilization conditions, only 20 MHz of frequency band spectrum is needed for operation. Meanwhile, the remaining 20 MHz, with an additional 10 MHz license, totaling 30 MHz, can be utilized for 5G technology. This reallocation varies for each operator worldwide. However, operators can leverage the idea and strategy of reallocating 4G and 5G frequencies globally, depending on the frequency licenses obtained in each country where the operator is licensed. This reallocation also serves as a trigger for conducting trials to obtain relevant measurements from 5G FWA technology, comparing what can be provided by fiber optic networks in terms of service performance enjoyed by broadband internet users.

Fig. 2 shows the primary 5G FWA access network configuration installed in many internet households as a fixed device, providing a clear contrast to the typical mobile 5G network, which relies on mobile handsets like common personal handphones or smartphones. 5G FWA systems comprise several components facilitating high-speed internet connectivity over wireless networks. The antenna is strategically positioned to receive and transmit signals from a nearby 5G FWA base station. Connected to the antenna is a modem/router, converting cellular signals into internet connectivity for the user. The modem/router also plays a pivotal role in managing data traffic and ensuring efficient bandwidth distribution among connected devices. This device typically supports advanced networking features such as network management, security protocols, and sometimes multiple frequency bands to enhance connectivity stability and speed. The FWA setup includes WiFi connectivity, which extends the internet service wirelessly within the user's premises. This allows multiple users and devices, including FWA handsets, to access the internet simultaneously without needing physical connections.

As part of the frequency spectrum reallocation, the rearrangement of the 2300 to 2400 MHz spectrum band has been implemented without causing security issues related to interference. The interference level maintained below –103 dBm for both 4G and 5G services indicates that there is no disruption to Quality of Service, thereby meeting the necessary standards for both uplink and downlink wireless transmission and complying with regulatory requirements. Additionally, data security issues are effectively integrated with the security systems already in place in the existing core network. These existing systems are designed to protect data and transactions on the whole network, ensuring the security and privacy of users remain safeguarded. This approach ensures that the spectrum reallocation not only enhances network capacity and efficiency but also maintains high security standards.

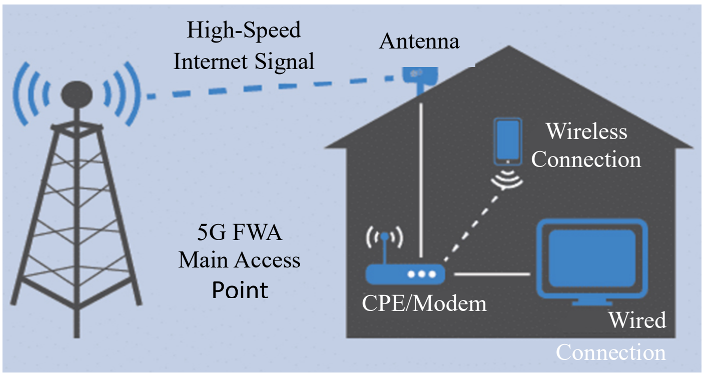


Fig. 2. Fixed wireless access

5. 2. Pilot implementation trials: development, setup and planning

The activation of 5G FWA using the 2300 to 2400 MHz spectrum band requires a structured approach encompassing several vital stages: planning, installation, optimization, and field testing. The stages are intended to consistently consider the actual conditions according to the natural network behavior of each operator so that the trial results can be applicable in the future for massive implementation. During the planning phase, the trial area was determined to be in a cluster named Alam Sutra, located 40–50 km outside Jakarta, Indonesia's capital city. This cluster primarily consists of an urban residential area and open spaces resembling rural conditions. The reason for selecting this cluster is that it adequately represents the objective criteria for implementing FWA as a replacement for traditional fiber optics, which cannot reach the area due to specific reasons.

In addition, from a technical perspective, a detailed assessment was conducted on the availability and assignment of spectrum for existing technologies, such as 4G LTE. This includes determining bandwidth allocation, network architecture, and hardware requirements. The installation phase involves deploying 5G-capable equipment, such as upgraded base stations, antennas, and backhaul systems, ensuring compatibility with the existing infrastructure. Optimization follows, focusing on fine-tuning network parameters like signal strength, frequency utilization, and load balancing to maximize the performance of both 4G and 5G services within the shared spectrum band. Finally, field testing evaluates user experience, ensuring adequate coverage, signal quality, and service performance across the target areas. These field tests help identify potential obstructions or challenges, allowing for further adjustments to network configurations, ensuring seamless 5G FWA deployment, efficient spectrum usage, and ultimate measurement data in period analysis.

5. 3. Collection of necessary measurements and service performance analysis based on potential users, coverage, data throughput and data of usage

These measurement data are utilized to assess changes in the performance of 4G LTE and 5G FWA services, referencing the 5G QoS wireless access standards, to evaluate their feasibility as replacements for fiber optics in line with this study's theme of user experience. This study leverages measurement data to meticulously analyze changes in the performance of 4G LTE and 5G FWA services. These assessments are anchored to the stringent 5G QoS wireless access standards, allowing for a comprehensive evaluation of their potential to replace traditional fiber optic networks effectively. The focus is mainly on how these technologies impact user experience, aligning with the study's thematic goal to determine their practicality as mere technological replacements and enhancements that could lead to better service delivery.

5. 3. 1. Potential 5-generation fixed wireless access user

5G FWA is emerging as a critical technology for telecommunications operators aiming to bridge the infrastructure gap where fiber optic solutions are not feasible. 5G FWA offers a more cost-effective and rapidly deployable alternative, particularly in densely populated urban areas where the costs and disruptions of fiber installation are very high and in rural areas where geographical challenges complicate fiber deployment. Telecommunications operators increasingly see the potential of 5G FWA and are keen to leverage it to expand broadband access in these challenging environments. Using radio signals to transmit data wirelessly, 5G FWA eliminates the need for extensive physical infrastructure required by traditional broadband setups, significantly reducing installation time and investment. This technology utilizes existing cellular network infrastructure, such as 4G LTE and the growing 5G networks, to provide high-speed internet services that rival wired connections. 5G FWA offers a solution for densely populated urban areas to quickly scale up broadband services to meet the growing demand without the disruptive, lengthy, and costly process of digging up roads to lay fiber cables. Moreover, 5G FWA solutions are scalable and flexible, allowing operators to adjust bandwidth and services according to customer demands and network capacity. This adaptability ensures that operators can provide tailored services that meet the diverse needs of urban and rural users alike, making 5G FWA a key component in the strategy to achieve widespread and equitable broadband access.

