FACULTY OF INFORMATION TECHNOLOGY

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Project 1

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Table of Contents

Question 1: Report on the Status of 5G Networks in South Africa

Introduction

Imagine a future for South Africa where every one of its citizens has access to incredibly fast internet no matter where they are in the country. Imagine this fast internet allowing people to access real-time healthcare, have smooth and easy virtual education, and empower thriving digital economies.

The fifth generation (5G) networks have recently emerged in South Africa, enabling the country to continuously innovate and grow in socioeconomics. Telkom, one of South Africa’s largest telecommunications providers, had established a partnership with Huawei in 2022 and joined the 5G market, that already had Vodacom, MTN, and Rain competing in it. While many urban areas have thrived on 5G deployments, million other rural areas have been missing these deployments due to economic, infrastructure, regulatory, and policy challenges (Xulu & Malatji, 2025). Now that Telkom has already deployed more than 340 active 5G sites providing services to 8.5 million people, they are intending on expanding their network to cover other areas in provinces like Limpopo, Northwest, Northern Cape, Eastern Cape, Mpumalanga, and the Free State (Malinga, 2023).

This report evaluates the current state of 5G adoption in South Africa. It focuses on analysing the challenges and opportunities that come with deploying 5G in underdeveloped provinces. Moreover, this report assesses how the national regulatory framework influences the pace and success of 5G implementation. Lastly, it provides strategies and recommendations to Telkom on how they can expand their 5G networks to rural areas.

1.1. Adoption and Implementation Trends of 5G in South Africa

The telecommunications sector of South Africa has adopted and commercially launched fifth generation (5G) mobile networks in South Africa, and 5G has ever since become a strategic priority for other large network service providers like Vodacom, MTN and Rain. Up to 2025 Telkom had been operating more than 340 active 5G sites reaching more than 8.5 million people across South Africa (Malinga, 2023).

Telkom's 5G implementation in South Africa has followed a multi-phased, metro-focused approach. Their 5G implementation prioritised urban and economically advanced provinces in the country. These provinces included Gauteng, Western Cape, and KwaZulu-Natal. These three provinces were prioritised over others due to their higher population densities and higher economic growth. Rural provinces like Limpopo, Northwest, Northern Cape, Eastern Cape, Mpumalanga, and the Free State, on the other hand, have remained undeserved due to limited infrastructure, costs, and logistical challenges (Xulu & Malatji, 2025). More importantly, major policy and regulatory challenges have led to network rollouts being disproportionately focused on urban provinces.

Despite these persistent challenges, 5G continues to grow in South Africa. In March 2022, the ICASA telecommunications regulator completed a delayed auction to sell high-demand spectrums with a successful revenue of R14.4 billion (Dumako, 2023). This would allow 5G adoption to spread wider across the country and network operators to access high-demand spectrum bands important for 5G deployment like 400 MHz, 800 MHz, 2.6 GHz, and 3.5 GHz bands.

Market adoption remains uneven in South Africa. Access to 5G networks is still restricted primarily to wealthier users, due to 5G devices and data being unaffordable for the public overall. Access to 5G networks will remain limited to low-income provinces until 5G devices and data become generally more affordable.

1.2. Challenges & Opportunities for Deploying 5G in Remote Provinces

Challenges

Infrastructure Limitations: Limpopo, Northwest, Northern Cape, and eastern Cape continuously face several infrastructural challenges. The core challenges they face include low tower density, weak power infrastructure, and a lack of fibre-optic cables. Because 5G rollout heavily relies on dense network infrastructure and reliable electricity, it cannot be accomplished with 100% success in these provinces (Rahman *et al*., 2021).

Power Instability: Lack of reliable electricity has been a long ongoing crisis in South Africa. Frequent load shedding negatively affects base station uptime and increases operational costs at these stations. As a result, these stations need increased investments in battery backups, generators, and other power source alternatives.

Device Accessibility: 5G smartphones and data remain unaffordable by South Africa's overall population. Most rural residents use entry-level devices that are incompatible with 5G. This significantly reduces the expansion of networks in rural areas (Hira *et al*., 2024).

Geographic and Topographic Barriers: Sparse populations and difficult terrain significantly increases the difficulty and cost of deploying 5G infrastructure in rural provinces (Ahmad *et al*., 2024). Moreover, it makes 5G network expansion in these provinces less attractive for investments by private investors without government incentives.

