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The Use of Spectrum Refarming to Enhance 4G Capacity and Quality of Service in Mobile Telephony

Albert Neequaye Kotey
Department of Computer Science, Texila American University, Georgetown, Guyana

Abstract

The fast growth and demand for mobile broad band service has driven Telecom network operators to adopt an innovative approached to improve network capacity and enhance Quality of service in Mobile Telephony. The high demand of mobile broadband to pave way for Spectrum refarming which involves reallocating underutilized frequency bands (e.g., 2G/3G) to more advanced networks like 4G LTE. The research focus and objectives was to investigate the impact of spectrum refarming on 4G capacity and QoS improvement and examines the technical, economic, social and regulatory challenges associated with spectrum refarming. The study will follow a quantitave and comparative approach and data collection was conducted through structured questionnaires and distributed to Telecom engineers, IT specialist with hands-on experience in Telecom, regulatory authorities, supporting staff outside IT and Telecom space. The findings indicate that spectrum refarming can significantly enhance the 4G network capacity, improve quality of service and user experience though its implementation is often limited by technical and regulatory challenges and per the results received from the survey, (88.6%) of respondents acknowledged spectrum refarming will significantly improve 4G coverage and capacity, (6.85 %) believed it is not possible and (4.5%) were uncertain. The study also contributes to the field that provide actionable recommendation for telecom operators and policymakers to improve the spectrum management practices. Additionally, (81.8%) of the respondents reported spectrum sharing policy should be introduced to facilitate refarming ,11.4% didn't support the idea of spectrum sharing ,6.8% of respondents not sure and total Reponses were 40.

Keywords: *4G LTE, Network Capacity, Quality of Service, Spectrum Refarming, Underutilized Frequency.*

Introduction

The rapid increase of mobile telecommunications has steered to an exponential increase in demand for high-speed internet and seamless connectivity. With the rise of data-intensive applications such as video streaming, cloud computing, and IoT services, mobile network operators face challenges in ensuring sufficient capacity and maintaining high-quality service [1]. The most effective strategies to address these challenges is spectrum refarming, which involves reallocating frequency bands from legacy technologies (e.g., 2G and 3G) to more advanced networks like 4G LTE [15]. By optimizing existing spectrum resources, spectrum refarming enhances network capacity, improves spectral efficiency, and provides a better quality of service.

The growing demand for 4G services has placed enormous pressure on the mobile networks, particularly in urban areas where spectrum scarcity is a major concern. The traditional spectrum allocation procedures, which dedicate fixed frequency bands to specific technologies, are becoming inefficient as older technologies become obsolete while the demand for newer generations increases [7].

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Corresponding Author: albertnii2003@gmail.com

Spectrum refarming enables mobile operators to repurpose underutilized spectrum from legacy networks, thereby reducing congestion, improving data speeds, and enhancing overall network performance [9].

Additionally, regulatory bodies play a major role in facilitating spectrum refarming by setting policies that ensure a smooth transition while minimizing service disruptions. As mobile networks prepare for the eventual shift to 5G, the spectrum refarming continues to be a vital mechanism in ensuring the sustainability and efficiency of 4G networks [17]. This study discovers the role of spectrum refarming in enhancing 4G network capacity and quality of service, examining the technical, regulatory, and operational aspects that contribute to its effectiveness.

Limitations and Challenges

Regulatory Constraints in Spectrum Refarming

Regulatory constraints in spectrum refarming involve a combination of technical, financial and administrative measures aimed at reallocating frequency bands to more efficient technologies or new services. This process requires changing the apportionment of spectrum bands, which are limited and valuable resources, and often necessitates regulatory approvals to guarantee effective spectrum utilization and rational competition among operators [6].

Policy and Licensing Frameworks

The implementation of technology-neutral licensing regimes is a significant regulatory approach to facilitate spectrum refarming. Such regimes enhance competition by allowing license holders to evolve the technology deployed and the services delivered as markets develop. However, challenges such as artificially created scarcity of spectrum can hinder optimal usage, necessitating policy and regulatory interventions [27].

