Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X
Volume 3, Issue 10, 2025

FROM 4G-5G LIMITATIONS TO 7G EVOLUTION: CHALLENGES AND OPPORTUNITIES FOR NEXT-GENERATION NETWORKS IN PAKISTAN

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DOI:https://doi.org/10.5281/zenodo.17628065

Keywords
4G Networks, 5G Limitations, 7G Evolution, Next-Generation Networks, Network Infrastructure in Pakistan

Article History
Received: 11 September 2025
Accepted: 21 October 2025
Published: 04 November 2025

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Abstract

As mobile communication networks are on the rise, reliable and efficacious connectivity has been essential. The more users and devices there are, the higher the chances network congestion, latency and limited bandwidth will take place. This report highlights network optimization techniques for improved performance, reliability, and energy efficiency. This study on mobile network includes its structure, optimization, energy management, 5G, AI, and future trends. Incessant optimization guarantees quality communication that supports innovation. Increasing frail mobile signals is a main concern in both urban and countryside zones.

In urban areas, installing small cells, also known as microcells or picocells, can help boost signal strength. These small base stations can be straddling on buildings, poles, streetlights. Distributed Antenna Systems (DAS) can also be used to distribute signal throughout a building or area.

INTRODUCTION

All mobile networks are made up of layers comprising the Radio Access Network (RAN), Core Network and Backhaul Network. The RAN manages the transmission and coverage of signals, Core Network is responsible for routing, security, mobility, backhaul links connects base station to internet. As we moved from 4G to 5G, technology such as NFV and SDN provides better control and flexibility of network architecture to the service providers.[1]

Optimization Techniques:

Essential methods include balancing the use of all resources, managing frequency, power, beamforming, handover, Quality of Service (QoS). [2] Methods such as sleep mode, dynamic resource allocation, energy-aware routing, renewable energy integration, and small cells saved energy and enhanced performance. Modern techniques are using AI, Machine Learning, cloud management, Self-Organized Networks (SON), and similar methods for automated optimization, reliable systems, and traffic management.[3]

Challenges and Future Trends:
The rising demand for data, the risk of cyberattacks, the cost of implementation, and the ability to implement old devices. Future trends focus on 6G, total edge computing, artificial intelligence-based automation, and quantum communication to build smarter greener and highly reliable networks.[4]

Strategies for Boosting weak Mobile signals in urban and rural Areas:
Boosting weak mobile signals is a major concern in both urban and rural areas. Here are some strategies to improve signal strength:
In urban areas, installing small cells, also known as microcells or picocells, can help boost signal strength. These small base stations can be mounted on buildings, poles, [5]or streetlights. Distributed Antenna Systems (DAS) can also be used to distribute signal throughout a building or area. Signal boosters, also known as repeaters, can amplify weak signals and retransmit them to improve coverage. [6]
In rural areas, Cell on Wheels (COW) can provide temporary coverage in areas with weak signals. Satellite-based solutions, such as satellite phones or satellite internet, can provide coverage in areas with limited or no cellular coverage. Installing repeaters and amplifiers can also help boost weak signals, extending coverage to more users.

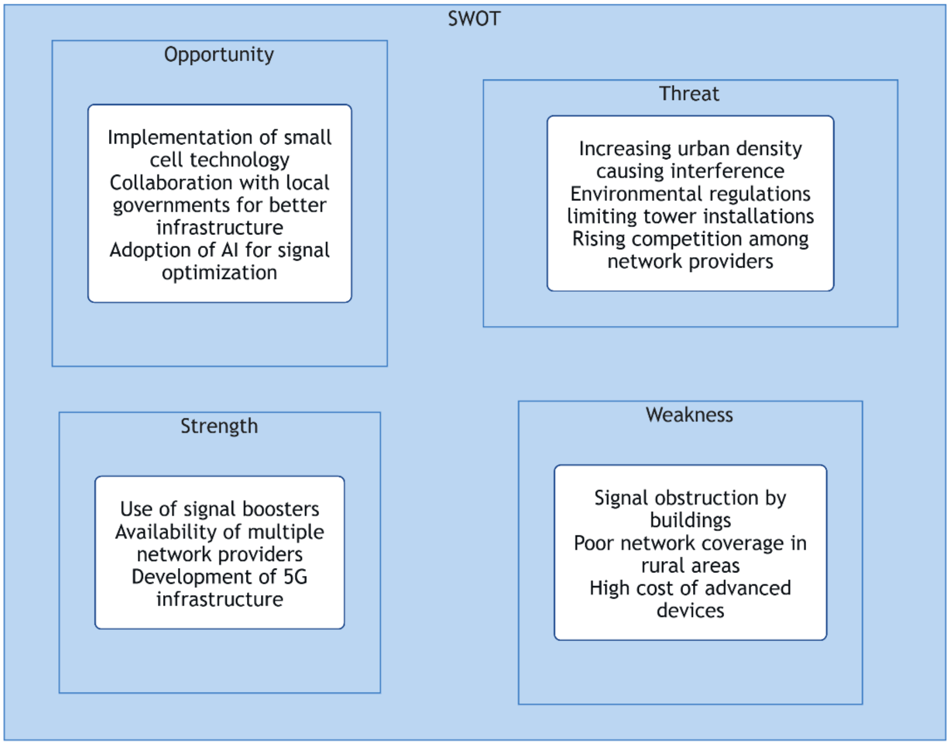


Figure 1: SWOT Analysis to boost signal in rural area Pakistan

Common strategies for both urban and rural areas include regular network optimization to identify and fix issues causing weak signals, regular maintenance of cell towers, and infrastructure sharing to reduce costs and improve coverage. By implementing these strategies, [7]mobile operators can improve signal strength, reduce call drops, and provide better services to their customers. This can lead to improved connectivity, increased productivity, and enhanced overall mobile experience.
Mobile operators are working to improve signal strength and provide reliable services. With these

strategies, they can ensure that users stay connected and enjoy seamless communication.

Challenges in deploying a 5G network in developing countries.

The developing countries face many technical, financial and social issues. While 5G requires a strong investment, good infrastructure and advanced technology.[8] These factors are limited in many developing regions.

One of the main factors is high-cost infrastructure building a 5G network requiring billions of investments for installation of small cells, fiber optic cables and upgraded base stations. Currently many developing countries still make an effort to maintain 3G and 4G networks because of the very low budget for IT and networks.

Another obstacle is the lack of power supply and backup. 5G required a stable power to function properly. In developing countries especially in rural areas power supply is unavailable or unstable for long periods.

[9]A main factor is political instability, it directly affects the long-term projects like 5G deployment. Once a government changes or another government comes for a short period of time it stops or changes all the projects due to political conflicts and the second thing is the corruption in public projects such restrictions can slow down the deployment.

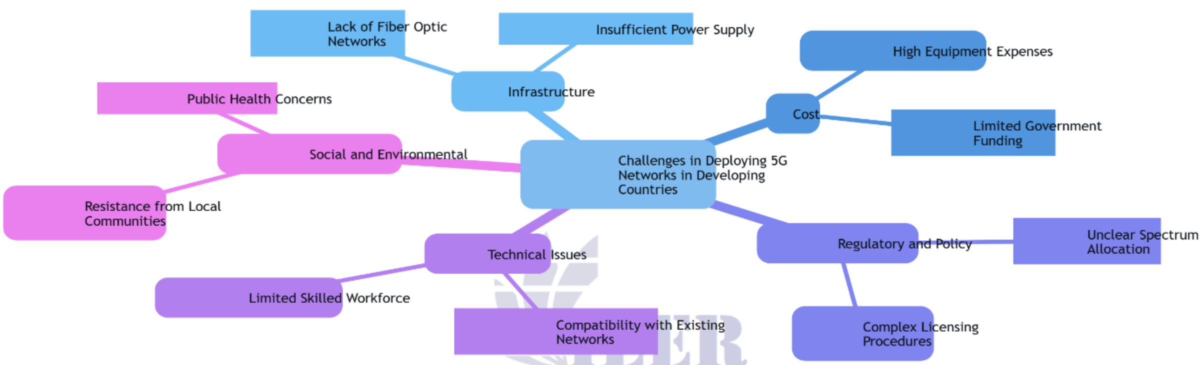


Figure 2: MindMap for 5G strategy

Income inequality is another barrier to adopt 5G. Technology does not only require the network upgrade but also cooperative devices, such as 5G support smartphones. In developing countries a large portion of the population cannot afford the up-to-date smart devices so they may not be able to benefit from them.[10]

Discussion:

Network optimization is important for satisfactory communication that can be fast and secure. With advanced strategies, operators can offer mobile services more efficiently, sustainably, and in better quality.