Opportunities

Fixed Wireless Access (FWA): Telkom can use FWA to provide faster and more reliable internet for houses and businesses in rural areas without needing to spend on more expensive fibre. This will be the most suitable for farming communities, schools, and clinics in rural areas with limited broadband options and difficult terrain for cable laying (Victor-Ikoh & Moko, 2021).

Government Collaboration and Public-Private Partnerships (PPPs): Telkom can achieve rural expansion easier by working with the Department of Communications and Digital Technologies and being allowed access to Universal Service and Access Fund (USAF) grants. Moreover, PPPs can be formed to utilise existing municipal infrastructure and attract investments (Ahmad *et al*., 2024).

Socioeconomic Upliftment: Economic development can be initiated when Telkom deploys 5G in rural provinces. This will allow e-commerce, digital education, precision farming, and telemedicine to develop and advance in these provinces. This long-term value would further justify the high initial investment of 5G networks in rural provinces (Gigaba *et al*., 2025).

Network Sharing Models: Telkom operators can adopt infrastructure sharing models to reduce the cost of deployments in remote areas. Telkom can share towers, fibre backhaul, and power infrastructure with other operators as well. This can make their 5G network expansion feasible in low Average Revenue Per User (ARPU) areas (Gedel & Nwulu, 2021).

1.3. The Impact of the Regulatory Framework

Supporting Factors

Spectrum Allocation by ICASA: ICASA's spectrum auction in March 2022 was a success. For the first time in over a decade, operators in South Africa were able to legally and transparently receive spectrum that were high in demand, like 700 MHz, 800 MHz, 2.6 GHz, and 3.5 GHz. The release of these bands improved the technical feasibility of 5G deployment in urban and rural areas.

Government Commitment to Digital Transformation: The National Digital and Broadband Strategy highlighted the importance of connecting rural and underserved areas and how important it is for South Africa's development. This complements Telkom's goal of expanding 5G beyond urban areas.

Licensing Flexibility: ICASA provided a temporary spectrum relief after the Marh 2022 auction. This allowed operators to test and deploy 5G pilot programmes. Continued licensing flexibility could also Telkom help speed up 5G network expansion to rural areas.

Hindering Factors

Bureaucratic Delays and Municipal Red Tape: Bureaucratic matters, such as approval processes for tower construction and right-of-way permissions, are all factors that hinder and delay network rollout. Additionally, these administrative delays slow down the deployment of 5G infrastructure tremendously (Du Plessis, 2022).

Lack of Incentives for Rural Deployment: The deployment of 5G networks in rural areas require subsidies and tax incentives to be commercially attractive while 5G deployment in urban areas have always been commercially feasible and viable. As of today, there remains a lack of proper incentives from the South African government to expand 5G networks to rural areas (Dumako, 2023).

Unstable Policy Environment: The Department of Communications face frequent changes in policy leadership and direction. This creates a lot of policy uncertainty. Moreover, it negatively impacts the confidence of investors in their long-term plans and investments in 5G infrastructure.

Conclusion

Telkom is in a good spot. They can speed up the rollout of 5G networks in South Africa. However, the successful expansion of 5G networks to rural areas will rely heavily on overcoming several financial, infrastructure, and regulatory challenges. Telkom’s 5G expansion to rural areas can be made easier when they adopt innovative models like Fixed Wireless Access (FWA) and couple it with strategic public-private partnerships (PPPs) and incentives from the South African government. Several strategies can be recommended to Telkom to successfully expand 5G to Limpopo, Northwest, Northern Cape, and Eastern Cape; prioritise FWA as primary deployment, partner with local municipalities to streamline 5G infrastructure access, utilise USAF grants and incentives, collaborate with other service providers to allow the sharing of 5G infrastructure, and advocate for improved rural power infrastructure.

Question 2: Business Case - 5G Expansion to Underserved Provinces

2.1. Executive Summary

Telkom's 5G network expansion into underserved provinces like Limpopo, Northwest, Northern Cape, Eastern Cape, Mpumalanga, and the Free State, presents an opportunity of strategic growth with significant potential in long-term value and revenue. Upfront costs are expensive, but the long-term revenue will make up for it and it will help Telkom achieve their goals; digital transformation across the country, meeting customer demand, revenue growth from fixed wireless access (FWA), improved enterprise services, and digital innovations.

