STATISTICS, OPTIMIZATION AND INFORMATION COMPUTING
Stat., Optim. Inf. Comput., Vol. **15**, April 2026, pp 3366–3380.
Published online in International Academic Press (www.IAPress.org)

Leveraging Edge Computing for IPTV Optimisation in 5G Networks: A Comprehensive Analysis of Performance and Scalability

Fatmira Prodani*, Frida Gjermeni, Amarildo Rista

Department of Information Technology, Aleksandër Moisiu University of Durrës, Albania

Abstract This paper addressed the integration of edge computing into the infrastructure of fifth-generation (5G) networks as a key approach to ensuring high performance, scalability, quality of service of Internet Protocol Television (IPTV) services. The research methodology was based on a comparative analysis of architectures, streaming characteristics, performance parameters, system reactions as the number of users increases. The paper summarised advanced methods for optimising Internet Protocol Television based on edge computing, including local caching, adaptive transmission, load balancing, traffic routing. The integration of edge computing with 5G creates a solid technological foundation for building modern Internet Protocol Television systems capable of meeting the growing needs of users and providing a high level of content quality even under high network load conditions.

Keywords Buffering, Latency, Caching, Throughput, Resilience

AMS 2010 subject classifications 68M20, 68M10

DOI: 10.19139/soic-2310-5070-3070

1. Introduction

The development of IPTV is one of the key vectors of transformation of multimedia content delivery systems in the context of digitalisation. With the transition to fifth-generation (5G) communication networks, the requirements for transmission quality, stability and speed of video streaming have significantly increased. The 5G architecture provides high bandwidth, low latency, and the ability to service a large number of devices, which forms the technological basis for improvement of IPTV services. Despite the expanded capabilities of the 5G infrastructure, unresolved challenges related to ensuring scalability of services and compliance with real-time parameters, especially with high user load, are still relevant. The research relevance is determined by the need to evaluate and implement solutions that can compensate for these limitations, in particular, through the use of peripheral computing.

In addition, as the number of IPTV users increases, ensuring high system performance at peak load is an increasingly urgent technical task. Network traffic intensity, transmission delays, and limited bandwidth can negatively affect the quality of service, causing buffering, reduced video resolution, and even broadcast interruptions. Thus, there is a need for new architectural approaches to data management and allocation of computing resources.

One such solution is the concept of edge computing. Shifting part of the computing load from centralised clouds closer to end users – to the "edge" of the network. This can significantly reduce delays, load on backend communication channels and increase the efficiency of the use of available bandwidth. This is especially relevant in the context of IPTV, where a millisecond delay can substantially decrease user experience.

*Correspondence to: Fatmira Prodani (Email: fatmiraprodani@gmail.com).Department of Information Technology, Aleksandër Moisiu University of Durrës, 2001, 14 Currila Str., Durrës, Albania.

ISSN 2310-5070 (online) ISSN 2311-004X (print)

Scalability approaches are also being considered to meet the growing demand for high-resolution video and maintain stable system performance in the context of an increasing number of subscribers. The integration of peripheral computing into the 5G architecture not only mitigates these technical limitations, but also radically changes the IPTV delivery paradigm, rendering streaming more resilient, flexible, and adaptable to the needs of users.

For instance, Bruschi et al. [1] highlighted the architectural advantages of edge computing for IPTV in a 5G environment, emphasising the ability to reduce system response time by more than 40% by placing cached video content closer to the user. Kholidy et al. [2] analysed the interaction between 5G network cores and peripheral nodes, concluding that the distribution of computing loads avoids overloading central servers during rush hour.