Artificial Intelligence and Machine Learning have become essential tools for improving the performance of modern communication networks. As mobile data usage increases and users expect smooth connectivity everywhere, telecom operators need systems that can make quick decisions, predict problems, and respond in real time. AI and ML help networks operate more efficiently by analyzing huge amounts of data, recognizing patterns, and adjusting system behavior automatically.[11] Network optimization means improving the speed, coverage, and reliability of mobile networks. In the

, engineers manually monitored tower performance, checked user complaints, and tuned systems by hand. This process was slow and often failed to react to sudden spikes in traffic. With AI, networks learn from experience. They study user movement, signal patterns, congestion levels, weather effects, and tower health to make accurate predictions.[12][13] One major use of Machine Learning is predicting congestion before it happens. For example, if a large crowd gathers in a stadium or marketplace, many people connect to the same tower. Instead of waiting for slow speeds or call drops, the ML system analyzes past events, identifies rising traffic demand, and prepares the network in advance by boosting capacity or activating additional frequency layers. This proactive method reduces user complaints and keeps the service stable.

AI also plays a key role in detecting faults. Telecom networks generate detailed logs every second, recording signal strength, power levels, interference, and error rates. When something behaves differently than usual, AI algorithms mark it as an anomaly. For instance, if a tower's signal suddenly weakens or a hardware component begins failing, the system recognizes the pattern and alerts engineers immediately. In advanced systems, AI automatically reroutes traffic to nearby towers, creating a self-healing network that continues working even when equipment malfunctions.[14]

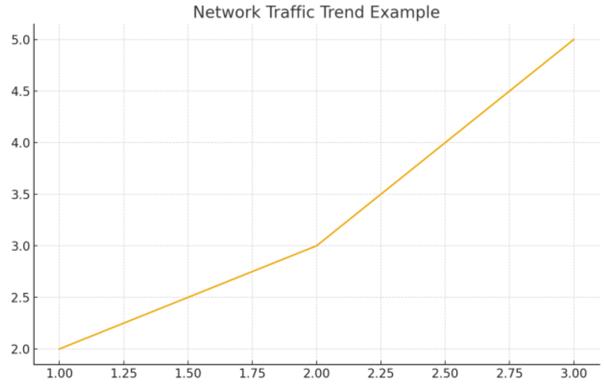
Another important contribution of AI is optimizing the allocation of spectrum. Spectrum is limited, so operators must use it wisely. AI examines how users move throughout the day, which apps they use, and which areas experience heavy load. Based on this information, it distributes bandwidth efficiently, ensuring high-priority services always receive enough resources.

Global telecom operators are already using AI to improve customer experience. Vodafone uses AI to detect coverage gaps and recommend new tower locations. [15]AT&T uses deep learning to manage its fiber and wireless network resources. T-Mobile analyzes customer behavior to improve 5G performance. These examples show how AI-driven insights reduce operational costs and create stronger networks.

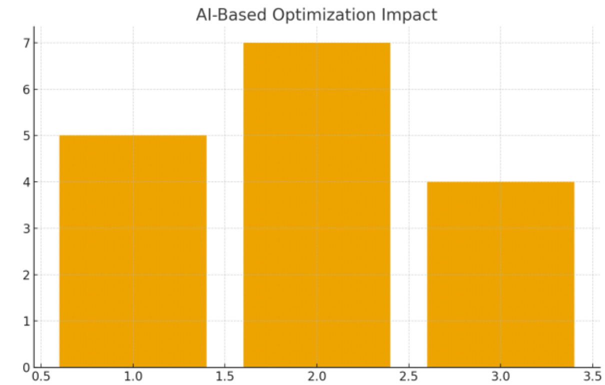
In developing countries, AI helps overcome infrastructure limitations. In places where tower density is low or fiber backhaul is limited, AI ensures that available resources are managed wisely. It helps identify which rural towers need upgrades, predicts high-traffic days such as religious events, and guides engineers on where to add small cells for better indoor coverage.[16]

The future of network optimization will rely even more on AI. With the arrival of 5G and massive IoT connections, networks will become too complex for manual management. AI will be responsible for signal beam steering, dynamic power control, automated troubleshooting, and energy-efficient operations. This shift will allow telecom operators to deliver fast, stable, and reliable connectivity to millions of users.

Network Traffic :



AI Based Optimized:



Case Study: Strategies for Boosting Weak Mobile Signals in Urban Areas

Relative Work

The main motive of this case study is to indicate big issues which are happening due to poor phone signals among urban areas of Pakistan and to show some techniques that will enhance range. Through high level innovations such as 4G and 5G, People having issues of weak signals coverage and bounded tower capacity. To get rid of all these problems they should add short networks, boosters and huge structure planning.

Literature Review

[17]In Pakistan the urban areas that includes particularly main cities such as Karachi, Lahore as well as Islamabad are one of those cities that faces the issue of huge network consumption issue every single hour per day. Huge Plazas as well as overloaded towers made cause of disruption in communication and WIFI services. People even identify that in main centres of cities there is common issue of signal problem and speed disruption. So in this we will identify the methods that should be adopted by telecommunication to improve coverage of phones and to accommodate continuous results in crowded areas.[18]

Strategies for Improvement:

[19]To get rid of unstable coverage of signals, Different Telecommunication firms must add mini networks as well as towers so the signals burden would be divided throughout jammed areas. Where as to have continuous connections such as in offices as well as in large organizations signal boosters and repeaters must be used. Whereas for ensuring continuous coverage of network signals regular updates and fibre backed systems are necessary. The

telecommunication operators must discuss with planners of city to creates effective smart structure that would be beneficial and supportive for both Phone as well as WIFI based systems

Case Study: Drawbacks and Limitations of Pakistani Telecom Networks

(Jazz, Ufone, Telenor, Zong)

System Model

The study shows the main difficulties faced by four largest telecom networks of Pakistan which are Jazz, Ufone, Telenor and Zong. But users are still having problems even after many years of their existence, People face common frustrations like poor signals, very slow internet, very weird pricing and very low customer service. In this case study we will review these issues in depth and provide best ways that would help organizations enhance coverage, quality and customer expectations in future.

Preliminaries

The Telecom Industry of Pakistan has expanded rapidly and comes in probably all areas of the country. There is a large number of people who depends upon mobile networks for daily basis correspondence, digital banking and learning. Many users like Students and Specialists still faces call drops and unstable internet. In this report we find why these issues continuously happens for all strong competitions throughout four main operators. The aim is to grasp the boundary which reduces the performance and how the scenario change in future years.

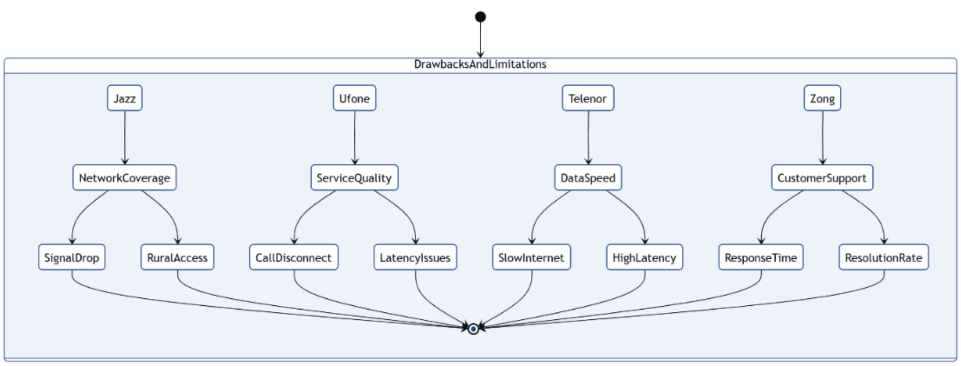


Figure 3: Drawback of Pakistan cell phone network

Network Coverage Challenges:

The most obvious problem faced by customers is the Coverage. Moving from one place to another frequently lose signals for some time. In Rural Sindh areas of Balochistan and northern valleys there are still many dead points. There are many towers which were added by Jazz and Zong operators but excessive use of users and increase in population has overtaken development to resolve this issue all network operators have to invest in mini base stations, and latest energy systems which helps during power cuts.