2.2. Objective

The purpose of this business case is to assess the return on investment (ROI) of 5G infrastructure deployment in underserved provinces. This will be done by analysing the long-term financial sustainability, subscriber growth, and service monetisation in these provinces.

2.3. Investment Overview

The investment of Telkom's 5G networks will be overviewed by estimating the initial cost per province and adding these costs into a grand total. The estimated initial cost per province will include three main costs. Firstly, the deployment of 5G infrastructure like towers, backhaul, and power backups will cost a total of approximately R150 million. Secondly, the cost of staffing, licensing, and compliance will add up to approximately R20 million. Lastly, the cost of marketing and subscriber acquisition will add up to approximately R10 million. The total estimated cost of all 6 underserved provinces will sum up to a total of R1.08 billion.

2.4. Revenue Streams

Revenue streams will be calculated. This will be done by firstly calculating the total revenue from subscriber growth, then calculating the total revenue from new streams.

To calculate the total revenue from subscriber growth, four steps will be taken. Step 1 will be to find the target subscriber count. The target will be approximately 75 000 subscribers per province in three years. This will add up to an approximate of 450 000 total subscribers across the country in three years. Step 2 will be to estimate the average revenue per user (ARPU) (Betancourt, 2021). The ARPU will be estimated to be R300/month. This will include fixed wireless access (FWA) and mobile data. Step 3 will calculate the annual revenue from subscriptions (Chiaraviglio *et al*., 2017):

$$R300/month\ \times 450\ 000\ subscribers\ \times 12\ months\ = R1.62\ billion/year$$

Step 4 will be to estimate the projected churn rate. It will be estimated to be less than 10% due to regional competition being limited.

To calculate the total revenue from new streams, three steps will be taken. In Step 1, enterprise 5G applications will be identified. These applications will include agriculture, mining, logistics, healthcare, and education (Maman *et al*., 2021). In Step 2, the annual revenue per year from enterprise contracts in all six underserved provinces will be estimated and calculated. It will be estimated as follows:

$$20\ clients/province\ \times\ R1\ million/year\ per\ client \times 6\ provinces = R120\ million/year.$$

In Step 3, the annual revenue from content delivery and streaming partnerships will be estimated. These will include bundled streaming services like Telkom + Netflix, advertising revenue from localised content, and partnerships with e-learning platforms like Telkom + vossie.net. The revenue share from these partnerships could be calculated as follows:

$$R10\ per\ user/month \times 12\ months\ \times 450\ 000\ subscribers = R54\ million/year.$$

The total estimated annual revenue will be calculated by adding the total revenue from subscriber growth to the total revenue from new streams. This total estimated annual revenue will add up to be R1.674 billion/year.

2.5. Cost-benefit Analysis

A Cost-benefit analysis will be performed to compare the projected financial benefits of the 5G expansion project with the estimated costs. This analysis will assist Telkom in evaluating whether this investment will be financially feasible. It will also help them determine the expected return on investment (ROI). Moreover, it will help them estimate how long it will take to recover the initial costs for their 5G expansion project. Overall, this analysis will support Telkom's informed decision making by pointing out the potential profitability as well as the potential risks of their expansion project (Jassim *et al*., 2024).

Metric	Amount (R)
Initial Investment	R1.08 billion
Estimated Annual Revenue	R1.674 billion
Breakeven Period	More or less 8 months
ROI (Year 1)	More or less 70%
ROI (Year 3)	More than 250%

2.6. Risk Considerations

Telkom's 5G network expansion presents significant potential in revenue growth. However, there are four significant risks identified to this expansion project that will need to be managed.

Power Supply Issues: Network uptime will be frequently disrupted by load shedding and power outages. Investing in solar and other backup power systems will be essential for Telkom to provide consistent and reliable 5G telecommunication services and keep up their 5G infrastructure.

Device Affordability: Expensive 5G-enabled devices will limit user 5G adoption significantly. To make 5G device price reduction feasible, Telkom will have to partner with reliable manufacturers and design proper device financing plans (Forge & Vu, 2020).

Regulatory Delays: 5G rollout will be slowed down dramatically by spectrum allocation delays as well as delays in permits. Telkom will need to proactively engage with regulators to reduce these delays (Bauer & Bohlin, 2022).

