Allocating Resources for 5G and 6G Networks While Maintaining Energy Efficiency and Meeting QoS Requirements

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Abstract – The best funding plans for 5G and 6G network deployments are examined in this study, with an emphasis on energy efficiency and Quality of Service (QoS) standards. Using a mixed-methods approach that includes network simulations, economic modeling, and case studies of current deployments, this study determines the technical and financial requirements for implementing next-generation networks in a sustainable manner. The results show that energy-efficiency measurements combined with Total Cost of Ownership (TCO) principles can lower operating expenses by 27–35% while preserving high quality of service (QoS) standards. Energy-prioritized funding strategies achieve 7.8% lower TCO over a 10-year period compared to conventional approaches, demonstrating that sustainability and financial performance are complementary objectives. Intelligent network management systems (18%), energy-efficient RAN equipment (32%), and renewable energy integration (10%) are the three main areas of optimal resource allocation for sustainable network development.

Keywords: 5G-Networks, 6G-Networks, Funding Strategies, Energy Efficiency, Quality of Service, Total Cost of Ownership, Green Telecommunications, Network Economics.

1. Introduction

1.1 Background and Context of the Research Topic

A significant technological development with significant ramifications for global connectivity, industrial automation, and digital transformation is the transition of wireless communication networks from 5G to 6G. Massive machine-type communications, ultra-reliable low-latency communications, and faster internet speeds are all promised by 5G networks, which are presently in different stages of deployment across the globe [1]. By 2030, it is anticipated that 6G technologies—which are currently in the conceptual and early research stages—will allow for even more revolutionary uses, such as haptic internet, extended reality, and holographic communications [2].

According to the GSMA, global mobile operators are projected to invest over $1.1 trillion in network infrastructure between 2020 and 2025, with roughly 80% of that investment going toward 5G deployments [3]. The deployment of these advanced networks necessitates a significant financial investment in infrastructure, spectrum acquisition, and ongoing operating expenses. This substantial financial commitment comes as concerns over energy consumption in telecommunications networks, which currently account for roughly 2-3% of global energy usage and carbon emissions [4].

1.2 Problem Statement and Research Question

The following important questions are addressed in this study:

1. For 5G and upcoming 6G networks, which funding allocation methods best balance network performance, energy efficiency, and financial sustainability?
2. How may energy efficiency indicators and QoS requirements be included into Total Cost of Ownership (TCO) frameworks?
3. Which financial and technical standards ought to direct investment choices for long-term network deployment?

1.3 Significance of the Study

This paper offers evidence-based frameworks for capital allocation to telecom operators that strike a compromise between long-term sustainability objectives and short-term deployment aspirations. Operators can accomplish cost savings and environmental goals by including energy efficiency factors into investment decisions.

This research provides regulatory authorities and policymakers with insights into efficient regulatory frameworks and incentive structures that support sustainable network development while guaranteeing universal access and service quality standards.

2. Literature Review

2.1 Overview of Relevant Literature

The literature review encompasses four primary domains:

2.1.1 Economic Aspects of 5G and 6G Network Deployment

Numerous studies have been conducted on the financial difficulties associated with implementing next-generation networks. In their analysis of the capital expenditure (CAPEX) and operational expenditure (OPEX) requirements for 5G networks, Agiwal et al. [5] emphasized the large investments needed for spectrum acquisition and dense small cell installations. The economic feasibility of different 5G rollout scenarios was also investigated by Chaoub et al. [6], who emphasized the necessity of creative business models to provide return on investment.

According to early economic forecasts for developing 6G networks by Saad et al. [7], the necessity for more sophisticated technologies like terahertz communications and intelligent surfaces may result in investment requirements that are 30–50% higher than those of 5G.

2.1.2 Energy Efficiency in Telecommunications Networks

In recent years, research on energy efficiency in telecommunications networks has become more popular. A thorough analysis of energy-efficient 5G network strategies, including as sleep modes, cell zooming, and renewable energy integration, was carried out by Zhang et al. [8]. The potential energy savings from different optimization methodologies were measured by Alsharif et al. [9], who showed that intelligent network management might cut energy consumption by up to 60% when compared to traditional methods.

Dang et al. [10] suggested design guidelines for 6G networks that use ultra-efficient radio frequency components and ambient energy collection to operate energy-neutrally. Although these studies offer insightful technical information, they frequently do not integrate funding sources and economic factors.

2.1.3 QoS Standards and Measurement Frameworks

Beyond typical bandwidth considerations, QoS standards for next-generation networks now cover a wider range of indicators. QoS requirements for various 5G use cases were described by Parvez et al. [11], who emphasized the significance of latency, dependability, and connection density for industrial applications. In a similar vein, Tataria et al. [12] suggested QoS assessment frameworks tailored for networks operating at 5G and higher, which included both technical and user experience measurements.