Spectrum Sharing and Efficiency

The Spectrum Management addresses methods of how spectrum can be used by operators and regulatory agencies efficiently. The deployment becomes smooth when network vendors have a strong engagement with regulators, which benefits them to increase and expand their coverage as a result of spectrum resource allocation by making use of existing frequency to deploy higher [17].

Achievements of Spectrum Refarming in 5G

1. **Cost Efficiency:** By repurposing existing spectrum, operators can reduce capital expenditures associated with acquiring new spectrum licenses. This approach allows for a more efficient use of current resources, leading to significant cost savings [3].
2. **Cost-Effectiveness:** Operators can increase capacity for newer technologies like LTE without the need to acquire additional spectrum through auctions, making refarming a cost-effective strategy [26].
3. **Accelerated 5G Deployment:** Refarming facilitates quicker 5G rollouts by reallocating spectrum from outdated technologies, enabling operators to meet growing demand more swiftly [28].
4. **Optimized Spectrum Utilization:** Dynamic spectrum refarming allows for the reallocation of spectrum from underutilized bands to more heavily used ones, ensuring that networks operate at peak efficiency and reducing operational costs [28].
5. **Improved Coverage and Capacity:** By reallocating spectrum from outdated technologies, operators can enhance both coverage and capacity of 5G networks, leading to better service quality [19].
6. **Better Quality of Service:** Users experience fewer call drops, increased

internet speeds, and improved overall connectivity [12].

Purpose of the Study

The objective of this study is to examine the role of spectrum refarming in enhancing 4G network (QoS). As mobile telecommunications evolve, demand for high-speed internet and reliable connectivity necessitates efficient spectrum utilization. With legacy networks such as 2G and 3G becoming obsolete, reallocating their spectrum resources to 4G LTE has emerged as a viable strategy to address spectrum scarcity and improve network performance [20]. The objective of the study aims to analyze the technical, regulatory, and operational aspects of spectrum refarming, identifying best practices and challenges associated with its implementation [15].

Specifically, the study tries to find:

Assess the Effect of Spectrum Refarming on 4G Network Capacity – By reallocating spectrum from legacy technologies, operators can enhance bandwidth availability and accommodate more users, thereby reducing congestion and improving data speeds [9].

Evaluate the Influence of Spectrum Refarming on Quality of Service – This involves examining improvements in key performance indicators such as download speeds, latency, and call drop rates following spectrum repurposing [12].

Identify the Regulatory and Policy Considerations – Spectrum refarming requires government and regulatory intervention to ensure a smooth transition and minimize disruptions to existing services. This study will explore frameworks and policies that facilitate efficient spectrum reallocation [15].

Examine Case Studies of Successful Spectrum Refarming Initiatives – Analyzing real-world implementations will provide insights into best practices, potential challenges, and lessons learned from mobile operators that have effectively adopted spectrum refarming [23].

By addressing these objectives, this research intends to provide a broad understanding of spectrum refarming and approach to improving 4G network performance while laying the groundwork for future 5G deployments. The outcomes of this survey will be valuable for network operators, policymakers, and telecommunications researchers in making knowledgeable decisions regarding spectrum management and optimization.

Problem to be Resolved

The increase growth of mobile broadband usage, driven by data-intensive applications, cloud computing, and IoT services, has led to increased network congestion and spectrum scarcity, particularly in urban areas. As a result, mobile network operators struggle to satisfy the rising demand for high-speed and reliable connectivity, leading to performance degradation, slower data speeds, higher latency, and deteriorating (QoS) [10].

A significant challenge in addressing these issues is the scarcity of spectrum resources, as many frequency bands remain allocated to legacy technologies such as 2G and 3G, which have seen declining usage [20]. While mobile Telecom operators continue to inject capital in network expansion, acquiring new spectrum is costly and subject to strict regulatory policies, making efficient spectrum management a necessity [15].