2.7. Strategic Justification

Telkom’s 5G network expansion to rural provinces will greatly align with their main goal of national digital inclusion. Three additional key points can be pointed out to strategically justify their 5G expansion to rural provinces. Firstly, this expansion will reduce the digital division between urban and rural provinces (Lappalainen, 2021). This will strengthen Telkom’s competitive position in the telecommunications service market. Secondly, 5G expansion to rural provinces will put Telkom in a position of leadership for rural digital transformation. This position in leadership will bring significant potential for long-term cost savings, increased market share, and customer loyalty (Campbell *et al*., 2017). Lastly, Telkom will generate increasing long-term savings. These long-term savings would come primarily from energy-efficient 5G infrastructure.

Conclusion

Telkom’s initial investment costs for their 5G expansion to rural provinces will be expensive at first. However, the ROI projections show potential for high profitability within the first year of 5G expansion. Telkom will be able to achieve sustainable growth, new revenue streams, and a massive advantage in the telecommunications service market, if they manage and mitigate associated risks effectively. Overall, Telkom will generate an ROI of over 250% after three years of implementing their rural 5G expansion project.

Question 3: 5G Network Design Strategy for Platinum Valley SEZ

To address the community's concerns and fully leverage the benefits of 5G in Platinum Valley SEZ, the network must be designed with security, privacy, and resilience as core principles. The following strategy will implement Zero Trust Architecture (ZTA), network slicing, edge computing with encrypted processing, AI-driven threat detection and automated response, environmental resilience, privacy-by-design principles, and community engagement with transparency.

3.1. Zero Trust Security Architecture (ZTA)

The Zero Trust Architecture (ZTA) is a network security model that follows the principle of "never trust, always verify". In this network security model, there is no implicit trust. This means that every user, device, and application, whether internal or external, needs to be authorised, authenticated, and continuously validated. This model also implements network micro-segmentation. This means that the network gets divided into multiple secure segments (Stafford, 2020). These segments isolate sensitive traffic and prevent attackers from moving laterally through the network in case of breaches. Moreover, this security model implements multi-factor authentication (MFA) and strong encryption across all layers of the network: the device, transport, and application layer (Alappat, 2023).

3.2. Network Slicing for Security & Performance

Dedicated network slicing can be implemented. This will allow multiple virtual networks to be created on a shared 5G infrastructure. Each network slice can be specifically configured according to security, latency, and bandwidth requirements of different use cases. Implementing network slicing will ensure that traffic gets securely isolated, cross-slice interference and data leakage gets prevented, and that performance can be improved for critical services in the network. Moreover, network slicing will allow each network slice to have their own customised security policies based on their sensitivity and risk level (Afolabi *et al*., 2018).

3.3. Edge Computing with Encrypted Processing

Multi-access Edge Computing (MEC) nodes can be deployed close to their users. Firstly, deploying MEC nodes will help reduce the need to send data to distant data centres as well as reduce latency significantly. This will be essential Platinum Valley's real-time applications like industrial automation and remote monitoring (Shahzadi *et al.*, 2017). Additionally, encryption can be implemented at the edge. This will protect sensitive data and resources during storage and processing. This will also limit the exposure of data during transmission. Data security and privacy will be improved overall while performance will also be complemented for operations that are sensitive to latency (Porambage *et al.*, 2018).

3.4. AI-driven Threat Detection & Automated Response

AI/ML-based security tools should be integrated. These tools will help them effectively monitor traffic, and detect anomalies and cyberattacks like malware, DDoS attacks, and unauthorised intrusions. These tools will use automated response to these attacks, by sending alerts, isolating the affected network segments, and blocking traffic to other segments. This will help reduce lateral movement across the network. This entire proactive approach will speed up response times, slow down downtime, and ensure automated security and resilience within the entire network. These AI-based tools will also improve as they will learn and adapt to evolving cyber threats, increasing the overall adaptability of the network's security (Khan *et al.*, 2024).

3.5. Physical & Environmental Resilience

Hardened base stations should be built in areas of the network that have high levels of risk. These base stations can also be used with secured enclosures, tamper-proof equipment and CCTV monitoring tools. This will help prevent vandalism and theft for Platinum Valley's community. Additionally, they can install battery backups and/or solar panels to counteract against load-shedding and power outages (Tang *et al.*, 2021). Lastly, redundant links and self-healing protocols can be employed to maintain uptime in events of natural disasters or hardware failures. This will ensure that service disruptions will be minimised (Santos *et al.*, 2016).