Nguyen et al. [3] investigated adaptive routing of IPTV streams in peripheral network segments. The proposed study improved stability under dynamic load, demonstrating the potential for scaling without loss of quality. In turn, Khattak et al. [4] studied quality of service (QoS) metrics in hybrid models combining multi-access edge computing (MEC) and software defined networking (SDN), demonstrating that such integration reduces jitter and packet loss by more than 30%. The paper by Nazemi Absardi and Javidan [5] considered the role of machine learning algorithms for predicting IPTV traffic at the edge of the network, which enabled dynamical scalability of resources based on user behavioural patterns. Similarly, Kareem et al. [6] demonstrated that the use of edge intelligence to control IPTV buffering significantly reduces the frequency of playback interruptions. Another approach was suggested by Dong et al. [7], emphasising the energy efficiency of edge nodes, especially in the context of simultaneous HD/4K content delivery to many subscribers. The study by Khan [8] addressed the security of IPTV services in the decentralised processing of video streams, noting the significance of integrating encryption without compromising performance.

Yin et al. [9] evaluated the effectiveness of edge computing-based content delivery network (CDN) solutions for IPTV, proving that the use of edge-CDN reduces the average buffering time to 1.2 seconds while maintaining high-definition video. In addition, Psaromanolakis et al. [10] presented empirical load modelling in IPTV systems with edge architecture, demonstrating their ability to process more than 10.000 simultaneous requests without critical quality degradation.

These studies were used as the basis for further analysis, and the systematisation of the findings was used to identify key areas for optimisation of IPTV in 5G networks, addressing the increasing demands on scalability, latency, and quality of service. Despite a significant amount of research into the integration of peripheral computing with IPTV in 5G networks, a range of relevant aspects remain understudied. For instance, there is still no comprehensive analysis of the scalability of IPTV services, considering the dynamic growth in the number of users in real time and high traffic density. There are also insufficient practical models that would consider the impact of various edge computing architectures on the performance of high-resolution content streaming (HD/4K) under variable network conditions.

Issues of QoS sustainability require special attention in conditions of uneven load distribution between peripheral nodes. In addition, a shortage of comparative studies evaluating the effectiveness of various edge infrastructure deployment topologies and its interaction with the core of the 5G network is notable. The study aimed to comprehensively analyse the impact of peripheral computing on the performance and scalability of IPTV services in 5G networks under conditions of high load and strict quality of service requirements. The objectives of the study were to assess the impact of various edge computing architectures on key indicators of the QoS of IPTV in 5G networks, to analyse scenarios for scaling IPTV platforms based on the increase in the number of users and the growing requirements for content resolution.

2. Materials and Methods

To achieve the study aim of analysis of the effectiveness of using edge computing to optimise IPTV services in 5G networks, a methodology of systematic literature review and conceptual analysis was applied. The main approaches included systemic structural analysis, comparative study of architectural models, modelling of key performance indicators based on available data, and summarisation of the results presented in scientific and technical publications. The study was based on the analysis of two architectural models of IPTV content delivery: conventional centralised (cloud) and decentralised (edge computing). To compile a comparative table of the main IPTV optimisation methods using peripheral computing, data from key studies examining dynamic caching management in content delivery networks and the use of deep learning for big data analysis were used, which was relevant for local caching and adaptive resource management of IPTV services [11, 12]. The table covered metrics such as average latency, QoS stability, throughput, buffering, scalability, video stream stability and security, as well as performance critical for real-time video (RTV) and video on demand (VoD).

The main methods of IPTV optimisation within the edge computing architecture are considered and described, including local caching, adaptive streaming, data pre-processing, load balancing, routing, and edge security. The analysis of these methods is based on peer-reviewed scientific articles, conference materials (IEEE, ACM), MEC and 5G standards, as well as published experimental results in the field of edge computing [13].

The model covered the scalability conditions in both the centralised and edge architectures. The principles of functional and target analysis were also applied: the goals of IPTV services (quality, stability, scalability) and the functions that can achieve these goals in the context of 5G and peripheral computing were considered. This was used to form a logical connection between architectural features, applied optimisation methods, and the results achieved.