To understand the convenience offered by 5G FWA technology and the existing market potential, measuring the results of trial implementations that reveal both market potential and readiness across different user or customer segments is essential. These measurements provide critical insights into the performance and scalability of 5G FWA in real-world scenarios, allowing for a detailed evaluation of network capabilities and user experiences. By analyzing these results, telecommunications operators can identify key opportunities, assess the readiness of various market segments, and develop targeted strategies to enhance service adoption and maximize the impact of 5G FWA across diverse customer bases. Fig. 3 below shows the mobile user handset profile in a dense urban testing cluster that can represent the condition of customer readiness in a significant Southeast Asian city or other developing country awaiting massive implementation of the future 5G FWA network. It shows that only 2.54 % of customers genuinely experience the 5G user experience, where the handset and the network services are based on 5G. Beyond this figure, there are 5.83 % of customers whose handsets are 5G provisioned but have not yet received 5G network services. Additionally, 3.50 % of customers own 5G handsets but have not been provisioned for 5G, and the remaining 88.12 % are customers who still use non-5G handsets. This figure illustrates how 5G FWA has the potential for future broadband internet penetration needs and provides insights for telecommunications operators to capitalize on the advantages of 5G FWA.

In other words, in Fig. 3, it can be inferred that in terms of mobile broadband internet, the capabilities of handsets used by customers mobilizing in that area, as previously mentioned, have a high potential to generate profitable 5G payload traffic for operators if a Base Station with 5G capabilities is established in the area. In addition to this information, there is a possibility and potential for these mobile broadband internet data consumers to be interested in using fixed broadband data, for which it is possible to offer a solution with 5G FWA. This is common for their broadband internet data needs at home in areas without fiber optic networks, using mobile internet data to meet their internet data needs. From this potential, trials can be conducted so that when our 5G FWA network is set up, these mobile users or customers can also purchase fixed internet data service packages and utilize the ready-to-serve 5G FWA network.

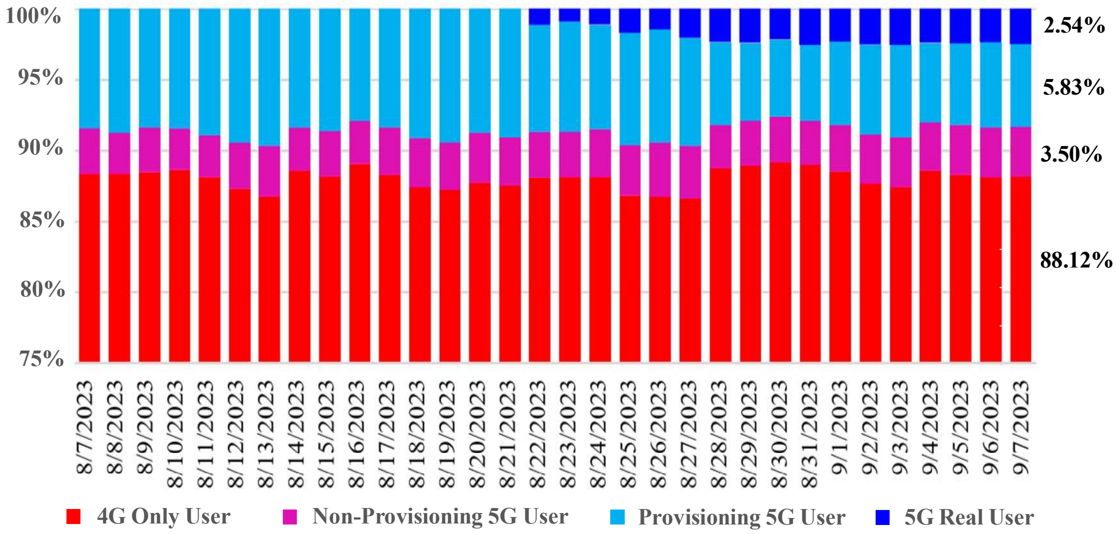


Fig. 3. 5 Generation mobile user distribution

5. 3. 2. Coverage and data throughput

In the observation area, the trial phase involved the installation of 5G FWA devices at strategically selected locations to maximize coverage and signal quality. Before measurements were conducted, an optimization phase was necessary to ensure that both coverage and signal quality met the service standards of the respective operator. This involved adjustments to antenna installation and radio parameter tuning. The signal testing route is shown in Fig. 4 below. Although 5G FWA is intended for fixed services, the testing was conducted by sampling the signal along a moving route by the drive test tool. Additionally, the trial aimed to assess the expansion of internet coverage within the test area. Before implementing 5G FWA, certain areas in Alam Sutra experienced poor connectivity due to a lack of physical infrastructure. After the deployment, as shown in Fig. 4 below, these areas demonstrated signal strength and reliability improvements, indicating that 5G FWA can bridge connectivity gaps in underserved locations.

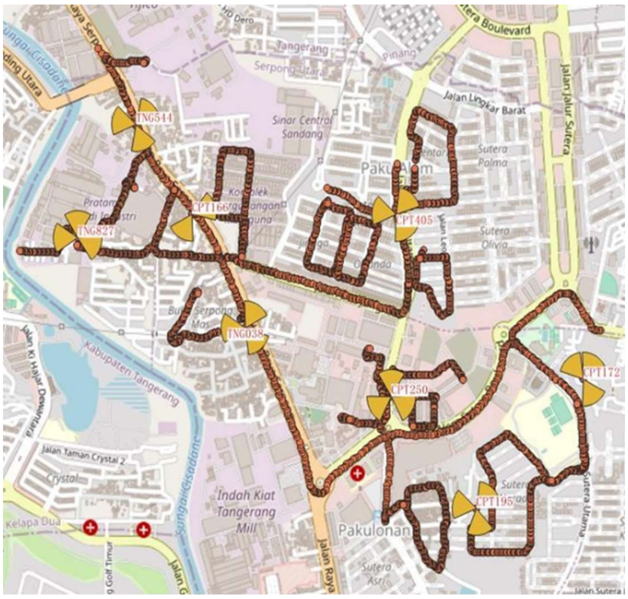


Fig. 4. Fixed wireless access route test by wireless drive test tools

This stage also monitored the penetration of users who subscribed to the 5G FWA service during the trial period. The goal was to understand user adoption rates and satisfaction levels with the new technology. Feedback collected from trial participants highlighted the ease of installation and enhanced internet quality as significant advantages. This user data is invaluable for refining deployment strategies and improving service offerings.