Spectrum refarming has developed as a potential solution to these challenges, allowing operators to reallocate underutilized spectrum from legacy networks to more advanced technologies like 4G LTE. However, several obstacles hinder the full implementation and effectiveness of spectrum refarming.

The novelty of this research lies in its unique approach to leveraging spectrum refarming as a strategic solution for enhancing 4G network capacity and (QoS) while ensuring a seamless transition to 5G. Unlike previous studies that focus on spectrum management in isolation, this research provides an integrated analysis of

refarming strategies, technological innovations, regulatory frameworks, and future implications for 5G networks. The key novel contributions include:

Integration of Dynamic Spectrum Sharing, (DSS) for 4G Enhancement

Unlike traditional spectrum refarming that involves complete frequency band reallocation, this study incorporates DSS, to allow multiple mobile generations (2G, 3G, 4G) to coexist within the same spectrum. This enables a gradual transition to 5G while maximizing 4G performance [23].

AI-Driven Spectrum Refarming Optimization

This research explores how Artificial Intelligence and Algorithms for machine learning can optimize spectrum allocation by analyzing real-time network traffic, device compatibility, and frequency interference. AI-driven spectrum optimization is a recent advancement that improves spectrum efficiency and reduces QoS degradation [9].

Comparative Analysis of Global Spectrum Refarming Policies

Unlike conventional studies focusing on a single regulatory environment, this research conducts a comparative analysis of spectrum refarming policies across different regions (e.g., the FCC in the U.S., Ofcom in the UK, and TRAI in India) to determine the best regulatory practices for optimizing 4G networks [16].

Impact Assessment on 4G QoS and Network Performance

The research introduces an empirical evaluation framework that measures the real-world impact of refarming on 4G network throughput, latency, coverage, and user experience. Unlike prior research, this study provides quantifiable benchmarks to evaluate improvements in QoS metrics [7].

Future-proofing Refarmed Spectrum for 5G Expansion

Most studies treat 4G and 5G as separate network transitions, but this research highlights how refarmed spectrum can work as a tie between LTE-Advanced Pro (4G) and 5G. It evaluates strategies for co-existence between Long Term Evolution and with the 5G New Radio in refarmed bands [14.

This research offers a novel contribution by integrating spectrum refarming with AI, DSS, regulatory benchmarking, and QoS analytics to maximize 4G network capacity and service quality. It also gives the opportunity for a smoother shift to 5G, ensuring efficient utilization of limited spectrum resources.

Materials and Methods

Research Design

The study adopts a qualitative research design on spectrum refarming to enhance 4G capacity for the improvement of QoS using online open-ended questionnaires. The quantitative approach was considered appropriate for capturing diverse view of major key stakeholders which allows a thorough exploration of technical, policy, social and economic issues [8].

Participants

The target population consist of direct and indirect experts with professionals such as telecom engineers, network engineers, IT specialist, regulatory authorities, supporting staff in the telecom space. The participants were selected using purposive sampling to ensure the people in right skills of specialization in relation with subject matter area with the requisite professional experience in the respective domains are chosen.

Research Instruments

Online questionnaire was used as primary research instrument for data collection. The questionnaires were designed for close-ended question and multiple questions which allow

participants and professionals in the telecommunication sector, including telecom engineers, regulators and IT professionals, regarding their perception on spectrum refarming and its impact on 4G network performance in relation to capacity, coverage and QoS.

The key questions that were focused on:

1. The concept of spectrum refarming?
2. The level of understanding of spectrum refarming?
3. Whether spectrum refarming can significantly improve 4G network coverage and capacity?
4. Telecom operator's priority of spectrum refarming over acquiring new spectrum bands?
5. How the spectrum sharing policies should be introduced to facilitate refarming?
6. The role government should play in supporting spectrum refarming?
7. The challenges face by operators when implementing spectrum refarming?
8. The biggest economic barrier to spectrum refarming?
9. What improvements would you like to see in your 4G service after spectrum refarming
10. Do you think spectrum refarming will pave way for a smooth transition to 5G?