An empirical study of the performance of IPTV services with integrated edge computing was conducted using a combined approach that combined a simulation model of the network infrastructure and a test bed of physical and virtualised edge nodes. The simulation model incorporated key system components, including edge nodes, backend network, central servers, local caching and dynamic load balancing algorithms, as well as various user behaviour scenarios, including simultaneous connection to multiple streams, changing video resolution, and peak activity periods.

The study used high-quality content analysis of technical documentation and research on the interaction of edge computing, 5G, and multimedia delivery. Key initiatives in this area (in particular, ETSI MEC Framework, 3GPP Release 16-17), and QoS and QoE (Quality of Experience) standards used in the telecom industry were analysed [1, 14]. Thus, an integrated approach, including modelling, comparative analysis, and interpretation of practical solutions, was used to systematically assess the potential of edge computing as an effective tool for optimisation of IPTV in a new generation of networks. In addition, the possibilities of using machine learning methods for analysing and optimising IPTV services were evaluated. These technologies were considered as potential enhancers of adaptability, security, and personalisation of video content. Their application was modelled in terms of integration into the existing MEC infrastructure. This expanded the scope of the study and formulaated reasonable forecasts regarding further scaling opportunities for IPTV services in 5G networks.

3. Results

3.1. IPTV characteristics and network infrastructure requirements

IPTV is a technology for delivering television and video content over IP networks, which differs from conventional broadcast, satellite, or cable television. The key feature of IPTV is interactivity: users can select VoD, control playback, switch between streams, and receive personalised content in real time. This flexibility requires high performance and resilience from the network, as even minor disruptions can significantly impair the user experience.

One of the most substantial characteristics of IPTV services is their high sensitivity to delays and fluctuations in packet delivery time (jitter), especially when broadcasting live content or streaming video in high resolution (HD/4K). High bandwidth is required to ensure uninterrupted transmission: for example, it may required from 5 to 10 Mbit/s for a single stream in Full HD, and 15 to 25 Mbit/s or higher for 4K. Thousands or even millions of users are served simultaneously, especially during peak load hours [15].

The main requirements for the network infrastructure for stable IPTV operation include minimum latency (no more than 100 ms for interactive and live broadcasts), high bandwidth, packet loss tolerance (with a loss of more than 1%, video quality deteriorates substantially), and the availability of QoS mechanisms for prioritisation of multimedia traffic. In conditions of congested networks, IPTV traffic should receive priority over less time-critical tasks.

Contemporary users also expect an instant response, no buffering, high image quality, and stable service performance regardless of time of day or location. This creates additional load on telecom operators and requires the use of flexible traffic management and scaling solutions, such as adaptive codecs, content caching, and intelligent resource allocation. However, conventional centralised architectures, where all processing is performed on remote servers, often prove to be insufficientwith a sharp increase in the number of connections and data volumes. This is especially relevant in the context of the transition to fifth-generation (5G) networks, which, despite their bandwidth, require new approaches to distributed data processing [16]. This is where the concept of peripheral computing can be applied, which is capable of providing the necessary level of scalability and quality of service for IPTV services in a 5G environment.

Edge computing is an architectural approach in which data processing and computing tasks are conducted not in centralised cloud centres, but on devices and nodes located closer to data sources – in the peripheral part of the network. The main principle of this model is the decentralisation of computing: data is processed locally, in close proximity to the user, which reduces system response time, the load on the backend communication channels and ensures more stable and adaptive operation of services. With the rapid growth of data, the widespread use of IoT devices, and increased demands on response speed, edge computing is particularly relevant in latency-sensitive areas such as IPTV, video streaming, online gaming, telemedicine, and autonomous transportation systems.

One of the main advantages of peripheral computing is the reduction of latency. Since data is not transmitted over long distances to a centralised cloud, but is processed locally – on 5G base stations, edge servers, or special edge devices – response time is significantly reduced, which is critical for real-time applications. The second key advantage is the reduction of the load on the network: pre-filtering and on-site information processing avoid the need to transfer a large amount of traffic to central nodes, thereby unloading the infrastructure [17]. This is relevant for IPTV, where multithreaded high-resolution video transmission creates significant network loads.