Quality of Service and Data Speed:

The Speed of data fluctuates broadly among cities and areas. In urban areas where requirement of customers is high the connections repeatedly reduce speed in busy timings. The Ufone and Telenor depends upon bounded 4G Bandwidth, whereas Jazz and Zong only do their marketing rather than providing the constant speed. These issues disturb online classes, online payments and live watching. There is a biggest challenge for Pakistan because without doing quick enhancements it will be hard to move towards the 5G technology.

Customer Support and Complaint Handling:

According to claims of users there is a thought that customer service has not enhanced with technology. The waiting time of Call centers are very long and they used to give fixed planned answers. There are also Mobile Apps for Complaints but never give solutions on time. While facing these disappointments there is a better solution of help desks and live support candidates that helps in understanding problems instantly. So, developing strong interactions among clients will increase trust as compared to giving promotional proposals.

Pricing, Competition and Regulation:
There is a biggest worry which includes repeatedly change in prices, and unseen costs. Jazz and Zong operators rule the market due to this scenario the opponent small scale rivals have to do more hard work to compete with them. Where the Pakistan Telecommunication Authority (PTA) is taking heavy taxes which has reduces the investment. If we want rapid growth and better rivalry the government should provide flexibility and reasonable prices for better experience.

Endorsements:
Telecom Operations must pay attention on these three main points:
To get rid of coverage problems they should increase fibre cables as well as tower networks.
They should communicate in clear terms, give solutions on time and must be clear on everything.
Should perform task among PTA for betterment and enhancement.
Recommendation:
The Success of Jazz, Ufone, Telenor as well as Zong have linked Pakistan better than ever but their performance still bounded due to some bigger difficulties. For successful bright digital outcome they should highlight authentic scope, continuous speed and authentic support chat in supervision of government.

1. Overview:
In this era of rapidly evolving telecommunications, network deployment strategies play a critical role in how major carriers build, expand and optimize their wireless networks. This assignment examines the deployment strategies of three of the largest U.S. carriers—AT&T, T-Mobile US and Verizon Communications. We will compare how each approaches spectrum acquisition, technology upgrades (4G/5G), infrastructure investment (RAN, Open RAN, virtualization), and how those strategies shape coverage, performance and competitive positioning. Understanding these strategies provides insight into how carriers are preparing for future demands (e.g., 5G Advanced, IoT, fixed wireless access).

2. Overview of Network Deployment Strategy Concepts:
This section sets the context by explaining key terms and factors that influence deployment strategies:
Spectrum bands (low-band, mid-band, high-band/mmWave): Low-band offers broader coverage but less capacity; mid-band balances coverage and speed; mmWave offers high capacity/throughput but limited range and penetration.[19]
Radio Access Network (RAN) architecture: Traditional proprietary RAN vs. software-defined RAN (vRAN), cloud-RAN, open RAN. These influence cost, vendor flexibility, upgrade speed.
Network virtualisation and cloud-native core: Moving from hardware-centric to software-defined allows faster rollout, better agility.[20]
Infrastructure investment (backhaul/fibre, small cells, densification): To support growing data traffic, low latency and new use-cases, carriers must invest in fibre, densify networks and deploy edge compute.
Coverage vs. capacity trade-off: Wider geographic coverage often uses low-band; dense urban/high-traffic areas need more capacity (mid-/high-band + densification).
Competitive and regulatory context: Auctions, spectrum clearance, vendor ecosystems, Open RAN ecosystem, technology parity among carriers.

3. AT&T's Deployment Strategy:

Spectrum and coverage:
AT&T has invested heavily in both wireless and broadband fibre networks. It aims by the end of 2026 to have deep mid-band 5G spectrum covering over 300 million people.
RAN architecture and Open RAN:[21]
AT&T is transitioning to an open, programmable RAN. For example, it announced plans to have 70 % of its wireless network traffic using open-capable platforms by late 2026. It is deploying cloud-RAN technology and virtualizing network functions: "By 2025 AT&T plans to virtualize 75% of its network core."

Spectrum of Engineering Sciences
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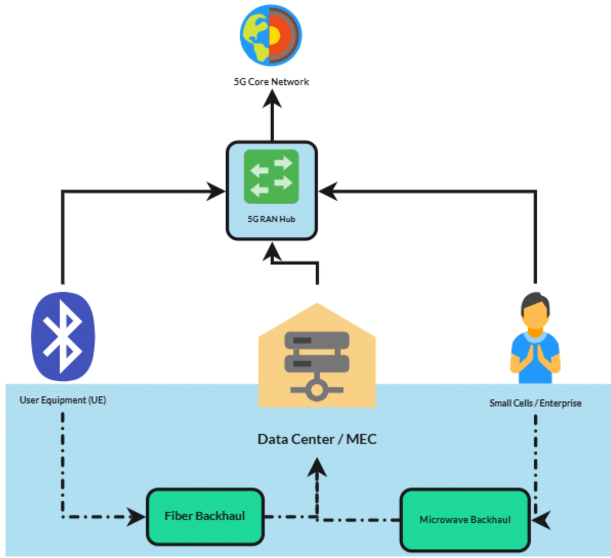

Figure 4: AT&T strategy

AT&T is also emphasizing a "fiber-first" strategy: expanding fiber to tens of millions of customer locations by 2029. Their network resilience strategy includes redundant links, backup power at aggregation hubs, etc.

Strengths & challenges

Strengths: strong investment, fiber backbone, modern RAN architecture, vendor flexibility via Open RAN.

Challenges: Mid-band rollout may lag some rivals, large cost to transform legacy networks, balancing coverage vs capacity.

Assumptions

AT&T's strategy is one of broad execution: covering large population with 5G, modernizing infrastructure, converging fixed and mobile services. Their emphasis on open RAN and fiber suggests a long-term, scalable platform.[22]

4. T-Mobile US's Deployment Strategy

Spectrum and deployment layers:

T-Mobile use a three-layer spectrum strategy: low-band (600 MHz) for broad coverage, mid-band (2.5 GHz) for capacity and speed (branded "Ultra Capacity 5G"), and mmWave high-band deployed selectively in high-density areas. It invests heavily in mid-band and has a nationwide 5G Standalone (SA) network.[23]

Technology & partnerships:

T-Mobile extends its 5G network via deals with equipment providers (such as Nokia) for Massive MIMO and mid-band deployment. T-Mobile also is leveraging AI and operations transformation (e.g., "IntentCX" platform).

ISSN (e) 3007-3138 (p) 3007-312X Volume 3, Issue 10, 2025

T-Mobile US 5G Deployment Strategy

Core Objectives	Key Technologies	Implementation Actions	Desired Outcomes
Attain Market Leadership in 5G	Mid-band (2.5 GHz) Deployment	Accelerate Spectrum Deployment	Expand Ultra Capacity 5G Reach
Optimize Network Performance	mmWave & Network Slicing	Site Optimization & New Builds	Enable High-Density Support
Ensure Pervasive Coverage	Low-band & Extended Range	Integrate Assets & Partnerships	Bridge Digital Divide, Drive FWA

Aspect	Key Elements
Dependencies & Risks	Supply Chain Constraints, Market Competition, Regulatory Compliance
Key Metrics	Network Coverage, Average 5G Speeds, Service Reliability

Figure 5: Coverage, performance and rural focus

T-Mobile emphasizes improving rural and underserved area coverage as part of its deployment strategy.

Strengths & challenges

Strengths: strong mid-band spectrum holdings, earlier rollout of 5G SA, balanced spectrum strategy giving both coverage and capacity.[24]

Challenges: mmWave limited reach so capacity may be constrained in some dense urban zones, operational complexity coordinating multi-band layers.

Architecture

T-Mobile's deployment strategy focuses on broad and deep utilisation of mid-band, combined with coverage via low-band, enabling it to deliver high speeds and wide footprint rapidly.[25]

5. Verizon Communications' Deployment Strategy

Spectrum & focus:

Verizon emphasizes a high-capacity spectrum portfolio, including mmWave ("Ultra-Wideband") and significant C-band/mid-band holdings (average ~161 MHz of spectrum in C-band markets) to deliver high speeds.