Table 1. Summary of Key Relevance Questions

Question	**Purpose & Relevance**
How familiar are you with the concept of spectrum refarming?	Accessing the baseline knowledge and professionalism engagement in the subject
What is your level of understanding of spectrum refarming?	Respondents to have conceptual understanding and how it is related to capacity, coverage and QoS.
Do you think spectrum refarming can significantly improve 4G network capacity and coverage?	To explore the effectiveness of refarming as a strategy to improve coverage and QoS.
Should mobile operators prioritize refarming over acquiring new spectrum?	The spectrum resources are limited, expensive, underutilized and refarming addresses the cost benefit and operational expenses faced by operators & regulators.
Do you think spectrum sharing policies should be introduced to facilitate refarming?	To provide a regulatory framework and support dynamic spectrum management by introducing policies that will reduce barriers and encourage collaboration.
What role should government play in supporting spectrum refarming?	Government should develop refarming policies guidelines, transparent, regulatory process and bringing stakeholders together in resolving disputes pertaining to spectrum refarming.
What challenges do you think operators face when implementing spectrum refarming?	To allow respondents to share experiences or insights that may delay or hinder refarming process. This may include resistance from stateholders, intereference management and high transition cost.
What is the biggest economic barrier to spectrum refarming?	To understand economic dimension of refarming & pinpoint barriers such as high

	capital expenditure, lack of financial incentives and regulatory fees.
What improvement would you like to see in your 4G service ?	To capture user feedback on the current states of 4G services and identify service gaps, highlight priority areas for future development and provide insights to customer satisfaction.
Do you think spectrum refarming will prepare the way for a smooth transition to 4G?	To serve as a best method for the transition to 5G technology and evaluate stakeholders confidence as a preparatory step for the future network upgrade

Data Collection Procedure

Data were collected using a semi-structured, close-ended questionnaire designed on Google Forms. The questionnaire included questions that explored respondents' understanding of spectrum refarming, the perceived benefits and challenges, and its impact on 4G network performance capacity, coverage, and QoS. close-ended questions allowed respondents to elaborate freely, which is essential in qualitative inquiry [22].

Participation was voluntary, and respondents were informed about the confidentiality of their responses and the overview of the study. Reminders were sent weekly to enhance the response rate and encourage participation from underrepresented groups.

Basically, research findings should be generalizable to the populace from which the sample is drawn i.e., the sample must accurately represent the population [24].

Google forms was used for data collection and secure storage of responses ensuring ethical compliance by embedding an informal section and ensuring participant anonymity.

Results & Discussion

Q01. Age Category of Respondent

The age group of the respondents exhibits majority of the participants are within the middle age working group. This age category of respondents is considered to be more experienced and professionally active in the telecommunication and IT sectors.

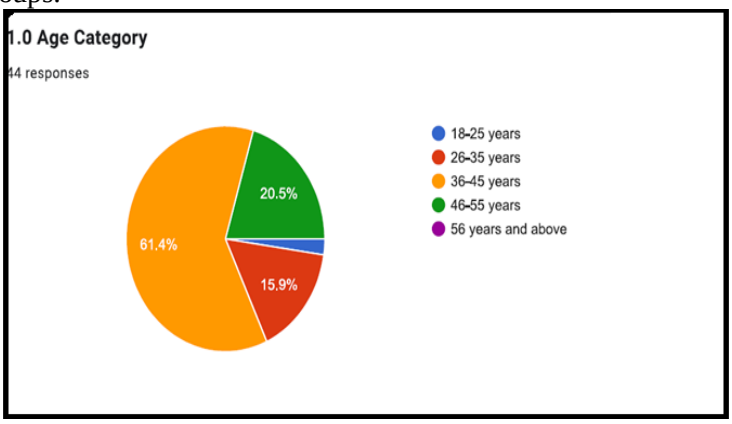

Figure 1. Age Group

The questionnaire garnered 44 responses with 61.4% respondents with age category of 36-45 years gaining the maximum participation as indicated in Figure 1 above.