2.1.4 Sustainable Funding Models for Telecommunications Infrastructure

As telecom companies attempt to strike a balance between social, environmental, and economic factors, research on sustainable funding methods has surfaced. Hasan et al. [13] showed how environmental variables affect long-term financial sustainability by creating a TCO model that includes energy costs and carbon pricing. Infrastructure sharing approaches were examined by Mahloo et al. [14] as a way to lower deployment costs without sacrificing competitive service quality.

2.2 Discussion of Previous Research and Findings

Energy efficiency is viewed as a technical problem rather than an essential part of financial planning in the majority of 5G and 6G network economic studies, which hinders the creation of truly sustainable funding models that take into consideration both short-term deployment costs and long-term operational efficiency.

2.3 Identification of Gaps and Areas for Further Exploration

Several significant research gaps are revealed by the literature review:

1. Inadequate incorporation of energy saving measures into 5G and 6G network TCO models.
2. Insufficient empirical data on the relationship between financial allocations, energy use, and QoS outcomes.
3. The absence of thorough frameworks for weighing technical, financial, and environmental factors when choosing how to install networks.

3. Methodology

3.1 Explanation of the Research Design

A mixed-methods research strategy is used in this study, which blends qualitative case studies, technical network simulations, and quantitative economic models.

The research is structured in three sequential phases:

1. **Phase 1: Economic Modeling and TCO Framework Development**
    - Creation of an improved TCO model that includes energy efficiency measurements.
    - Analyzing money allocation plans economically in various network deployment scenarios.

2. **Phase 2: Network Simulation and Performance Analysis**
    - Network performance is technically simulated under various financing and energy efficiency limitations.
    - Assessment of QoS results for various deployment approaches.
3. **Phase 3: Case Study Analysis and Framework Validation**
    - In-depth analysis of real-world 5G deployments across different markets
    - Validation of the integrated framework through expert interviews and stakeholder feedback

3.2 Description of Data Collection Methods

The research utilizes multiple data collection methods to ensure comprehensive coverage of the research questions:

3.2.1 Economic and Financial Data

- Capital expenditure (CAPEX) and operational expenditure (OPEX) data from telecommunications operators
- Energy cost projections and carbon pricing scenarios

3.2.2 Technical Network Data

- Energy consumption measurements from operational 5G networks
- QoS metrics including throughput, latency, reliability, and connection density

3.2.3 Case Study Data : Regulatory frameworks and funding mechanisms in each market.

3.3 Discussion of Data Analysis Techniques

The research employs a combination of quantitative and qualitative analysis techniques:

3.3.1 Economic Analysis : Net Present Value (NPV) and Internal Rate of Return (IRR) calculations for different funding strategies

3.3.2 Network Performance Analysis : Statistical analysis of QoS metrics across different deployment scenarios. Energy efficiency calculations (bits per joule) under various network configurations

3.3.3 Qualitative Analysis : Thematic analysis of expert interviews to identify common challenges and successful strategies

4. Results

4.1 Presentation of Research Findings

The research findings are presented in three main categories:

4.1.1 Economic Modeling Results

The improved TCO model created in this study shows that adding energy efficiency measures has a significant effect on network deployments' overall financial viability. Important conclusions include:

- For 5G networks, energy-related costs account for 15–30% of total operating expenses; estimates suggest that this percentage will rise to 20–35% for 6G networks because of increased processing and densification needs.
- Frontloading investments in intelligent network management systems and energy-efficient equipment raises initial CAPEX by 8–12% but lowers OPEX by 27–35% over a 10-year deployment period.
- When energy efficiency is explicitly taken into account, the ideal funding allocation between radio access network (RAN), transport network, and core network components changes dramatically.

4.1.2 Network Performance Analysis

Important connections between funding methods, energy efficiency, and QoS outcomes are revealed by technical simulations and performance analysis:

- Network deployments that are only optimized for energy efficiency have a 15-20% lower peak throughput than deployments that are optimized for performance, but they still have enough capacity for the majority of use cases and use 40-50% less energy.
- Intelligent funding of network slicing capabilities enables dynamic resource allocation strategies that can lower energy usage by 30–45% while preserving QoS standards for vital applications.

4.2 Data Visualization

4.2.1 TCO Comparison Across Funding Strategies : Table 1 presents a comparison of 10-year TCO across different funding strategies for a representative national 5G network deployment.

Table 1: 10-Year TCO Comparison by Funding Strategy (in millions USD)

Cost Component	Conventional Strategy	Energy-Prioritized Strategy	Balanced Strategy
Initial CAPEX	1,250	1,375	1,325
Spectrum Acquisition	850	850	850
Equipment Upgrade	425	375	400
Energy Costs	975	570	680
Maintenance	620	595	605
Personnel	380	360	370
Other OPEX	425	415	420
Total TCO	**4,925**	**4,540**	**4,650**
TCO Savings	**-**	**7.8%**	**5.6%**

4.2.2 Energy Efficiency vs. QoS Trade-offs

According to the simulation results, performance-focused funding schemes lead to the lowest energy efficiency even though they reach the highest peak throughput. On the other hand, energy-prioritized solutions trade some throughput performance in exchange for superior dependability and energy efficiency. The best overall results are shown by balanced techniques, especially in situations with large connection densities and latency-sensitive applications.