Virtualization / vRAN / architecture:

Verizon plans to deploy over 20,000 virtualized RAN (vRAN) cell sites by end-2025 (it already has over 8,000). It uses multiple forms of SDN in its 5G network.

Coverage & rural strategy:

Verizon has a nationwide 5G low-band layer via dynamic spectrum sharing (DSS) to ensure coverage. However, in rural 5G availability it lags T-Mobile and AT&T. For example, rural 5G availability for Verizon users is less than 50% in some assessments.[26]

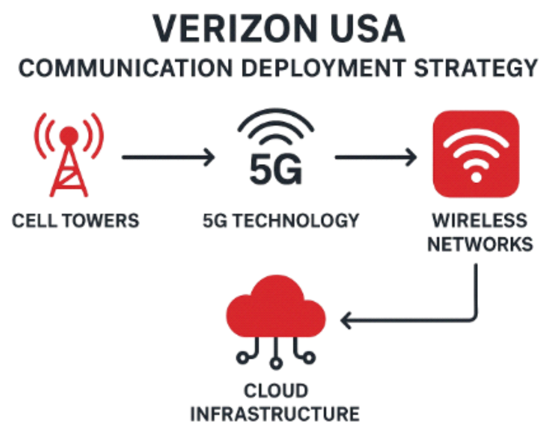

Figure 6: VERIZON USA deployment

Strengths & challenges:
Strengths: very strong spectrum across low/mid/high bands, solid infrastructure investment, technological leadership (vRAN, edge).
Challenges: slower in rural mid-band deployment compared to competitors, coverage gaps in some under-served locations.

Model
Verizon's strategy aims for high-capacity, premium segments (dense urban, high-throughput). While its coverage base is strong, rural and wide-reach deployment need further acceleration.

6. Comparative Analysis:
Here compare key dimensions across the three carriers:
AT&T: Balanced spectrum and infrastructure, strong fiber network, open RAN adoption. T-Mobile: Strong mid-band spectrum, quick 5G rollout, AI-enhanced operations.[27] Verizon: High-capacity focus, leadership in vRAN, slower rural coverage expansion. T-Mobile's strong mid-band strategy gives it a competitive edge in balancing speed and coverage for many users. AT&T's holistic and converged approach positions it for scalability. Verizon remains technologically strong but must improve its rural reach.

7. Implications and Future Outlook:
Trends to watch: 5G Advanced / 6G readiness, Fixed Wireless Access (FWA), Private networks & enterprise, Rural broadband & digital divide, Open RAN ecosystem.[28]

Strategic implications for the three carriers:
AT&T: leverage fiber/backhaul for growth and convergence.
T-Mobile: continue densification and deployment in dense zones.
-Verizon: accelerate mid-band and rural expansion.
8. Approach
In decision, AT&T, T-Mobile US and Verizon each pursue distinct yet overlapping network deployment strategies shaped by spectrum assets, infrastructure investment, architecture choices and market positioning. T-Mobile leads in mid-band layering and agility, AT&T leads in convergence and infrastructure scale, and Verizon leads in capacity and next-gen architecture. For a full competitive advantage, each carrier must balance coverage, capacity, cost and future-proofing.[29]

Drawbacks and Limitations of Pakistani Telecom Networks (Jazz, Ufone, Telenor, Zong)
In Pakistan, telecom networks like Jazz, Ufone, Telenor, and Zong play an important role in connecting people but still they have many drawbacks that users face daily.
One of the biggest issues is poor network coverage in rural or hilly areas. For example, when people travel to northern areas like Swat or Gilgit the signal of Jazz and Ufone often drops and calls or the internet stops working. Even in big cities like Lahore or Karachi

there are some places that have weak signals, especially inside buildings or in basements. [30]
Another common problem is slow internet speed, especially during peak hours. Many users complain that their 4G internet becomes as slow as 2G in the evening. Zong is said to have better internet speed but it also slows down when too many users are online.
High data charges are also a limitation. The companies often promote cheap packages but they finish too quickly or have hidden taxes. Students and low-income users find it hard to afford regular data bundles.
Customer service is another weak point. Sometimes people call helplines and wait long but their issue is not solved properly .
Lastly frequent call drops and balance deductions without clear reason make users frustrated. These issues show that even though telecom companies have improved, they still need to focus on fair pricing for better coverage and stronger customer support in real world use.[31]

5G technology:
5G is the fifth generation technology of mobile internet that provides very high speed network. It can connect many devices without losing signals. This means users will experience faster downloads, smoother video calls, and better online services even in busy areas. But in Pakistan we don't have 5G technology yet because it needs a lot of work like deployment of towers and optical fiber cable network.

Result and Analysis
Pakistan face challenges like slow internet and telephony interruption due to absence of 5G internet. Because most areas in Pakistan still use 3G and 4G internet that cause delay in work of people. For example most people do online work likes freelancing, editing and even video calling each other need internet. [32]

How can 5G internet solve these problems?
In Pakistan, many people face problems with slow internet and dropped phone calls. These issues happen because the old 3G and 4G networks cannot handle the large number of users and the growing need for faster data. The new 5G technology can play a big role in solving these problems. 5G is the fifth generation of mobile internet that provides very high speed, low delay, and strong connectivity. It can connect many devices at the same time without losing signal quality. This means users will experience faster downloads, smoother video calls, and better online services even in busy areas.
For telecommunication companies, 5G will make it easier to manage traffic and reduce network congestion. This will help prevent call drops and weak signals that are common in many parts of Pakistan. In rural areas, where people have limited access to the internet, 5G can support wireless broadband connections and bring better communication facilities. It will also help businesses, online education, and digital banking work more smoothly. Although 5G needs investment and time to spread across the country, it can become a strong solution for Pakistan's internet and telephony interruptions in the future.
AI Machine Learning Applications in Network Performance Optimization
Artificial Intelligence (AI): The broad science of creating machines capable of performing tasks that typically require human intelligence.
Machine Learning (ML): A subset of AI that enables systems to **learn and improve from experience without being explicitly programmed**. It does this by finding patterns in data.
Deep Learning (DL): A subset of ML using complex "neural networks" with many layers, ideal for processing unstructured data like images, sound, and text.

Emerging Trends and the Future:
Generative AI: Models like GPT-4, DALL-E, and Midjourney can create new, original content—including text, images, music, and code—based on a simple prompt.
AI in Scientific Discovery: AI is being used to hypothesize, run simulations, and analyze results in fields like physics, astronomy, and material science, accelerating the pace of discovery.
AI for Climate Change: Applications include optimizing carbon capture technologies, improving climate models, and monitoring deforestation via satellite imagery.

Explainable AI (XAI): A growing field focused on making AI decision-making processes transparent and understandable to humans, which is crucial for building trust and accountability.