The 36-45 years was age group representing 61.4% respondents. This shows that a significant portion of participants are in the mi-d level stage having technical, regulatory or managerial skills making their contribution

highly invaluable for the study on spectrum refarming and 4G quality of service.

Age group of 46-55 years' account to 20.5% of the sample and this likely include Mid-level such as senior professionals and decision makers such as policy makers or seasoned engineers with rich experience in the telecom industry and IT space.

The 26-35 years comprising of 15.9% is made of early career professionals who are in technical roles and emerging leadership positions. Their perspective offer insights into operational challenges expectation for future development.

The 18-25 years represents 2.3% of respondents and this category indicating minimal participation from recent graduate trainee and this may reflect the specialized nature of the topic which requires technical & regulatory understanding.

The was no respondents above 56 years and this may due to lack of participation from professionals close to retirements.

Q02. Field of Study

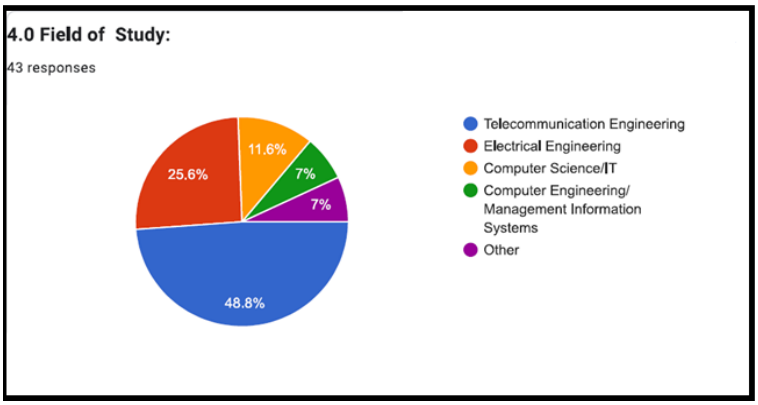

Figure 2. Field of Study

The respondents of this study come from a variety of academics & professionals within the engineering technology disciplines with 43 responses as indicated in figure 2. above.

Telecommunication Engineering (48.8%)

The dominant field of study for this research is the telecom engineers having almost half of the respondents with background align with the core subject of the research with technical expertise in spectrum usage, radio frequency planning and mobile network infrastructure [2].

(Electrical Engineering (25.6%)

A substantial portion of the participants was from electrical engineering space related to the telecommunication industry. These individuals often work in areas in such as signal processing, network systems & infrastructure and making their input relevant to the meaning of spectrum management and network performance [25].

Computer Science /Information Technology (11.6%)

This category of group has professionals in software and digital systems that contribute into how spectrum refarming may impact data services, and backend systems supporting 4G and future 5G services. [7].

Computer Engineering & Management Information Systems(MIS) (7%)

These respondents provide a combination of skilled persons in hardware, software and business systems which can be useful in understanding the operational, data handling and administrative challenges in deploying spectrum refarming and enhanced networking services [4].

Others (7%)

This respondent may come from non-technical areas such as economics, policy

studies, business offer valuable insights into strategic, economic framework and regulatory that impact spectrum policy and industry decisions [18].

Table 2. Summary of Key General Information and Current Network Experience Questions

Question ID	Question text	Response Option-1	Response Option-2	Response Option-3	Response Option-4
Q06	How familiar are you with the concept of spectrum refarming?	Very familiar [69.8%]	Somewhat familiar [30.2%]	Not familiar	
Q07	Which Mobile network operator do you often use?	MTN [65.1%]	Telecel [16.3%]	AT [11.6%]	Other [7%]
Q08	Which type of mobile device do you use?	Smartphone [97.7%]	Other [22.3%]	Basic Phone	Tablet