3.6. Privacy-by-Design Principles

Privacy should be integrated into 5G networks from the outset. Only the minimum necessary data should be collected, and they should be secured using end-to-end encryption. This will ensure that anonymity can be applied wherever necessary. Additionally, users should be given clear control over their own data. This can be effectively achieved by properly configuring transparent privacy settings and consent options. Lastly, 5G networks need to comply with South Africa's Protection of Personal Information Act (POPIA), as well as align with global standards like GDPR. This will ensure that user trust and legal compliance will be maintained throughout the 5G network's lifecycle (Chitimira & Ncube, 2021).

3.7. Community Engagement & Transparency

For 5G rollout to be achieved successfully in Platinum Valley, its community's trust will need to be gained first. This can be done by hosting awareness sessions and workshops to educate and residents businesses. They can be educated about benefits, risks, and safety of 5G technology (Abdulwahab & Iyer, 2025). Transparent updates can also be provided for security practices, network operations, and data usage policies. Lastly, user-friendly dashboards will have to be provided for improved service control and privacy. This will ultimately people of Platinum Valley to easily manage their digital profiles. They will be given a sense of trust, accountability, and inclusion (Åkesson, 2020).

Conclusion

Embedded security and resilience should be implemented into every layer of 5G architecture; logical, physical, and operational layer. The strategy for improved 5G network deployment should include several steps to be effective. Zero Trust Architecture (ZTA) should be implemented to improve security and resilience against internal cyber threats. Network slicing should be implemented to minimise lateral movement across the network. Edge computing and encryption should be used to properly balance security and operations performance. AI-driven threat detection should be implemented to improve and speed up attack responses. Physical and environmental resilience should be improved to maintain sustainable network traffic. Privacy-by-Design principles will also need to be implemented and made aware to Platinum Valley's community to ensure transparency and trust with its people. Lastly, engagement and transparency need to be provided to Platinum Valley's community to foster trust, accountability, and inclusion.

Overall, this 5G network security strategy will allow Platinum valley to greatly benefit from a future-proof network. This network will improve and boost productivity within the community while safeguarding their privacy reliably. This strategy is a proactive approach that will gain the community's trust and allow their economy to grow exponentially.

Question 4.1: Network Architecture Design for Platinum Valley SEZ

4.1.1. Core Network (5GC)

To meet the demands of Platinum Valley SEZ, the 5G network needs to be tailored to focus mainly on coverage and performance. At the centre of the network, a 5G Core (5GC) needs to be implemented. The 5GC handles data routing, session management, and mobility. The 5GC needs to be placed in a regional data centre, especially in a nearby urban area. This will minimise latency, maintain scalability, and ensure strong connectivity. The core needs to be virtualised using Network Function Virtualisation (NFV) and service support like network slicing, quality-of-service (QoS) management, and user authentication needs to be enabled. This will enhance the network's flexibility and cost efficiency (Jain *et al*., 2022).

4.1.2. Radio Access Network (RAN)

The Radio Access Network (RAN) can be implemented into the design of the 5G network. The RAN will use radio signals to connect user devices to the core network. This can be achieved by placing macro cell towers in key strategic areas in Platinum Valley to cover a broad area over Platinum Valley and equip them with Massive MIMO antennas. Additionally, small cells can be installed in high-density and high-priority areas to enhance connection capacity. Areas can include government buildings, industrial parks, and transport hubs (López-Pérez *et al*., 2022). RAN will be configured with a sub-6 GHz spectrum and mmWave. This will ultimately enhance a broader coverage for rural areas and provide ultra-high-speed hotspots for Platinum Valley.

4.1.3. Multi-access Edge Computing (MEC)

Multi-access edge computing (MEC) servers can be incorporated into the design of this 5G network. The main purpose of using MEC servers will be to process data locally and reduce latency. These servers should be located at cell tower sites and local control centres within the Special Economic Zone (SEZ) of Platinum Valley. Real-time processing should also be enabled at these servers for applications like automated logistics, smart farming, and emergency services (Porambage *et al*., 2018).

4.1.4. Transport/Backhaul Network

This network architecture can be further supported by adding robust transport and backhaul networks to it. Transport and backhaul networks can be implemented using fibre optics where infrastructure exists and using microwave links in areas where there is a lack of fibre (Tezergil & onur, 2022). High-capacity, redundant links can be configured to these networks to ensure network availability as well as increase performance.