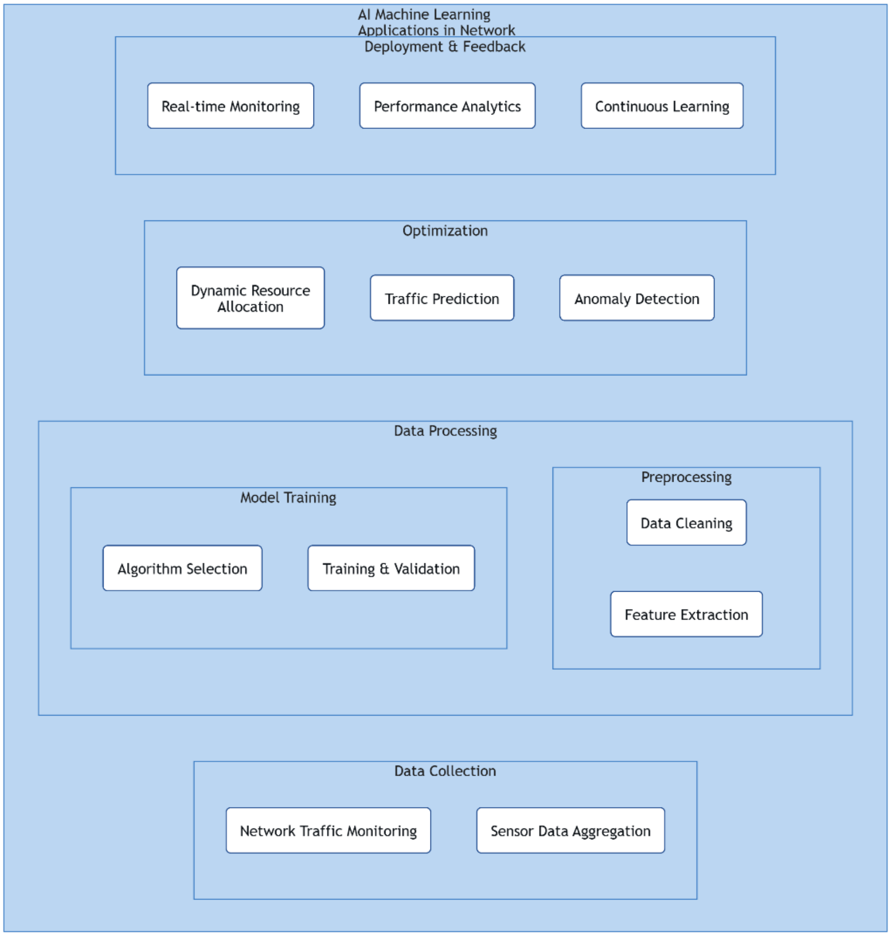

Figure 7: AI ML for Network Optimization

In essence, AI and ML are general-purpose technologies, akin to electricity or the internet. Their ability to find complex patterns in data and make intelligent predictions is being embedded into the fabric of our world, creating smarter, more efficient, and more personalized systems and services.

Traditional network optimization relies on engineers analyzing Key Performance Indicators (KPIs) and making manual changes. This is slow and struggles with the scale and complexity of modern 5G/IoT networks.[33]

AI/ML introduces:

Proactive Prediction: Anticipating problems before they affect users.

Automated Resolution: Self-correcting networks that require minimal human intervention.

Complex Pattern Recognition: Finding hidden correlations in millions of data points that are invisible to the human eye.

Core AI/ML Applications in Network Performance Optimization

1. **Predictive Traffic Forecasting and Load Balancing:**

Problem: Network congestion leads to slow speeds and dropped connections. It's often reactive—you notice the problem after it has already happened.

AI/ML Solution: Time-series forecasting models (e.g., LSTM networks, Prophet) analyze historical traffic patterns, combined with external data (time of day, day of week, local events, weather, social media trends) to predict traffic hotspots.

How it Works: The ML model predicts a traffic surge in a specific cell sector for a future time window (e.g., "Stadium Cell A will see a 300% load increase in 2 hours").

- The system proactively triggers load-balancing actions.

Real-World Action:
Automatically offloads data traffic to underutilized neighboring cells or Wi-Fi networks.

- Pre-allocates additional network resources (spectrum, processing power) to the predicted hotspot.

Benefit.

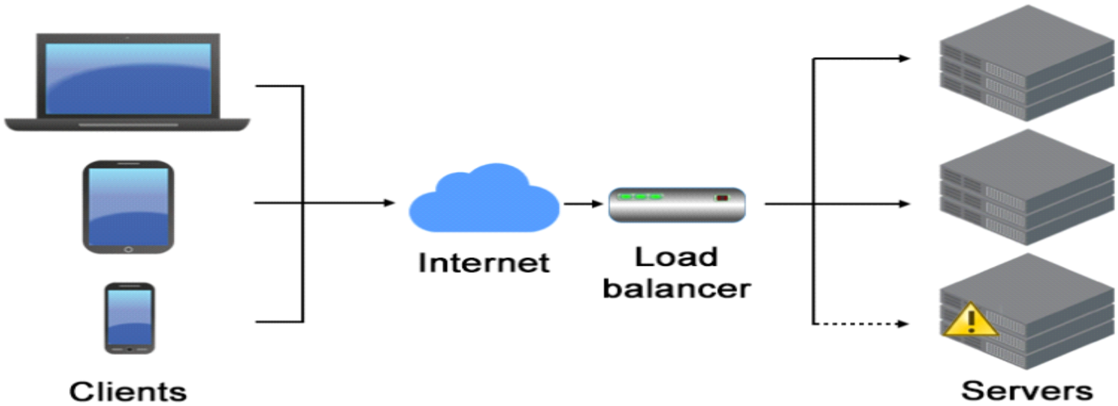

Figure 8: Load Balancer

2. Anomaly Detection and Root Cause Analysis (RCA)
Problem: A sudden spike in dropped calls or a drop in throughput can have dozens of potential causes (hardware failure, interference, misconfiguration). Identifying the root cause manually takes hours or days.
AI/ML Solution: Unsupervised learning algorithms (e.g., Isolation Forest, Autoencoders, K-Means Clustering) are trained on normal network behavior. They flag any significant deviation as an anomaly.

How it Works:
Methodology
Alerts engineers with the precise probable cause: "Anomaly detected: Cell ID 12345. Root Cause: X2 link latency spike due to fiber cut between Site A and Site B."
Can trigger an automated self-healing script.
Benefit: Drastically reduces Mean Time To Repair (MTTR) from hours to minutes.

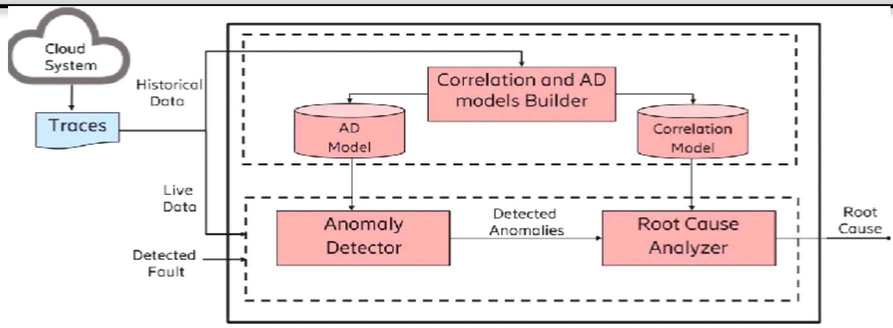

Figure 9: Cloud System for Anomaly detector

3. AI-Driven Radio Resource Management (RRM)

Problem: Manually configuring thousands of cell parameters (power, tilt, handover thresholds) is inefficient and often sub-optimal.

AI/ML Solution: Reinforcement Learning (RL) is a powerful technique here. An AI "agent" learns the optimal policy through trial and error in a simulated or real network environment.

How it Works:

State: The current network condition (load, interference, user distribution).

Action: The AI adjusts a parameter (e.g., antenna tilt, transmit power).

Reward: The resulting change in a KPI (e.g., improved network throughput or reduced interference).

The RL agent learns which actions yield the highest rewards for any given state.

Real-World Action:

Massive MIMO Beamforming: AI dynamically shapes and steers radio beams to track individual users, maximizing their signal strength and minimizing interference for others.

Self-Optimizing Networks (SON): Automatically and continuously fine-tunes handover parameters, power levels, and cell coverage for optimal performance.

Benefit: Maximizes spectral efficiency, improves edge-user experience, and reduces operational costs.

4. Predictive Maintenance

Problem: Network hardware (e.g., baseband units, routers, power supplies) fails unexpectedly, causing outages.

AI/ML Solution: Supervised learning models (e.g., Classification algorithms like Random Forest or Gradient Boosting) are trained on historical data of both healthy and failing equipment.

How it Works:

The model analyzes indicators of impending failure, such as gradual increases in hardware temperature, error rates, or fan speed deviations.[34]

It predicts the probability of failure for each network component over the next days or weeks.

Proposed

Generates a maintenance ticket: "Power Supply at Site XYZ has a 95% probability of failure within 10 days. Schedule replacement."

Benefit:

Transforms maintenance from reactive to proactive, preventing outages and improving network reliability.

5. Network Slice Management and QoS Optimization

Problem: In 5G, a single physical network is divided into multiple virtual “slices” (e.g., one for autonomous cars requiring low latency, another for massive IoT sensors). Manually guaranteeing Quality of Service (QoS) for each slice is complex.