Table 3. Summary of Key Current Network Experience

Q09	How will you rate the coverage of your 4G Network?	Excellent {22.7%]	Good [54.5%]	Average [20.5%]	Poor [2.3%]
Q10	Do you experience network congestion during peak periods?	Yes [52.3%]	No [20.5%]	Sometimes [27.03%]	
Q11	What is the most common network issue you face?	Slow Internet Speed [68.2%]	Call Drops [9.1%]	Poor Coverage [9.1%]	Other [11.4%]

Q06: A total of 43 responses according to Table 2. above, out of which (69.80%) respondents were fine with the concept of refarming and (30.20%) of respondents are somewhat familiar and (0.00 %) not familiar. The results indicate clearly that respondents are professionals from telecommunication engineering and IT space who have greater knowledge in spectrum refarming.

Q07: The respondents in this category were using MTN network which has (65.1%) of the 43 responses, Telecel (16.3%), AT (11.6%) and Other (7%).However as at end of July 2024 MTN has gained the largest market share of subscriber base which culminated to 75.33%, Telecel Ghana had a 17.7% of the market share and AT with 7.51% of the current subscribers' market share and this was a true representation of the results by the respondent according to Table 2. [21].

Q08: According to Table 2, appreciable number of the respondents used smartphone as mobile device which contribute to 97.7% above average compare to other devices such as Basic Phone (0%.00), Tablet (0.00%) & Other (2. 3%).In a nutshell, Smartphone is the most used device for communication and once spectrum refarming is deployed, it creates opportunity for users to upgrade their mobile devices which in turn will increase the usage of smartphone devices.

With reference to Table 3, many of the participants had good 4G coverage representing 54.5% compared to 22.7% of excellent coverage and this depend on the type of mobile networks the respondents have subscribed to for better services. Moreover,

majority of the respondents admitted they have congestion of (52.3%) at peak period and No congestion represents (20.5%) with sometimes congestion of (27. 3%).Spectrum refarming when implemented by operators will increase capacity and minimize network congestion. In additionally, with respect to Table 3, the greatest network issues faced by respondents was slow internet since majority of them experience issues due to congestion at peak hours which impact slow data due to capacity constraints. Refarming of GSM bands to be deployed to improve 4G coverage and capacity enhancing quality of service.

Key Technical Questions

Q15.0 Which of the following is a major technical challenge faced during spectrum refarming?

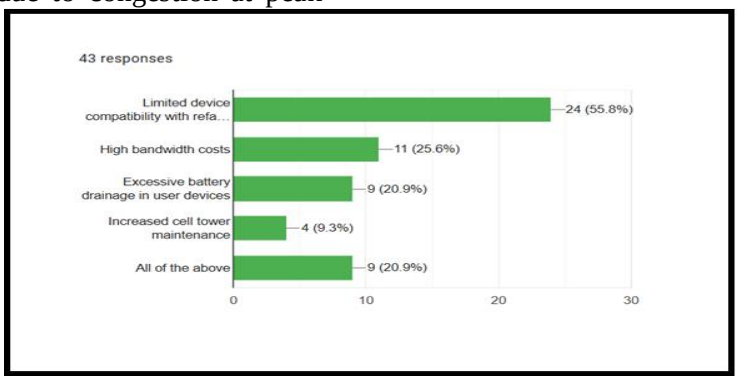

Figure 3. Technical Challenges

Q15: From Figure 3 above, responses from 43 participants were received as the major technical challenges faced during spectrum refarming. The key issue identified represents (55.8%) which is the limited device compatibility with refarming bands. The challenge becomes critical because, following spectrum refarming data traffic volume is likely to improve significantly if device compatibility is considered as priority at early planning stage enabling users to purchase handsets that support the newly deployed frequency bands. Also, high bandwidth cost pose threat to operators in securing required spectrum for deployment.

Q18.0 What type of network optimization strategies should accompany spectrum refarming?