In exploring 5G FWA using the 2300 to 2400 MHz spectrum band, a comprehensive approach was employed to assess its effectiveness through empirical data collection. A sample of 100 data calls was gathered using a drive test tool from Customer Premises Equipment (CPE) as the primary objective measurement and smartphone as a reference due to a single base station serving both these handset devices, providing a robust dataset for analysis. To evaluate the performance of the 5G FWA, the cumulative distribution function (CDF) method was utilized, focusing on two critical parameters: the Reference Signal Received Power (RSRP) and Data Throughput.

RSRP is a crucial indicator of signal coverage, reflecting the strength of the signal received by a device from a cell. Understanding the coverage area and signal quality provided by the 5G FWA deployment is crucial. Conversely, throughput represents the data speed achievable within the network, essential for gauging the user experience regarding data transmission speeds. The key to understanding the proof lies in the data distribution analysis used, which is the Cumulative Distribution Function (CDF) method. The CDF method provides a statistical way of summarizing and visualizing the distribution of data points. The Cumulative Distribution Function (CDF) is a crucial statistical tool used to show the proportion of values in a dataset that do not exceed a specific value. Let's consider values such as QoS observation threshold values or acceptability thresholds. The parameter that most correlates with internet data between FWA and fiber optic networks is coverage, which typically represents the distance from the optical distribution point to the customer's household, as well as data speed measured by throughput. These parameters values will be analyzed and compared between different conditions before and after an intervention to assess the resulting outcomes. CDF is beneficial in many applications, including telecommunications, because it provides a visual and analytical way to understand the distribution of values such as signal strength, data transmission speed, or other QoS variables. In this context, the CDF plots the probability that a variable, such as RSRP or Throughput, is less than or equal to a specific value. This method is particularly useful in telecommunications research as it helps delineate the percentage of test samples achieving particular signal strength or speed thresholds. It offers a clear view of network performance across the spectrum band under study. This analysis is pivotal in identifying optimal deployment strategies and operational adjustments needed to maximize the efficiency and coverage of 5G FWA systems.

The deployment of 5G FWA using the 2300 MHz spectrum has led to a substantial enhancement in network performance, as demonstrated by the trial results. One of the critical aspects of this deployment was its ability to significantly improve 5G services while maintaining the stability and reliability of existing LTE networks. Post-deployment measurements showed that, for LTE services, critical parameters such as the Reference Signal Received Power (RSRP) and throughput remained consistent with pre-existing levels. This is a crucial finding, as it indicates that the introduction of 5G capabilities did not disturb or degrade the performance of the LTE network, which continues to serve a large portion of the user base. The coexistence of 5G and LTE on the 2300 MHz spectrum demonstrates a carefully managed strategy that ensures both networks can operate effectively without creating service degradation. By preserving the integrity of LTE services, the deployment achieved a seamless transition, allowing users to benefit from the advanced speeds and capacity of 5G without any trade-offs in the quality of LTE connections.

In Fig. 5 below, the Cumulative Distribution Function of RSRP for the threshold below –80 dBm improved from 55 % to 40 %, indicating an approximate improvement of 15 % compared to the condition before the implementation of 5G FWA. According to the legend provided, the pre-intervention condition uses a red curve legend where the 2300 to 2400 MHz spectrum was entirely used by LTE technology (L2300). After the intervention, the 2300 to 2400 MHz spectrum band is used separately by both 4G LTE technology (Post_L2300), represented by a light green curve legend, and 5G FWA technology (Post_NR2300) using a blue curve legend. This curve indicates fewer CPEs receive signals below –80 dBm, suggesting a 15 % increase in signal strength coverage (Post_NR2300), where 4G LTE is relatively maintained (Post_L2300), which is shown by the curves almost overlapping between pre and post_L2300. The –80 dBm RSRP threshold is used considering measurements conducted outdoors using a drive test tool. This is accounted for with an allowance of up to 20 dB of attenuation to reach indoor levels of –100 dBm, the RSRP threshold from the design and planning of typical cellular wireless networks to achieve adequate quality, depending on each operator's policy.

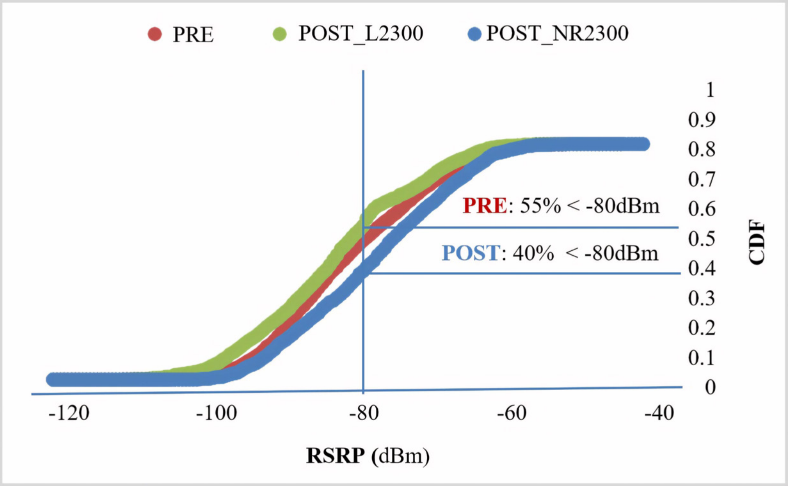


Fig. 5. Cumulative distribution function of CPE coverage

On the other side, in Fig. 6 below, the Cumulative Distribution Function of RSRP for the threshold below –80 dBm improved from 65 % to 40 %, indicating an approximate improvement of 22 % compared to the condition before the intervention of 5G FWA. According to the legend provided, on the CPEs side, the pre-intervention condition uses a red curve legend where the 2300 to 2400 MHz spectrum was entirely used by LTE technology (L2300). After the intervention, the 2300 to 2400 MHz spectrum band is used separately by both 4G LTE technology (Post_L2300), represented by a light green curve legend, and 5G FWA technology (Post_NR2300) using a blue curve legend. This curve indicates fewer Smartphones receive signals below –80 dBm, suggesting a 22 % increase in signal strength coverage.