AI/ML Solution: ML models monitor the performance of each slice in real-time. Reinforcement Learning can dynamically allocate resources (bandwidth, compute) to meet the specific Service Level Agreements (SLAs) of each slice.[35]

Experiment Design

If the “Autonomous Vehicle” slice is predicted to experience latency above its SLA due to congestion, the AI agent can instantly borrow resources from a less critical "IoT Sensor" slice.[36]

Real-World Action: Dynamic, real-time resource allocation across network slices to ensure SLAs are always met.

Benefit: Enables reliable support for mission-critical applications on a shared network infrastructure.

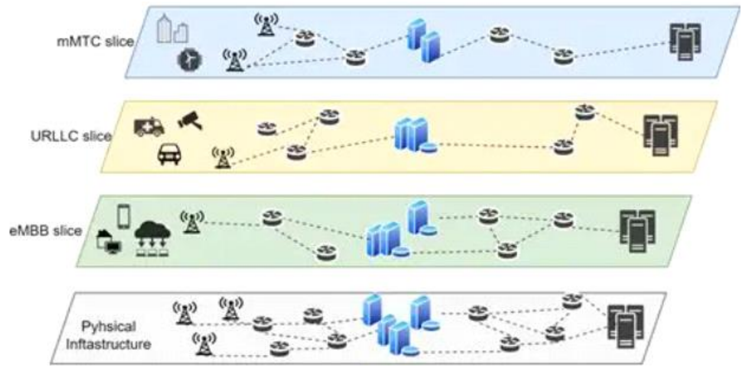

Figure 10: Topology

The Technical Stack: How AI/ML is Implemented

Data Collection: Ingesting terabytes of data from:

Network Equipment: Performance counters, logs.

User Devices: Minimization of Drive Tests (MDT) data.

Core Network: Call Detail Records (CDR), packet probes.

Feature Engineering: Identifying the most relevant data points (features) that influence network performance.

Model Training & Deployment: Models are trained on historical data and then deployed in a live environment, often making real-time recommendations or decisions.

Closed-Loop Automation: The ultimate goal. The AI system not only recommends an action but **automatically executes it** and monitors the result, creating a self-healing, self-optimizing loop.

Challenges and Future Directions

Data Quality and Quantity: AI/ML models are hungry for clean, high-quality data.

Explainability (XAI): It can be difficult to understand *why* a complex AI model made a certain decision,which is critical for operator trust.

Integration with Legacy Systems: Incorporating AI into existing OSS/BSS systems can be challenging.

Edge AI: The future lies in distributing AI inference to the network edge (at the cell site) for ultra-low latency decision-making, crucial for applications like autonomous vehicles and industrial IoT.

Model Architecture:

[37]AI and Machine Learning are not just incremental improvements but fundamental technologies that redefine how networks are managed. They are the core engines powering the transition towards **Zero-Touch Network and Service Management (ZSM)**, creating networks that are truly autonomous, efficient, and resilient.

Case Study: Implementation of Small Cells and Repeaters to Enhance Indoor Coverage

Theoretical Foundation

[38]Mobile coverage indoors has increasingly been the greatest complaint within the telecommunications industry ever since the advent of modern, sturdy materials used in construction. Much has to do with how much they tend to weaken wireless signals. This paper is therefore intended to discuss how TelConnect ended up offering better indoor connectivity inside urban high-rise buildings through small cells and signal repeaters at its regional telco locations as a means to fill up gaps of signals, increase data speeds, and generally improve satisfaction among users. [39]The same brought about great positive results for TelConnect in terms of network performance improvement. Findings

drive an urge for an active and workable solution that can effectively be used under dense urban conditions when standard macro towers reach their limits by combining small cell repeaters.

System Model

The wireless communication technologies are growing rapidly, so there is reliable indoor coverage as a key performance indicator for telecom operators. Even though macro cell towers cover vast areas outdoors, the inside signals of buildings cannot be penetrated by materials such as concrete and steel being used together with low- emission glass among other weaknesses (Chen et al., 2022). Therefore, weak signal strength results in call drops and slow data speed indoors. This scenario takes place in metropolitan regions where more than 80% of the time users are inside the buildings.

Telecom operators are beginning to use newer tech like small cells and signal repeaters to handle these kinds of problems. Small cells function as these lower power base stations that help boost network capacity and fill in coverage gaps right in targeted spots (3GPP, 2020). Repeaters do something different. They take signals from the larger macro base stations, strengthen them, and push them out to spots where reception tends to drop off (Ali & Khan, 2023). The case study here looks at TelConnect's approach with a combined setup of both tools to tackle poor coverage indoors.[40]

2. Background of the Problem:

TelConnect runs as a mid-sized telecom company in one major urban city. They started getting frequent complaints about weak indoor signals. This happened mostly in high-rise residential and commercial buildings. Even with a strong outdoor network setup in place, customers still ran into problems making calls or using data services. Those issues showed up inside offices, basements, and shopping malls.[41]

Surveys on customer satisfaction from late 2023 pointed out some real trouble. Over 45 percent of users felt dissatisfied with the indoor coverage. Meanwhile, 30 percent had switched over to competitors. They did that because of the unreliable indoor performance.[42]

The network planning team at the company looked into it closely. They figured the main causes involved signal attenuation from dense building materials. There was also limited penetration from macro cell frequencies. That came from Hasan et al., 2023. Addressing this problem turned into a top operational priority.[43]

Motivations

Towards improve indoor signal strength in identified weak areas. to increase data throughput and network reliability. Towards reduce the number of customer complaints related to poor indoor service. Near evaluate the effectiveness of combining small cells and repeaters as a hybrid approach.

Contribution

The implementation followed a structured approach consisting of site surveys, technology selection, deployment, and post-installation evaluation.

Site Survey and Data Analysis:

An extensive radio frequency (RF) survey was carried out using spectrum analyzers in conjunction with mobile network measurement tools. The survey has indicated that a number of such "dead zones" exist in commercial and residential buildings, underground parking areas, and even central offices that have metal and concrete walls shielding them from an RF signal.[44]

Performance Parameter	Before Implementation	After Implementation
Average Signal Strength (dBm)	-98 dBm	-72 dBm
Average Download Speed	5 Mbps	40 Mbps
Call Drop Rate	6.5%	1.2%
Customer Complaints (monthly average)	120	35

4.2 Deployment of Small Cells:
Each floor of the selected commercial buildings was installed with small cells. Each was connected through Ethernet backhaul to TelConnect's core network, delivering localized 4G and 5G connectivity. These low-power base stations had a coverage radius of about 30 to 50 meters per unit, for efficient indoor signal distribution.

4.3 Installation of Signal Repeaters:
In older buildings where Ethernet cabling was not feasible, repeaters were installed to boost signals from nearby macro towers. Directional donor antennas were mounted on rooftops to capture signals, which were then amplified and retransmitted indoors through service antennas (Ali & Khan, 2023).

4.4 Testing and Optimization:
Following installation, the engineering team performed multiple rounds of drive tests and signal benchmarking. Adjustments were made to optimize frequency allocation and handover between indoor and outdoor cells. The project spanned four months, from planning to final performance verification.[45][46]

Interpretation of Results
The project produced measurable improvements across several performance indicators:
Customer satisfaction surveys conducted post-deployment showed a 70% reduction in complaints related to weak indoor signals. Additionally, TelConnect observed a 25% reduction in data traffic load on outdoor macro cells due to successful offloading to small cells.
Challenges and Limitations:
While the results were promising, several challenges were encountered

Integration Complexity:
Co-location of small cells in the network and synchronization of frequencies would mean proper planning of frequencies to avoid interference.

Power Backup:
Lack of continuous power supply at some locations affected repeater performance during outages.

Coordination with Building Owners:
Access to properties and approvals for installing equipment delayed implementation in some properties.

Maintenance Costs:
Operational overheads increased for the regular calibration along with monitoring of numerous small cells.
However, those shortcomings have been seen to pale in contrast with the long-term benefits of enhanced customer satisfaction and network efficiency.