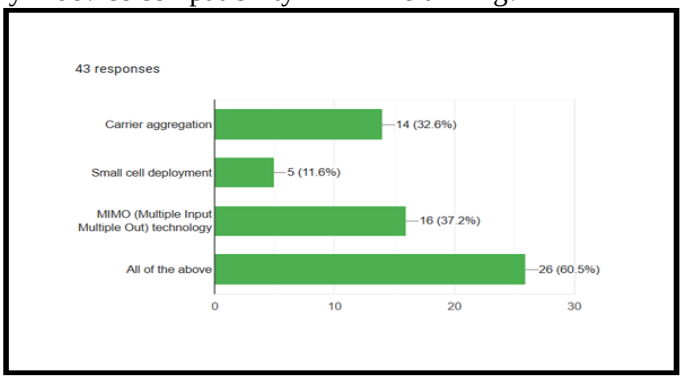

Figure 4. Optimization Strategies

Q18. According to Figure 4 above, the survey results shows that (60.5%) of respondents believe that combination of the strategies including carrier aggregation, small cell deployment and Multiple –Input Multiple-Output should be employed. The (37.2%) of respondents pointed out MIMO as key enabler to increase spectral efficiency and improve signal quality. Meanwhile, (32.6%) favored carrier aggregation since it affords the

operators the opportunity to combine multiple frequency bands to create more channels to boost data throughput and (11.6%) of the respondent emphasized small cell deployment to improve coverage and capacity at high traffic are

Key Regulatory Questions

Q24. What are the key regulatory barriers to implementing spectrum refarming?

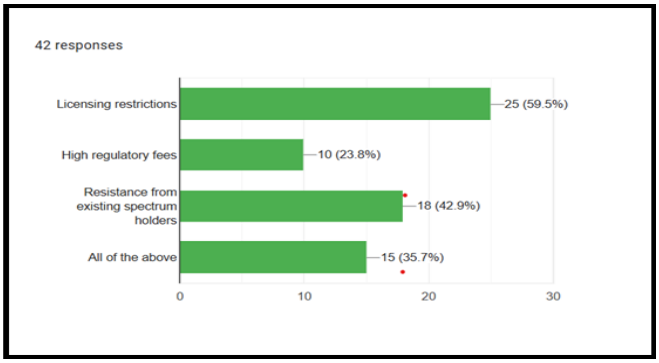

Figure 5. Regulatory Barriers

From the Figure 5 above, the outcome of the study shows significant regulatory to the implementation of spectrum refarming as indicated in the survey results, (59.5%) of respondents identified licensing restrictions as the most critical. Additionally, (42.9%) of the respondents pointed to resistance from incumbent spectrum holders who reluctantly fails to release existing allocation due to vested commercial interest of operational service disruption. (23.9%) cited high regulatory fees which discourage operators from engaging refarming initiates in spite of the gains.

Q27. What role should government play in supporting spectrum refarming?

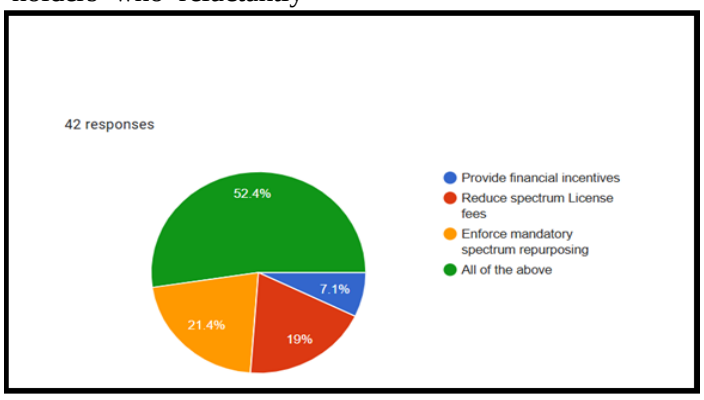

Figure 6. Government Role

From Figure 6 above, survey results indicate that the function of government is considered as pivotal in processing successful spectrum refarming. A (52.4%) of respondents selected All of the above suggesting that, a complex approach involving both regulatory and financial strategies was most effective. Moreover, (21.4%) of the participants suggest the government to enforce mandatory spectrum reallocation policies ensuring the underutilized spectrum band will be reassigned for efficient use of 4G or 5G. (7.1%) point to the significance of financial incentives to encourage infrastructure upgrades and adoption of new technologies.