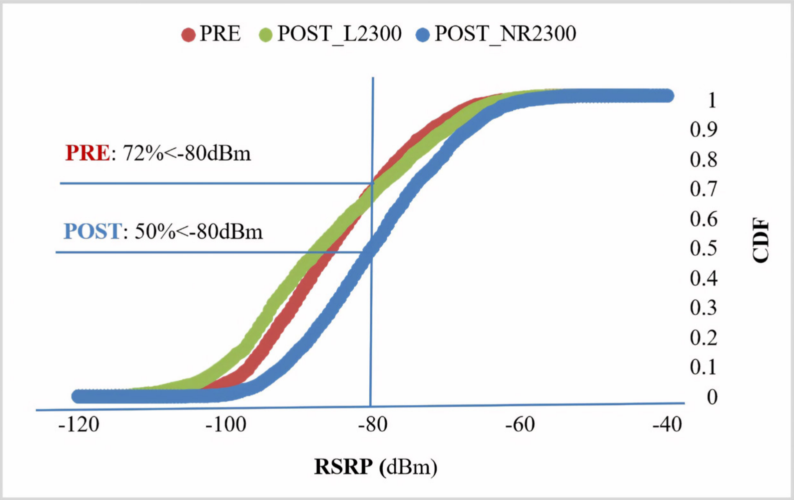


Fig. 6. Cumulative distribution function of smartphone RSRP coverage

The Fig. 7 provided below showed a significant increase in download throughput. The Cumulative Distribution Function of CPE throughput showed a 50 % improvement, shifting from 60 % to 10 % with a threshold of less than 20 Mbps. Similar to the RSRP curve legend mentioned earlier, the initial state before the intervention is denoted by a red curve legend, indicating that the 2300 to 2400 MHz spectrum was fully utilized by LTE technology (L2300). Following the intervention, this spectrum band was divided by bandwidth, with 4G LTE technology (Post_L2300) represented by a light green curve legend and 5G FWA technology (Post_NR2300) represented by a blue curve legend, showcasing an evident improvement in data transmission speeds across the network, resulting in 90 % user satisfaction where 4G LTE relatively maintained, which is shown by the curves almost overlapping between pre and post_L2300. Notably, 85 % of users will be satisfied with a minimum threshold of 50 Mbps. Satisfaction here is defined as the percentage distribution of users who receive throughput above the thresholds, namely 20 Mbps and 50 Mbps. Mathematically, it is obtained by subtracting the CDF of users receiving throughput below the acceptability from 1–15 % for the 50 Mbps threshold. The 20 Mbps threshold was chosen considering HD video service on fiber optic transmission for a single user. In contrast, the 50 Mbps threshold was determined based on the design and planning of typical cellular wireless networks to ensure satisfactory quality for three to five users, bearing in mind the individual policies of each operator. The selection of HD video is chosen given that HD video services consume significant bandwidth among many internet data users compared to other services. Thus, its usage as a threshold is quite relevant for observing the distribution of throughput before and after an intervention. Therefore, using this threshold is quite beneficial for examining improvements in service in terms of throughput speed in this study.

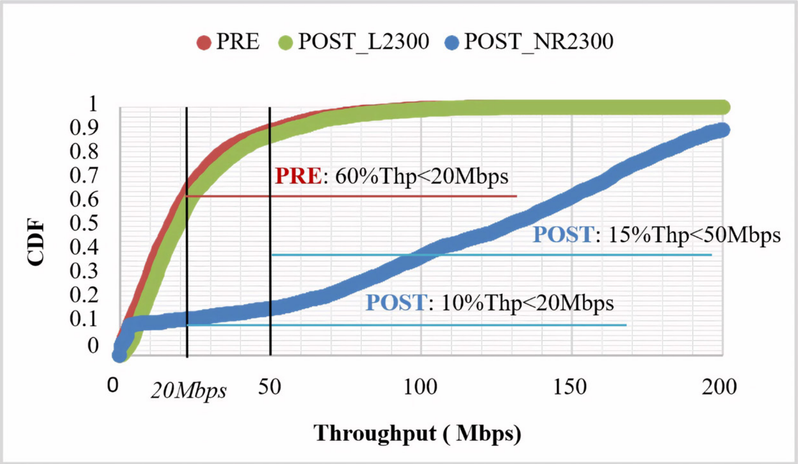


Fig. 7. Cumulative distribution function of CPE throughput

Further, Fig. 8 below also shows a significant increase in download throughput. The Cumulative Distribution Function of CPE throughput showed a 60 % improvement, shifting from 65 % to 5 % with a threshold of less than 20 Mbps. Similar to the explanation above, the initial state before the intervention is denoted by a red curve legend, indicating that the 2300 to 2400 MHz spectrum was fully utilized by LTE technology (L2300). Following the intervention, this spectrum band was divided by bandwidth, with 4G LTE technology (Post_L2300) represented by a light green curve legend and 5G FWA technology (Post_NR2300) represented by a blue curve legend, showcasing an evident improvement in data transmission speeds across the 5G FWA network, resulting in 50 % user satisfaction where 4G LTE still relatively maintain, which is shown by the curves almost overlapping between pre and post_L2300. Notably, 75 % of users will be satisfied with a minimum threshold of 50Mbps. Satisfaction here is defined as the percentage distribution of users who receive throughput above the thresholds, namely 20 Mbps and 50 Mbps. Mathematically, it is obtained by subtracting the CDF of users receiving throughput below the acceptability from 1–25 % for the 50 Mbps threshold.