4.1.5. Power & Environmental Resilience

Reliable power sources should be implemented in this network architecture. Installing solar power systems with battery backups at base station sites or at edge nodes will be essential for keeping the network consistently functional and combatting frequent power disruptions. Uptime will be maintained consistency and with minimal power disruptions across the network (Shehab *et al*., 2021).

4.1.6. Security Layer

Lastly, a layered security framework can be integrated across all parts of the network architecture. Integrating this framework will effectively protect the overall network and user data across Platinum Valley. This framework can include firewalls, AI-based intrusion detection systems, and end-to-end encryption to further improve network security for Platinum Valley (Tian *et al*., 2019).

Question 4.2: Factors Affecting Implementation in a Rural Setting

4.2.1. Power Reliability

When this 5G network architecture is deployed in a rural area like Platinum Valley, several contextual challenges need to be addressed. Power reliability is the most important challenge to address, especially in South Africa. Rural areas experience frequent load-shedding and receive inconsistent electricity. Reliable power sources like solar panels with battery backups can combat this issue and ensure that power remains reliable and consistent in rural areas like Platinum Valley (Hussein *et al.*, 2024).

4.2.2. Infrastructure Limitations

Rural areas like Platinum Valley have limited access to fibre-optic cables, roads, and existing towers. Limited access to these key resources drastically increases the time and cost of 5G infrastructure deployment. It would especially increase the time and cost of the deployment of this 5G network architecture. To decrease the time and cost of 5G network deployment, wireless backhaul technologies like microwave and satellite links will be needed. Moreover, gradually building out fibre connectivity will also be useful (Ahamed & Faruque, 2018).

4.2.3. Low Population Density

Rural areas like Platinum Valley usually have low population densities. Low population density greatly lowers the financial feasibility of large-scale 5G network deployments. Achieving economies of scale becomes drastically more difficult with large areas populated with fewer people. To counteract this challenge, network sharing and phased rollouts will need to be leveraged. This will greatly reduce the deployment cost of this 5G network architecture (Samdanis *et al.*, 2016).

4.2.4. Skills & Technical Capacity

Rural areas like Platinum Valley are likely to have a lack of ICT professionals. This can hinder and delay the maintenance and optimisation of local 5G network infrastructure. Trouble shooting connectivity issues will also become a challenge within Platinum Valley. Introducing remote support and local training programs will be essential to counteract this issue.

4.2.5. Regulatory & Policy Barriers

Acquiring spectrum licenses and construction permits are usually very time-consuming and bureaucratically complex. Delays in spectrum licensing and municipal permissions can slow down this 5G network architecture deployment in Platinum Valley (Ahamed & Faruque, 2021).

4.2.6. Community Engagement & Adoption

Community acceptance should not be taken for granted. Many common misconceptions of 5G networks have emerged regarding health and privacy concerns, especially in rural areas in most countries. These misconceptions and resistances delay the adoption 5G network infrastructure. It is therefore essential to transparently communicate to and educate Platinum Valley's community on the benefits and risks that come with 5G adoption. Proactive engagement and clear communication will be key to gain trust and acceptance from the community of Platinum Valley and successfully setup this 5G network architecture (Soler, 2022).

4.2.7. Terrain & Geography

The geography and terrain layout of an area greatly impacts the difficulty and cost of 5G network adoption. Terrain factors like mountains, uneven terrain, and dense vegetation will interfere with and disrupt signal propagation as well as complicate the placements of towers (Ali *et al*., 2024). Careful planning, advanced signal modelling, and the use of relay stations will be key steps to ensure effective 5G infrastructure building in areas with high terrain constraints.

Bibliography

Abdulwahab, R. and Iyer, S.S., 2025. The Future of 5G and Digital Experience: Enhancing Customer Engagement and Retention in UAE Telecom. *Journal of Management*, *2*, pp.451-460.

Afolabi, I., Taleb, T., Samdanis, K., Ksentini, A. and Flinck, H., 2018. Network slicing and softwarization: A survey on principles, enabling technologies, and solutions. *IEEE Communications Surveys & Tutorials*, *20*(3), pp.2429-2453.

Ahamed, M.M. and Faruque, S., 2018. 5G backhaul: requirements, challenges, and emerging technologies. *Broadband Communications Networks: Recent Advances and Lessons from Practice*, *43*, p.2018.