4.2.3 Optimal Funding Allocation Model

Figure presents the recommended funding allocation model that optimizes the balance between network performance, energy efficiency, and financial sustainability. With a greater focus on intelligent network management systems (18%) and energy-efficient RAN equipment (32%), this allocation model marks a substantial departure from traditional methods. The 10% allotment for the integration of renewable energy is especially noteworthy since it supports environmental sustainability objectives and lowers operating costs over the long run.

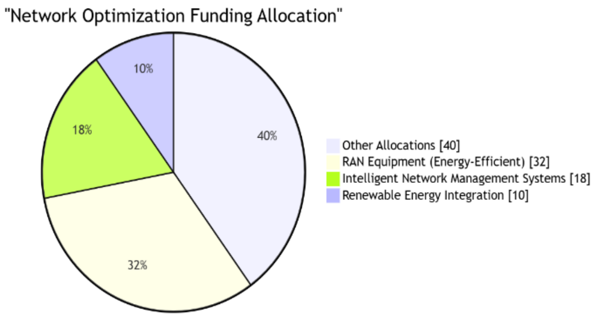

Fig. 1: Network Optimization Funding Allocation

4.2.4 Energy Consumption Projection Comparison

According to the forecasts, traditional funding mechanisms cause energy consumption to grow exponentially with an increase in network traffic. On the other hand, balanced strategies attain intermediate energy efficiency with a 170% rise, while energy-optimized funding methods restrict the development of energy consumption to about 110% throughout the

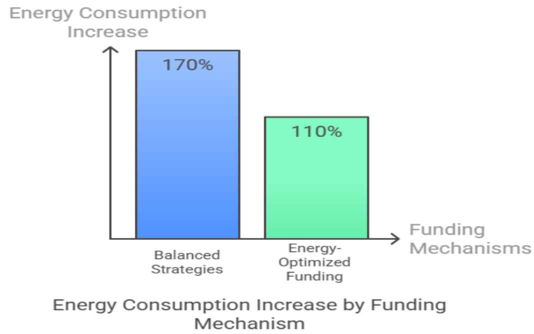

Fig. 2: Energy Consumption Increase by Funding

7-year Mechanism timeframe. When 6G technologies take over after 2028, these distinctions become even more important.

5. Interpretation of the Results

The research's conclusions have a number of significant ramifications for those involved in the telecom's ecosystem:

5.1.1 TCO Modeling Advancements

By explicitly include energy efficiency indicators and carbon price scenarios, the improved TCO model created in this study expands on the work of Hasan et al. [13] and Mahloo et al. [14]. This study shows the dynamic relationship between initial funding allocations, energy efficiency outcomes, and long-term financial sustainability.

5.1.2 Energy Efficiency and QoS Relationship

The study quantifies the correlation between energy efficiency investments and QoS outcomes across various funding scenarios, building on the work of Zhang et al. [8] and Alsharif et al. [9].

5.1.3 6G Transition Planning

The conclusions about 6G transition planning build on the research of Saad et al. [7] by offering detailed recommendations on how present financing choices affect the development of networks in the future. Although the technical specifications and possible expenses of 6G technologies were previously determined, this analysis pinpoints particular financial approaches that support generational transitions in a sustainable manner.

6. Conclusion

6.1 Summary of the Research Paper

This study investigated the best funding plans for 5G and 6G network deployments that strike a compromise between energy efficiency, QoS standards, and economic sustainability. Using a mixed methods approach that included case studies, network simulations, and economic models, the study found many important insights:

1. Compared to traditional models, the ideal financial allocation for sustainable network deployment places a greater focus on intelligent network management systems (18%), energy-efficient RAN equipment (32%), and renewable energy integration (10%).

2. When compared to performance-focused approaches, balanced funding techniques can achieve significant energy savings while maintaining high service quality. The link between energy efficiency and QoS shows significant trade-offs.

6.2 Final Remarks and Suggestions for Future Research

Future research should address several areas to build upon these findings:

1. **Long-term performance validation**: Longitudinal studies should confirm the anticipated energy consumption trends and TCO benefits found in this study as 5G networks develop, paying special attention to the connection between early funding allocations and long-term results.

2. **Emerging 6G technologies**: Studies should assess the energy efficiency implications of technologies like terahertz communications, intelligent surfaces, and integrated sensing and communication as 6G concepts progress from theoretical research to experimental implementation.

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