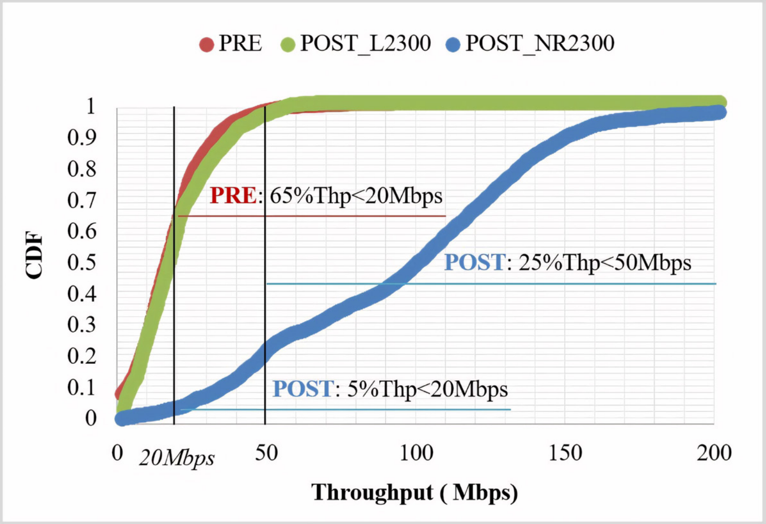


Fig. 8. Cumulative distribution function of smartphone throughput

5. 3. 3. Other QoS parameters

As additional information, considering the vast amount of network QoS data and the fact that not all parameters directly impact customer expectations, it is possible to focus primarily on coverage and throughput using cumulative distribution analysis. Here, profiles of some QoS parameters will be displayed during the intervention to demonstrate no decrease or degradation in these parameters. They remain relevant to the user experience, as the trial is conducted on a live network. Some of these parameters include the Call Setup Success Rate (CSSR) in data transaction, which measures the success rate of data access to the network, and the session drop rate, which measures the failed rate during ongoing data calls in both the existing 4G LTE network and the new 5G FWA network.

From Fig. 9, 10 above, it is evident that the 5G Fixed Wireless Access (FWA) intervention within the trial cluster did not lead to any reduction in the 4G LTE Call Setup Success Rate (CSSR) or the 4G LTE Session Drop Rate (SDR). This performance stability indicates that the integration of 5G FWA did not adversely affect the existing 4G LTE network's performance. The consistent performance of the 4G LTE CSSR and SDR throughout the trial period underscores the network infrastructure's capability to support concurrent operations of both technologies without compromising service quality. This outcome is significant, demonstrating the effectiveness of the implemented strategies to ensure that the introduction of new technology does not disrupt the ongoing reliability and user satisfaction associated with established 4G LTE services.

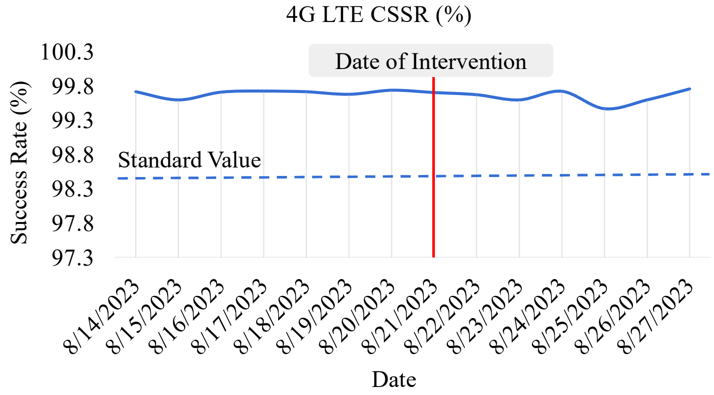


Fig. 9. 4 Generation long-term evolution call setup success rate

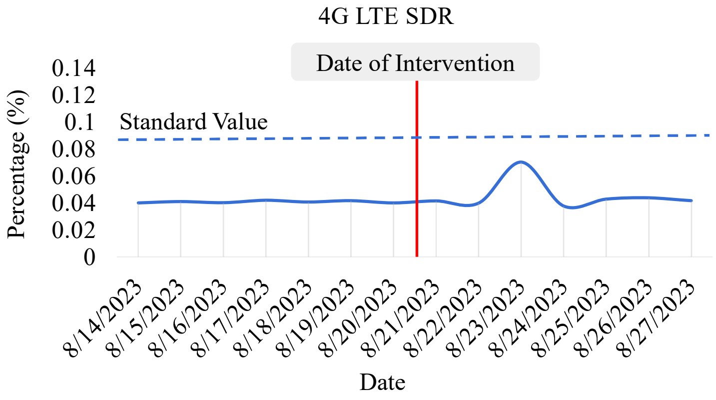


Fig. 10. 4 Generation long-term evolution service drop rate

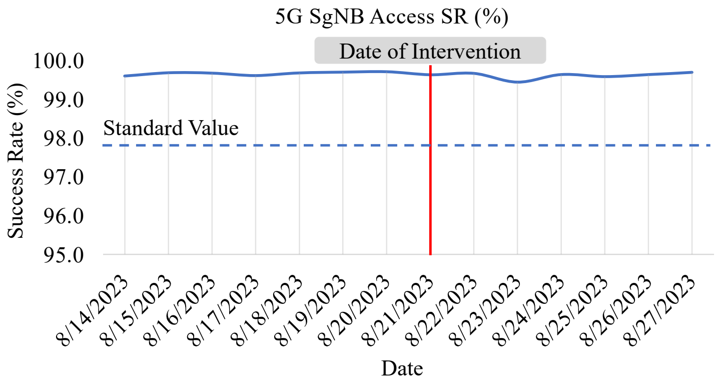


Fig. 11. 5 Generation secondary SgNodeB access rate

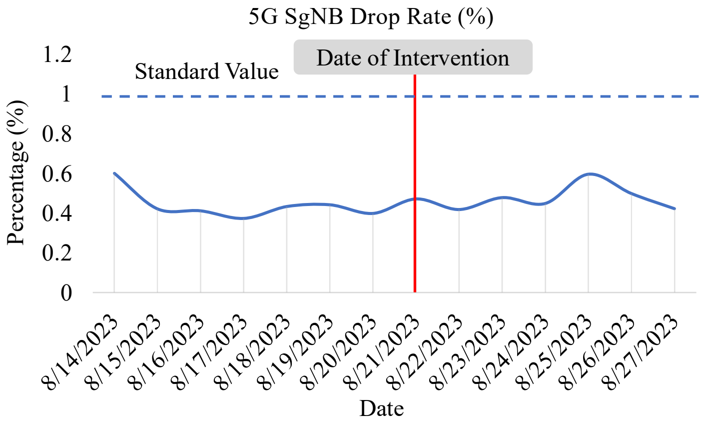


Fig. 12. 5 Generation secondary SgNodeB drop rate

Fig. 11, 12 above further reveal that the 5G Fixed Wireless Access (FWA) intervention within the trial cluster did not lead to a decline in the FWA SGNodeB Access Success Rate or the FWA SGNodeB Drop Rate. This consistent performance underscores the robustness of the 5G FWA infrastructure in managing network stability and connectivity effectively, even under the real live of trial conditions. The high access success rates and low drop rates maintained during the introduction of 5G FWA technology reflect positively on the seamless functionality and reliability of the system. These results highlight the efficacy of the 5G FWA deployment in ensuring that new network enhancements do not disrupt service continuity, a crucial factor for maintaining user trust and satisfaction during network upgrades.