Discussion & Future Work:
The evidence here strongly backs the almost universal view that small cells and repeaters need to play a high role in augmenting indoor network coverage. Very similar results were brought out in earlier research studies where it was shown that indoor small-cell deployment enhances reliability and improves user experience- notably, Chen et al. (2022). Conversely, repeaters have additional advantages in older buildings or complex constructions, where installing new network cables could be costly or impractical (Rahman & Lee, 2021).[47]
TelConnect then struck the desired balance between these two technologies, with the small cells providing high capacity and stable indoor connections and the repeaters assuring continuity of signals in hard-to-reach areas like basements and inner offices. Together, they formed a layered coverage system that nullified the disadvantages that came with exclusive reliance on outdoor macro towers.[48]
In addition to technological advancement, the project taught the unarguable importance of working together day by day in the installation and optimization process among network engineers, building owners, and customers. This experience confirms that planning alone is not sufficient; human and logistical coordination is of equal importance.
In summary, TelConnect's hybrid deployment serves as a prime case study for how telcos can go down a sustainable, yet effective avenue for indoor coverage. As data from smartphones continues to soar, telecom operators will have to mint multi-tech solutions,

which will probably form the future basis for similar approaches to be integrated indoors.[49]

Forthcoming Work

Follow-up research studies have suggested that by the deployment of small cells and repeaters TelConnect significantly improved indoor coverage and service quality. This project was not only able to improve the quality of services to customers but also optimize the overall network through effective load balancing. This project shows that hybrid solutions will be a viable, long-term strategy for an operator faced with similar indoor coverage challenges. Future projects should consider utilizing AI for real-time optimized signals and further rollout of 5G small cells.

Proposition

Network stability depends on strong and reliable communication channels. Two major technologies that support modern communication are fiber optic backbones and satellite links. These systems ensure global connectivity, fast data transmission, and stable performance even during emergencies.

Fiber optic cables form the core backbone of the internet. They are thin glass strands that transfer data using light signals, allowing extremely high speed and low latency communication. These cables run across cities, countries, and oceans, connecting data centers and telecommunication networks worldwide.[50]

Satellite links use radio waves to send signals between Earth and satellites in orbit. They are especially useful in remote regions where fiber optic infrastructure cannot be installed.

Both technologies complement each other. Fiber optics handle heavy traffic with speed and stability, while satellites ensure accessibility and emergency communication.

Fiber Optic Backbone:

Fiber optic networks are highly stable because they have massive bandwidth and minimal signal loss. They are designed with redundancy, ensuring that if one cable is damaged, data is automatically rerouted through another path.

Satellite Links:

Satellite networks provide wide coverage and are extremely valuable during natural disasters like earthquakes, floods, and storms. When ground networks fail, satellite communication continues to operate.

Analysis

Fiber optic backbones deliver stable, high-speed performance, while satellite links offer resilience and wide coverage. Together, they ensure global network stability and uninterrupted communication.

Role of 5G Technology in Solving Internet and Telephony Interruptions in Pakistan

Pakistan has struggled for years with slow internet speeds and frequent network interruptions, especially in rural areas. The arrival of 5G technology offers a strong solution to these problems. With its ultra-fast speed, low latency, and high capacity, 5G can make both internet and telephony services more stable and efficient. [49][50]

Current 3G and 4G networks in Pakistan often become overloaded, causing dropped calls and slow connections. In contrast, 5G can handle far more users and devices at once without affecting quality. This means faster downloads, smoother video calls, and more reliable communication, even in crowded cities.

In remote areas where building fiber-optic networks is costly, 5G's wireless broadband can provide strong internet signals through fixed wireless access. This helps bridge the digital gap between rural and urban communities, allowing people in remote regions to benefit from online education, e-health services, and digital business opportunities.

The extremely low delay of 5G will also make voice and video calls clearer and more consistent, improving personal and professional communication. Industries like banking, media, and transport that depend on uninterrupted connectivity will gain the most.

In short, 5G has the potential to solve Pakistan's long-standing connectivity issues by improving speed, reliability, and coverage. With proper planning and investment, it can boost economic growth, support innovation, and connect millions of people to the digital world more effectively than ever before.

The Impact of Network Infrastructure on Internet Speed and Stability.

The impact of network infrastructure on internet speed and stability is very importance to use internet speeds on any country using higher internet like 4G, 5G. Network infrastructure has a direct and significant impact on internet speed and stability. Key factor like bandwidth capacity, latency, the type and quality of physical component and quality of hardware to network design and connection to connect devices through internet.

Physical Medium:

The physical medium used for data transmission is a primary determinant of speed and stability.

Fiber optic cables:

Fiber Optics Internet cable Insulate by cover. It provides high internet speed from long distance. The Fiber Optics Cable works all over the world through ocean.

Copper Cables (Ethernet/DSL):

Copper Cables like Ethernet, DSL have short Bandwidth which results in loss of signal over long Distances.

Wireless (Wi-Fi/5g/Satellite)

Wireless network offer mobility but can be affected by physical obstructions (walls, furniture), distance from the access point, channel overcrowding and other wireless devices.

Impact on Stability:

Hardware Quality and Maintenance:

Reliable, high-performance hardware is less prone to failure or performance fluctuations. Regular firmware updates and maintenance address vulnerabilities and bug fixes that can otherwise lead to instability.

Redundancy and Network Design (Topology):

A well-designed network architecture, such as a mesh or hybrid topology with redundant pathways, ensures that connected devices one to another and share data one place to another.

Latency and Packet Loss:

A robust infrastructure minimizes latency (data delay) and packet loss (lost data packets). High latency and packet loss can be caused by long physical distances from the data source.

Security:

Strong network security measures, such as properly configured firewalls and monitoring tools, protect the network from cyber threats and attacks like malware, Trojan and various (DDoS attacks).

Challenges in Deploying 5G Networks in Developing Countries:

The spread of 5G networks shows a big tech step forward that offers quicker connections, less waiting time, and help for new tools like IoT and AI systems. But some countries with lower income have hard times in using and putting into place this next way of technology.

A big problem is the readiness of roads and tools. Many growing countries do not have the long fiber lines, new base stations, and steady power systems needed for 5G. Fixing or creating this stuff needs a lot of money, which many leaders and phone companies find hard to pay. High costs to set up and little chance to get funds slow things down more .[47][50]

Another big problem is the lack of skilled workers. The good use of 5G needs smart engineers and IT folks who can handle tricky networks. In lots of developing nations, there is a hole in teaching and training systems that limits the availability of such expertise.

Rules and rules trouble also have a big part. Holds in wave space sharing, no clear country plans, and slow red tape get in the way of 5G setup. Plus, shaky politics and money doubts push away outside money in phone systems

In the end, digital gap is still a worry. While city places might gain from 5G, country and distant areas could be left out because of weak connections and low reasons for companies. To sum up while 5G can change talking and work its rollout in developing lands needs joined work in building roads, changing rules, and growing skills to beat these hard problems.

Comparative Study of Mobile Network Coverage: Pakistan vs USA:
The importance of mobile networks in modern life to communication, education or economy. In The global digital division some countries have strong coverage or others struggle. Why comparing **Pakistan and the USA** is meaningful ? because our country Pakistan is still developing vs USA is developed. **For example** "While the United States enjoys near-complete 4G or 5G access, Pakistan still faces coverage gaps in rural areas and hilly regions."[41][45]

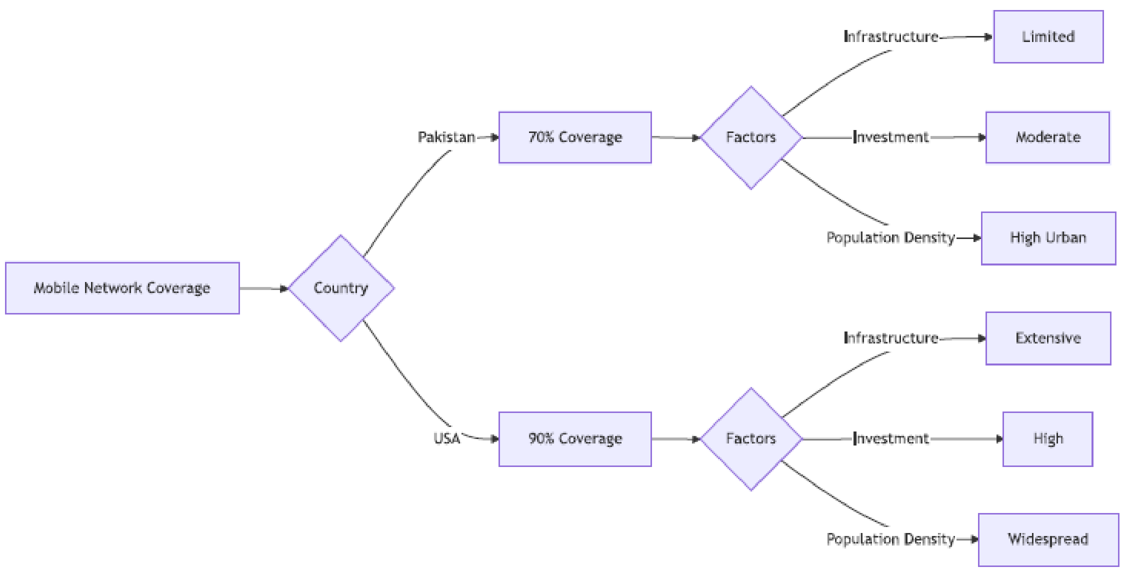

Figure 11: comparison between Pakistan and USA

In this , **our aim** is to compare network coverage, speed, and reliability between the two countries. We dissccus where our country faces issues uneven mobile coverage in Pakistan vs USA. Poor internet speed, dropped calls, or signal loss issues. Lack of investment and infrastructure challenges.