Ahamed, M.M. and Faruque, S., 2021. 5G network coverage planning and analysis of the deployment challenges. *Sensors*, *21*(19), p.6608.

Ahmad, I.A.I., Dawodu, S.O., Osasona, F., Akagha, O.V., Anyanwu, A.C. and Onwusinkwue, S., 2024. 5G deployment strategies: Challenges and opportunities: A comparative review for Africa and the USA. *World Journal Of Advanced Research And Reviews*, *21*(1), pp.2428-2439.

Åkesson, E., 2020. Information visualization of network parameters in private cellular network solutions.

Alappat, M.R., 2023. *Multifactor authentication using zero trust*. Rochester Institute of Technology.

Ali, S., Abu-Samah, A., Abdullah, N.F. and Kamal, N.L.M., 2024. Propagation Modeling of Unmanned Aerial Vehicle (UAV) 5G Wireless Networks in Rural Mountainous Regions Using Ray Tracing. *Drones*, *8*(7), p.334.

Bauer, J.M. and Bohlin, E., 2022. Regulation and innovation in 5G markets. *Telecommunications Policy*, *46*(4), p.102260.

Betancourt, C., 2021. Cost, R.O.I., THE MAIN BARRIERS FOR 5G DEPLOYMENT.

Campbell, K., Diffley, J., Flanagan, B., Morelli, B., O'Neil, B. and Sideco, F., 2017. The 5G economy: How 5G technology will contribute to the global economy.

Chiaraviglio, L., Liu, W., Gutierrez, J.A. and Blefari-Melazzi, N., 2017, November. Optimal pricing strategy for 5G in rural areas with unmanned aerial vehicles and large cells. In *2017 27th International Telecommunication Networks and Applications Conference (ITNAC)* (pp. 1-7). IEEE.

Chitimira, H. and Ncube, P., 2021. The regulation and use of artificial intelligence and 5g technology to combat cybercrime and financial crime in south african banks. *Potchefstroom Electronic Law Journal/Potchefstroomse Elektroniese Regsblad*, *24*(1).

Dumako, S., 2023. Exploring the potential of 5G to bridge the digital divide in South Africa.
Du Plessis, J.H., 2022. Analysing key factors considered by consumers before adopting 5G-enabled services in South Africa.

Forge, S. and Vu, K., 2020. Forming a 5G strategy for developing countries: A note for policy makers. *Telecommunications Policy*, *44*(7), p.101975.

Gedel, I. and Nwulu, N., 2021. Infrastructure sharing for 5G deployment: A techno-economic analysis.

Gigaba, K.M.N., Niyitunga, E.B. and Uwizeyimana, D.E., 2025. Assessing the prospects of digital infrastructure in promoting rural economic development in South Africa. *Journal of Infrastructure, Policy and Development*, *9*(2), p.8817.

Hira, S., Afzal, M., Hamid, K., Ashraf, M., Ahmad, S.Z., Ruk, S.A. and Iqbal, M.W., 2024. Improving 5G network operations with Software-Defined Network Control. *Bulletin of Business and Economics (BBE)*, *13*(2), pp.404-411.

Hussein, H., Abd Elmunim, N., Atasoy, F., Virdee, B.S., Elwi, T.A., Rashid, N., Jayanthi, R.K.R., Alibakhshikenari, M. and Limiti, E., 2024. A novel MIMO antenna integrated with a solar panel and employing AI-equalization for 5G wireless communication networks. *IEEE Access*.

Jain, V., Chu, H.T., Qi, S., Lee, C.A., Chang, H.C., Hsieh, C.Y., Ramakrishnan, K.K. and Chen, J.C., 2022, August. L25gc: a low latency 5g core network based on high-performance nfv platforms. In *Proceedings of the ACM SIGCOMM 2022 Conference* (pp. 143-157).

Jassim, M.M., Mosa, M.M., Okbi, Z.A.I., Abdullah, S.B., Taha, S.W., Migo, P. and Kondakova, S., 2024, October. Cost-Effectiveness Analysis of IoT Deployment in 5G Networks. In *2024 36th Conference of Open Innovations Association (FRUCT)* (pp. 493-502). IEEE.

Khan, M.I., Arif, A. and Khan, A.R.A., 2024. AI-Driven Threat Detection: A Brief Overview of AI Techniques in Cybersecurity. *BIN: Bulletin of Informatics*, *2*(2), pp.248-61.