5. 3. 4. Data of usage

Data of Usage (DoU) refers to the measurement of data consumption by users within a network, typically regarding the amount of data transmitted and received over a specified period. It is a critical metric in telecommunications and internet services, used to monitor and analyze users' behavior regarding data usage. DoU is essential for network operators to understand customer demand, optimize network resources, and design service plans that align with varying data consumption levels.

During the trial test of 5G FWA technology, there was a notable increase in Data of Usage (DoU) compared to the existing 4G technology. Specifically, the data payload per user on the 5G FWA network showed an increase of 2.41 % over the 4G LTE baseline as previous technology, as shown in Fig. 13. It can be interpreted that a 5G-capable handset device served by a 4G network will not be able to deliver Data of Usage (DoU) as high as when a 5G network serves a 5G handset device because the handset device is unable to optimize its capabilities on the 4G network fully. This explains the difference, which results in the DoU improvement gain when the 5G FWA network serves the 5G handset device. This indicates a substantial enhancement in data payload productivity over the operator network, representing feasibility in future investment and comparable to network productivity to a fiber optic or alternative fixed part of the FMC network.

This enhancement in DoU is significant as it reflects the higher capacity and efficiency of 5G networks in handling larger volumes of data, which is crucial for today's high-demand internet usage scenarios. The data from the trial test also underscores the potential of 5G FWA to meet the growing data needs of modern internet users, making it a viable option for enhancing broadband access, especially in areas where traditional fiber optic infrastructure is challenging to deploy. As 5G technology continues to evolve and expand, the increase in DoU is expected to become even more pronounced, driving further advancements in how telecommunications services are delivered and experienced by consumers.

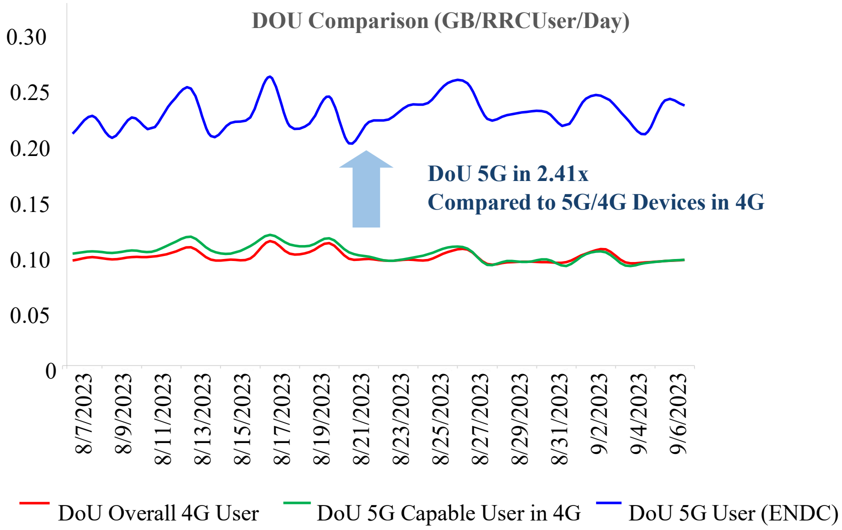


Fig. 13. Data of usage

This implies that when 5G users access a 5G network, their 5G handsets are optimized to deliver significantly larger 5G data payloads. Profiling these scenarios reveals that a 5G handset operating on a 5G network can handle a data payload 2.41 times larger than the same handset on a 4G network or a 4G handset operating on a 4G network. This enhanced performance is expected as 5G handsets are specifically engineered to maximize the capabilities of 5G networks, ensuring optimal functionality and superior data handling.

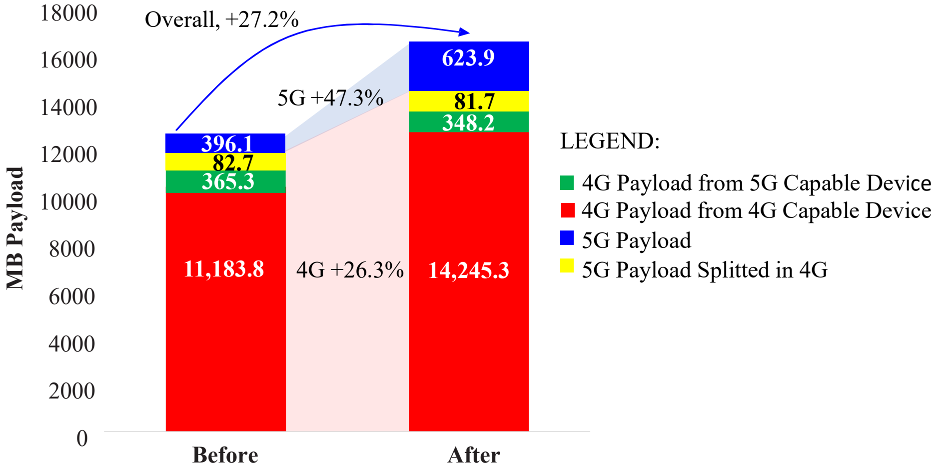
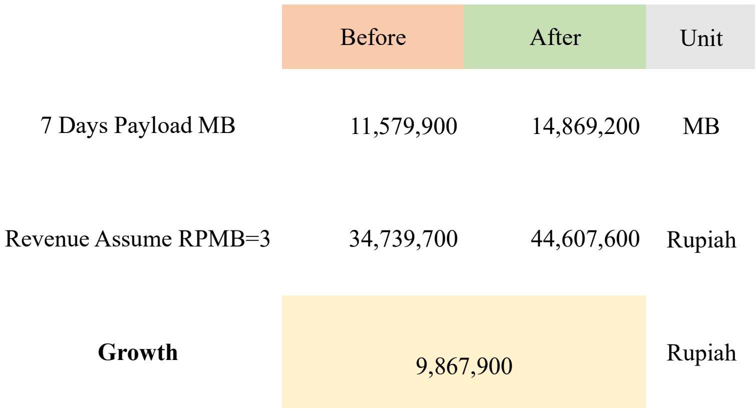


Fig. 14. Payload improvement

5. 4. Techno-economy analysis

Implementing 5G FWA technology presents a compelling techno-economic case, particularly when examining potential revenue growth driven by increased payload capacities. This analysis is needed regarding the investments to be made by operators, considering that massive implementation requires information on the revenue generated as a reference for future investment decisions. With 5G FWA trials showing a remarkable 60 % improvement in download throughput and an 85 % satisfaction rate at more than 50 Mbps, or 90 % of users will be satisfied if use 20 Mbps as the minimum download throughput threshold, there is a clear indication of enhanced user engagement and network utilization. This improvement directly translates into higher payload demands, signifying that users consume more data and utilize network services more frequently and intensively.