Key Economic & Social Questions

Q31. Will spectrum refarming lead to increase investment in mobile broadband infrastructure**?**

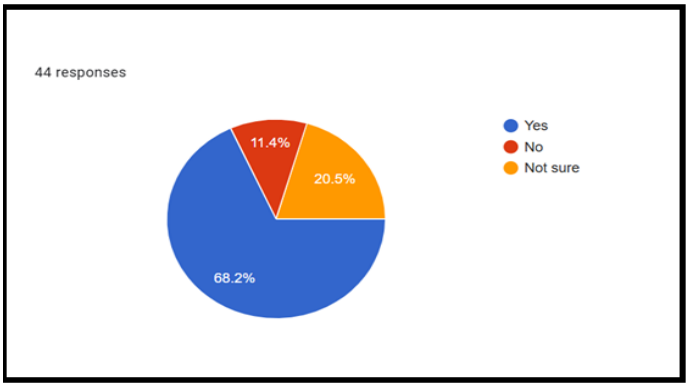

Figure 7. Investment in Broadband

Base on the Figure 7 above, (68.2%) of respondents agreed that refarming would lead to increase investment, while (11.4%) disagreed and (20.5%) was uncertain. Spectrum refarming not only enhances spectrum efficiency but accelerate in improving QoS and digital inclusion.

Q34. How will better 4G coverage impact social and economic activities in your region?

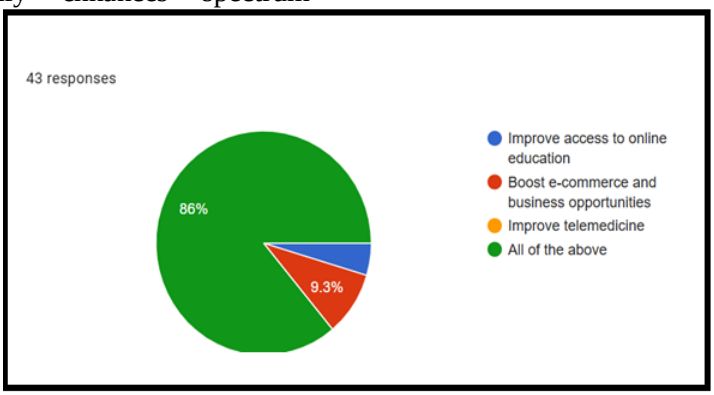

Figure 8. 4G Coverage

According to the survey results from Figure 8 above, (86%) of respondents selected All the above showing a strong census that enhanced broad band to have multiple interlinked benefits. (4.7%) of respondents noted that it will bring access to online education in the remote areas and bridging the educational gaps. (9.3%) of respondents pointed out how 4G coverage will boost e-commerce and business opportunities enabling entrepreneurs to adopt digital financial service and reach out to broader markets.

Conclusion

The study explored stakeholders' perception on the role of spectrum refarming in enhancing 4G network capacity and improving QoS and responses to questionnaires from professionals in telecommunication, IT, Regulatory in addressing the network constraints in spectrum refarming.

Moreover, the responses affirm that spectrum refarming is seen as practical solution to improve 4G performance and would increase investment in mobile broadband infrastructure.

Limited device compatibility, license restriction and high regulatory fees are barriers to implementation of spectrum refarming and requires the intervention of regulators in supporting the process through policy enforcement, cost reduction and financial incentives.

In addition, the results from survey participation indicates that improved 4G coverage will positively affect economic, social sectors with strong support for its impact on

online education, business growth and digital inclusion.

Finally, the spectrum refarming serve as a foundation for a smoother transition to 5G by optimizing existing frequency and reducing the need for entire spectrum acquisition.

Conflict of Interest

I Albert Neequaye Kotey hereby declared that, there is no conflict of interest regarding this research work

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