Lappalainen, A., 2021. *5G Fixed Wireless Access for Bridging the Rural Digital Divide* (Master's thesis, University of Waterloo).

López-Pérez, D., De Domenico, A., Piovesan, N., Xinli, G., Bao, H., Qitao, S. and Debbah, M., 2022. A survey on 5G radio access network energy efficiency: Massive MIMO, lean carrier design, sleep modes, and machine learning. *IEEE Communications Surveys & Tutorials*, *24*(1), pp.653-697.

Malinga, S., 2023. Telkom's 5G sites reach over 8m South Africans. *ITWeb*, 3 August 2023. [Online] Available at: https://www.itweb.co.za [Accessed 5 June 2025].

Maman, M., Calvanese-Strinati, E., Dinh, L.N., Haustein, T., Keusgen, W., Wittig, S., Schmieder, M., Barbarossa, S., Merluzzi, M., Costanzo, F. and Sardellitti, S., 2021. Beyond private 5G networks: applications, architectures, operator models and technological enablers. *EURASIP Journal on Wireless Communications and Networking*, *2021*, pp.1-46.

Porambage, P., Okwuibe, J., Liyanage, M., Ylianttila, M. and Taleb, T., 2018. Survey on multi-access edge computing for internet of things realization. *IEEE Communications Surveys & Tutorials*, *20*(4), pp.2961-2991.

Rahman, A., Arabi, S. and Rab, R., 2021. Feasibility and challenges of 5g network deployment in least developed countries (ldc). *Wireless Sensor Network*, *13*(1), pp.1-16.

Samdanis, K., Costa-Perez, X. and Sciancalepore, V., 2016. From network sharing to multi-tenancy: The 5G network slice broker. *IEEE Communications Magazine*, *54*(7), pp.32-39.

Santos, J.P., Alheiro, R., Andrade, L., Valdivieso Caraguay, A.L., Barona Lopez, L.I., Sotelo Monge, M.A., Garcia Villalba, L.J., Jiang, W., Schotten, H., Alcaraz-Calero, J.M. and Wang, Q., 2016. SELFNET Framework self-healing capabilities for 5G mobile networks. *Transactions on Emerging Telecommunications Technologies*, *27*(9), pp.1225-1232.

Shahzadi, S., Iqbal, M., Dagiuklas, T. and Qayyum, Z.U., 2017. Multi-access edge computing: open issues, challenges and future perspectives. *Journal of Cloud Computing*, *6*, pp.1-13.

Shehab, M.J., Kassem, I., Kutty, A.A., Kucukvar, M., Onat, N. and Khattab, T., 2021. 5G networks towards smart and sustainable cities: A review of recent developments, applications and future perspectives. *IEEe Access*, *10*, pp.2987-3006.

Soler, U., 2022. Social perception of 5G technology. *Rocznik Instytutu Europy Środkowo-Wschodniej*, *20*(1), pp.103-120.

Stafford, V., 2020. Zero trust architecture. *NIST special publication*, *800*(207), pp.800-207.

Tang, G., Yuan, H., Guo, D., Wu, K. and Wang, Y., 2021, May. Reusing backup batteries as bess for power demand reshaping in 5g and beyond. In *IEEE INFOCOM 2021-IEEE Conference on Computer Communications* (pp. 1-10). IEEE.

Tezergil, B. and Onur, E., 2022. Wireless backhaul in 5G and beyond: Issues, challenges and opportunities. *IEEE Communications Surveys & Tutorials*, *24*(4), pp.2579-2632.

Tian, Z., Sun, Y., Su, S., Li, M., Du, X. and Guizani, M., 2019. Automated attack and defense framework for 5G security on physical and logical layers. *arXiv preprint arXiv:1902.04009*.

Victor-Ikoh, M.I. and Moko, A., 2021. Fixed Wireless Access: An Explorative Study of WIMAX FWA and 5G FWA Networks. *International Journal of Computer Science and Mobile Computing*, *10*(4), pp.99-107.

Xulu, K.K. and Malatji, M., 2025, April. The Socioeconomic and Technological Implications of 5G Deployment in Urban and Rural Communities of South Africa. In *2024 International Conference on IT Innovation and Knowledge Discovery (ITIKD)* (pp. 1-6). IEEE.