	Before	After	Unit
7 Days Payload MB	11,579,900	14,869,200	MB
Revenue Assume RPMB=3	34,739,700	44,607,600	Rupiah
Growth	9,867,900		Rupiah

Fig. 15. Revenue estimation

Calculating the potential revenue from these enhancements involves projecting an increase in data consumption into subscription packages that yield data payload for operators. For instance, if the trial's increase in payload usage indicates that the average data consumption per user could rise by approximately 27.2 % compared to existing 4G services, as shown in Fig. 14, operators can multiply this by the RPMB (rupiah per megabyte) that shows the price per megabyte of data passing through the operator's network. This parameter generally indicates the average price of payload that passes through the internet network by dividing the total revenue by the total payload of an operator. So, the parameter will depend on the currency where the country and operator operate. The estimation and comparison before and after the trial can be seen in Fig. 15, where payload growth can be used to calculate revenue growth to reach Rp 44.6 billion, or a 27.0 % revenue improvement gain. This calculation only looks at the increase in payload from a network aspect. By offering tailored data packages that cater to the enhanced capacities of 5G FWA, operators can also attract new customers and persuade current users to upgrade their service packages, thereby further increasing the revenue for 5G FWA operators.

Overall, the techno-economic analysis suggests that investing in 5G FWA meets the growing demand for reliable and high-speed internet and strategically positions operators to capitalize on emerging market trends and user behaviors. Some lessons learned during 5G FWA trials, aside from the context of service performance and productivity, which are the main focuses of this research, influence trial test consideration because of the operator background setting. For the massive implementation of 5G technology, several considerations are crucial. First, it is essential to maintain service performance and optimize returns. Building base stations in clusters within one area is recommended to ensure uniform coverage and ease of managing quality. Second, capacity calculations between 4G and 5G base stations must be carefully conducted, as changes in the 5G network can affect the existing 4G network. Third, revenue gains should not be calculated per base station but aggregated across the entire cluster. This approach recognizes that 5G base stations simultaneously serve mobile and stationary users, making applying different Quality of Service (QoS) measures feasible. Fourth, from a business perspective, the potential of predatory market conditions must be considered, suggesting that sites be developed in mass with existing competition in mind. Finally, Fixed Wireless Access should also be regarded as a viable interim solution while waiting for the availability of fiber optic networks. Early deployment of FWA devices is a profitable strategy for acquiring customers, making it a critical component of considerations for massive implementation. This strategy will ensure that the 5G rollout enhances network performance and aligns with broader business objectives and market dynamics.

6. Discussion of implementation trial of 5G FWA result

In the Internet and telecommunications services industry, service coverage, network-related service performance, and data of usage are crucial in determining the extent to which market penetration can be achieved to enhance business performance by increasing payload productivity, which will drive revenue growth. These parameters also measure the service that accommodates user internet data experiences. As mentioned previously, it's essential to consider the coverage area, which denotes the geographical distance between the Optical Distribution Point (ODP) and the customer's household. Additionally, the data speed, as measured by throughput, is a crucial parameter that significantly impacts the transmission of internet data between Fixed Wireless Access (FWA) and fiber optic networks. Network productivity of fiber optic networks in which this 5G FWA trial study is conducted to assess its viability as a replacement for these fiber optic networks via 5G FWA technology that can facilitate a smooth technology transition with its innovative strategy of utilizing the 2300 to 2400 MHz frequency spectrum by dividing and reallocating this spectrum with 4G LTE technology is an intriguing question that forms the basis of this research idea. This trial and study have provided several answers through analysis of coverage and data throughput, yielding quite impressive results. Conducting trial tests in natural network environments offers many critical benefits for validating the performance and reliability of new technologies under real-world conditions, which is a distinguishing feature of this study.

However, before delving into discussions on coverage and data throughput, it should be noted that the results from detailed user profiling and distribution based on handset technology, as shown in Fig. 3, can only be obtained from a live network. These trials enable researchers to observe the behavior and interaction of new systems under typical usage scenarios, providing insights that might be overlooked in laboratory tests where real users are measured to explore the market potential from the conditions of handsets and the network types serving them. In terms of mobile broadband internet, the handset capabilities used by customers mobilizing in that area have a high potential to generate profitable 5G payload traffic for operators if a Base Station with 5G capabilities is established in the observation area. This indicates that existing customers, with information from measurements related to their handset capabilities and data usage, particularly when discussing Data of Usage (DoU), can serve as a reference for operators to invest in the construction of 5G FWA base stations during massive implementations in other areas in a similar manner to avoid investments that do not generate revenue.

The results of this trial show that the 5G FWA coverage level received by the CPE, which is equivalent and a substitute for the fiber optic network service coverage, measured by the RSRP of the CPEs during the trial, not only maintained but also experienced a significant increase as measured by the cumulative distribution function of RSRP CPE. These CPEs serve as gateways for wireless and wired devices, allowing all devices to connect to the global internet network. Fig. 5, the Cumulative Distribution Function (CDF) of RSRP for the threshold below −80 dBm improved from 65 % to 40 %, representing an approximate 25 % improvement compared to the conditions before the implementation of 5G FWA. The −80 dBm threshold is used to ensure signal strength of good quality, providing coverage distances of about 1.5 to 2.0 km from the base station to customer households by considering indoor penetration, and the measurement is taken from the outdoor drive test tool. This indicates that fewer CPEs receive signals below −80 dBm, which means a 25 % increase in signal strength coverage. This also shows that the trial not only maintained but improved the Cumulative Distribution Function of the threshold signal from before the trial. This means that 5G FWA is adequate to replace fiber optic coverage, which is typically measured from the customer distance to the Optical Distribution Point (ODP).