	Pakistan	United States
Technology Availability	Mostly 3G and 4G; 5G just starting in major cities	Widespread 4G and advanced 5G networks across states
Average Internet Speed	15–25 Mbps (mobile average)	80–150 Mbps (mobile average)
Network Stability	Frequently affected by power cuts, weak signals, and overload	Highly stable with strong backup systems and modern infrastructure
Telecom Infrastructure	Fewer towers, limited fiber optic backbone, and older equipment in some regions	Dense network of towers, high investment in fiber optics and satellites
Government Support and Policy	Moderate; focus on affordability but slow in modernization	Strong; continuous funding, regulation, and 5G expansion policies
Main Telecom Operators	Jazz, Zong, Telenor, Ufone	AT&T, Verizon, T-Mobile
International Investment	Supported by China (Huawei, ZTE) under CPEC and BRI	Supported by domestic investment and private sector innovation
User Experience	Inconsistent; signal drops common in	Smooth and reliable connectivity with

	crowded or remote zones	high customer satisfaction

"According to world reports, the United States maintains high-speed of 5G coverage across most of its territory, while Pakistan's network still depends mainly on 4G technology in major cities." Pakistan's main issues of low tower density, hilly terrain or limited investment. USA's success factors like fiber backbone, strong regulations, early 5G rollout.

Future Roadmap for Building a Reliable, Non-Stop Telecommunication Ecosystem in Pakistan:

Telecommunication has become an essential part of today's life that connects everyone across the country. In Pakistan, telecom sector grows over past 20 years. We are currently using 4G services and are now moving towards the 5G technology. However, the network is not stable as power shortage or old infrastructure can interrupt service. To build a reliable and fast telecommunication system in Pakistan we need a clear roadmap that concentrate on the advance technology, services for all areas, and long-term sustainability. A strong system like this makes sure people have access to their important services like healthcare, business, and communication anytime.[44][29]

Steps to Make a Reliable Telecommunication Ecosystem:

Improve Internet and Mobile Networks:

This is the first step to make the telecom system more reliable. Many rural and northern areas still have weak signals and poor connectivity that cause difficulty in communication, limited access to the internet, and slow down emergency responses. To fix this problem private and govt telecommunication companies need to work together to expand fiber optic networks and build more mobile towers in these areas so everyone get fast and better service.

Use New Technology:

The next step is to use advanced technologies. Like introducing 5G technology in Pakistan make the internet faster and more reliable. With the use of 5G people can download documents quickly, use new things, and make communication smooth.

The other important technology is satellite-based internet. It can provide connections to those areas where building towers are difficult. By using these technologies businesses can grow, students learn more, and people get more services.

Data Protection:

The other important step is to ensure cyber security. The communication system is becoming more digital, and the risk of cyberattacks is increasing. To overcome the risk of cyberattacks, we need strong security measures to protect data and build trust in users. Creating strict rules in telecom companies can help to reduce attack risk and make user data secure.

Energy Sustainability:

Energy is one of the most important things for keeping telecommunication running all the time. Most towers and internet services need electricity to work, and power outages in Pakistan can stop these services that cause problems for people and businesses. To solve this problem, use energy sources, like solar panels. Solar energy is reliable and works even in those areas where electricity is not always available. By using this solution, we make sure that internet and mobile services are available all the time and reduce electricity cost.

Train Skilled People:

Another important step to make the telecom system reliable is to develop skilled people who can manage and improve telecom networks. Pakistan needs well-trained engineers, technicians, and network managers to keep the system running smoothly. Technical institutes should work with telecom companies to create practical training programs. These programs can teach students about 5G technology, network management, cybersecurity, and other modern telecom tools. Internships and different projects can help students gain experience. By training more skilled professionals, Pakistan can make sure there are enough experts to maintain strong, reliable, and advanced telecommunication networks for the future.

Strength and weaknesses

Building a reliable, non-stop telecommunication system in Pakistan is very important for the country's development. By improving services and using advanced technologies we make the telecom system more reliable. A strong reliable network make people connected all the time and provides emergency services anytime. Making a modern telecommunication system will benefit everyone in the future.

The role of fiber optic backbone and Satellite links in network stability:

In fiber optic use glass or plastic cable for traveling signals. This is backbone of network and telecommunication. In which signal travel in high speed and high quality in over vast distance up to tens of kilometers. This cable also use in under sea . In which low chance signal lose. Signal transfer in light speed. Fiber networks boast very low latency, in which used time-sensitive applications like online gaming, video calling, and financial transactions. It is used for physical connectivity.Fiber optic cables are not susceptible to electromagnetic interference (EMI) or radio frequency interference (RFI), which often disrupt electrical cable .

Statellite links contribute network stability.

Conclusion:

Satellite communication can reach almost any location on Earth. When natural disasters damage networks, satellite systems can be serve as a vital lifeline for emergency services . Statellite used for globally and fiber optic used in urban areas. Satellites are fundamental for mobile communications across wide area. satellite internet can suffer from high latency weather disruptions, fixed wireless can offer lower latency and more stable connections when within range of a tower.

5G technology is expected to play a role in addressing internet and telephony interruptions in Pakistan. The government and telecom operators are working together to roll out 5G services, which promise faster data speeds.

5G will enhance connectivity, reducing call drops and internet interruptions.

5G technology will reduce latency, improving real-time communication and online services.The government plans to auction 5G spectrum by the end of 2025 or early 2026.The government aims to position Pakistan as a regional data transit hub. Pakistan faces infrastructure challenges, including limited fiber-optic coverage.

The high cost of 5G spectrum is a significant challenge.

Overall, 5G technology has the potential to transform Pakistan's digital landscape, but addressing infrastructure and regulatory challenges is crucial for successful implementation.

Spectrum Management and Bandwidth Allocation for Enhanced Connectivity

The good quality of mobile communication can be ensured with the help of the efficient spectrum management and bandwidth allocation. The number of users, devices, and demands on radio frequencies and bandwidth resources are increasing. This requires better management of these radio frequencies and bandwidth resources so the desired outcome will be; network connectivity will be seamless, interference will be reduced, and the performance of the network will improve. This report discusses basic techniques and strategies intended for spectrum utilization and bandwidth allocation to improve mobile network efficiency.

A spectrum refers to the range of radio frequencies used for wireless broadcasting. Bandwidth denotes the data-carrying capacity of a network connection. When managed wisely these two resources can support future demand for. The inefficient use of spectrum and poor bandwidth allocation can cause congestion in the network, low data rates, and a bad experience for users.

Techniques for Enhanced Connectivity:

Because dynamic spectrum allocation enables operators to deploy spectrum on a real-time basis, operators can reduce idle spectrum and lower interference. Carrier aggregation is a technology that combines several frequency bands for better and faster data rates. With cognitive radio technology, secondary users can share the spectrum with primary users by using unutilized channels. QoS mechanisms prioritize essential traffic so that voice and video applications function smoothly. Moreover, it uses SDN or Software Design Networking and AI to optimize the bandwidth automatically.

Efficient management of bandwidth and spectrum is essential for reliable, high-speed, mobile, energy-efficient networks. Through dynamic allocation, carrier aggregation, cognitive radio, and intelligent automation, network operators can provide better connectivity, reduce congestion, and address the increasing demand for smooth communication.

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