Subsequently, in terms of data speed observed using download throughput parameters, as shown in Fig. 7, there was a substantial increase, with the Cumulative Distribution Function of CPE throughput improving by 50 % for thresholds below 20 Mbps from 60 % to 10 %. This represents a significant enhancement in data transmission speeds across the network, with 90 % user satisfaction indicating customers experiencing data speeds below 20 Mbps. The 20 Mbps threshold is based on the data speed required to stream high-resolution internet video services. A minimum threshold of 50 Mbps was also measured to accommodate the use of more than one user simultaneously accessing internet video services, where the measurement results show 85 % of users will be satisfied.

Next result, the 2.41 % increase in Data of Usage (DoU) in Fig. 13 underscores the viability of 5G FWA as a primary internet service, reflecting increased engagement and users' reliance on the network. However, it does not yet consider the added capacity benefits of integrating 5G FWA, which will serve new potential customers. As is known, achieving mature traffic related to customer awareness of the existence of the 5G FWA network and their willingness to subscribe is not readily achieved during trials. This requires a grace period commonly referred to as time to market, followed by adjustments to the network capacity to be built. This necessitates more precise traffic forecasting and requires considerable time to understand customer behavior.

Lastly, with results on coverage, throughput, and data usage, during the network trial, the payload generated in the trial area saw an increase of about 27 %, as shown in Fig. 14. Based on estimates using price per megabyte, as shown in Fig. 15, revenue improvement was directly proportional to the payload increase around 27 %. This can be a reference for operators when investing in 5G FWA technology for massive implementation.

The limitation of this study is that the 5G FWA technology discussed mainly focuses on the wireless front end of internet service providers, connected to their customers with very early 5G FWA data traffic, which requires more mature and stationary data. Despite this, the limitation on the still early traffic dynamics related to capacity needs can be adjusted, typically through mechanisms for future capacity expansion. Nevertheless, this trial is sufficiently comprehensive to conclude service performance and network productivity parameters for replacing fiber solutions with 5G FWA technology. However, a shortcoming of this trial is that it is challenging to conduct end-to-end tests with 5G FWA services due to the very early adoption of technology, which prevents other network elements, particularly the Core and IT Network elements, from performing actual end-to-end 5G FWA services holistically. Typically, these core and IT infrastructures will evolve to form end-to-end services. This opens the door for alternative studies involving features operating in the core data network and IT network that manage internet service products at internet service providers or telecommunication operators in areas with mature 5G FWA traffic to further explore the performance of 5G FWA services from end to end. Such studies and research can be conducted to comprehensively assess the end-to-end impact from a network infrastructure perspective affecting the business in the internet service and telecommunications industry. Future research could focus on long-term user satisfaction and network reliability under various conditions and explore integrated services that combine FWA with other emerging technologies, such as Fixed Mobile Convergence (FMC), Internet of Things (IoT), and cloud computing. This holistic approach could unlock new business models and revenue streams for operators, driving forward the innovation and adoption of FWA globally by a hybrid product combination between mobile data service and fixed broadband in the future market.

7. Conclusions

1. The 5G Fixed Wireless Access (FWA) trial conducted in the Alam Sutra observation cluster has yielded valuable insights into the practical implications of 5G technology on broadband internet service delivery. The implementation of 5G FWA necessitates a substantial endeavor to enhance user experience to levels comparable with proposed fiber optic network solutions by reallocating the 2300 to 2400 MHz spectrum. This process demands meticulous reconfiguration of the wireless network, including the simultaneous use of the spectrum band for both 4G LTE and 5G FWA within the same service area. Strategic network planning and implementation are crucial to ensure that the transition supports existing services and optimizes the integration of new technology, thereby providing a user experience that fully harnesses the capabilities of 5G technology. This approach underscores the importance of thoughtful spectrum management and network design to achieve high-quality service delivery meeting the demands of modern internet users.

2. The pilot trial's development, planning, and implementation were rigorously conducted following a structured methodology that entailed comprehensive frequency reallocation. This process necessitated critical updates to hardware, software, and licensing frameworks to ensure that the network infrastructure was fully prepared to support the demands of the trial. These changes were not merely procedural but were strategically designed to enhance network performance and reliability, enabling precise measurement and optimization of network capabilities. By systematically implementing these enhancements, the trial setup was optimized to yield the most reliable data, thus providing a robust empirical foundation for evaluating the effectiveness of the frequency reallocation. This approach ensures that the findings are supported by quantitative data and reinforced by the integrity of the trial's methodology, which is critical for drawing credible and scientifically sound conclusions. The successful execution of these measures substantiates the reliability of the trial outcomes, thereby providing compelling evidence to support the efficacy of the network adjustments made during the pilot phase. This comprehensive and methodologically sound approach significantly contributes to the broader field of network management by demonstrating the practical implications of strategic 2300 to 2400 MHz frequency reallocation and network optimization.

3. Based on the successful measurements conducted, the performance of the 5G FWA service was analyzed based on potential users, coverage, data throughput, and other QoS parameters, as well as data of usage. Utilizing all these parameters on the 5G FWA network as equivalent benchmarks commonly used in analyzing broadband internet, including fiber optic networks, the reconfiguration of a wireless network with dual utilization of the 2300 to 2400 MHz spectrum for both 4G LTE and 5G FWA in a single service area has proven feasible and successful in trials to replace fiber optic networks, especially in areas where laying physical infrastructure is challenging or cost-prohibitive. From the results of the pilot trial measurements, it is evident that there has been an impressive increase in service coverage from -80 dBm from 65 % to 40 % based on the Cumulative Distribution Function (CDF), and a 50 % increase in download throughput, with a satisfaction rate of 90 % at data speeds exceeding 20Mbps or at the minimum threshold of 50 Mbps, with 85 % of users being satisfied. This demonstrates a substantial enhancement in internet speed and user experience in service coverage, two critical parameters that enable users to establish internet connectivity.

4. A techno-economic analysis has been conducted to assess the feasibility of the 5G FWA network revenue as an alternative broadband internet solution replacing fiber optics. Payload data usage indicates that the average data consumption per user could increase by approximately 27.20 % compared to existing 4G services, estimated to result in a 27.00 % revenue growth in network productivity through pricing per megabyte. This

dual-spectrum strategy enables operators to leverage existing infrastructure while transitioning to next-generation network capabilities, ensuring a smooth transition and continuous service improvement. This trial underscores the technical and revenue feasibility of 5G FWA and aligns with strategic business objectives by potentially broadening the consumer base and increasing market competitiveness.

Conflict of interest

The authors declare that they have no conflict of interest concerning this research, whether financial, personal, authorship, or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

The manuscript has data included as electronic supplementary material.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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