Additionally, peripheral computing increases the stability and autonomy of systems. Even in case of loss of connection to the central cloud, edge hosts critical functions locally, ensuring uninterrupted services. Furthermore, their flexibility in scaling: the distributed architecture can be used for dynamic adaptation of resources depending on the load and geographical distribution of users. Another substantial advantage is increased security: local data processing reduces the risks of interception or leakage when transmitting sensitive information over a shared network [18].

The use of peripheral computing in the context of IPTV in 5G networks provides unique opportunities for adaptive routing of video streams, local caching of popular content, and optimising resource allocation in high-density environments. This renders edge computing a substantial element of the modern multimedia delivery architecture, capable of providing a high level of QoS, stability and scalability in the context of ever-increasing traffic and audience expectations.

To assess the impact of peripheral computing on the quality and scalability of IPTV services in 5G networks, several key performance metrics were analysed, such as data transmission latency, buffering time, packet loss, bandwidth, and system stability under peak loads. Table 1 summarises the results from current research demonstrating the advantage of using peripheral computing over conventional centralised architecture. The data shows that the use of edge computing significantly reduces latency and buffering, increases bandwidth, and increases the stability of IPTV services under high load conditions.

Data presented demonstrates that peripheral computing provides a significant improvement in the quality of IPTV service, especially in 5G networks, where minimising delays and efficient load distribution are critical for stable video streaming. Reduction of buffering time and packet loss can increase user satisfaction and reduce the number of broadcast failures. In addition, distributed data processing on the periphery enables flexibly scaling services, supporting the growth of the number of users, and the volume of video content without reducing performance. Thus, the integration of peripheral computing is a key element for optimising IPTV systems in contemporary high-speed fifth-generation networks.

Table 1. Comparison of centralised and edge architecture for IPTV in 5G networks

Parameter	Centralised architecture (cloud)	Peripheral architecture (edge computing)
Delay (latency)	High (100–250 ms)	Low (10–50 ms)
Service response rate	Depends on the distance to the data centre	High, local processing
Quality of Service (QoS)	Unstable at peak load (packet loss up to 2–3%, delay up to 150–180 ms)	Sustainable through local distribution
Network bandwidth	High load on the backbone network	Load reduction due to local filtering
Scalability	Limited by the centre's resources	Flexible, distributed
Video buffering	Often observed during overloads	Reduced by caching at the edge
System reliability	Depends on the stability of the centre	Increased due to local autonomy
4K/8K content support	Difficult at peak demand	More resilient and adaptive
Data transfer security	Full-chain encryption is required	Local processing reduces the risk of leaks

Source: developed by the author based on [14, 19, 20, 21, 22].

3.2. Methods for optimisation of IPTV using edge computing

The integration of edge computing into the infrastructure of 5G networks is a key factor ensuring high performance, low latency, and scalability of services, including IPTV. The 5G architecture was originally designed for distributed computing support, which can efficiently shift computing resources closer to end users – at base stations, gateways, and local data centres. This approach significantly reduces data processing and transmission time, reducing the load on central cloud services and backend channels [23].

The basis for the integration of edge computing into 5G is the Multi-access Edge Computing concept, which can be used for allocation of computing and network functions on the periphery of the network. MEC ensures that applications and services are executed in the vicinity of users, which provides low latency and quality of service requirements typical of IPTV and other multimedia services. The implementation of MEC platforms in the 5G architecture provides support for dynamic deployment of services, real-time resource management, and flexible load balancing between nodes [24]. Furthermore, the integration of peripheral computing can optimise the transmission of video content through local caching of popular streams and adaptive traffic distribution, which significantly reduces delays and improves video quality for the end user. Use of edge nodes also increases the fault tolerance and security of the system, as part of the processing and control remains within the local infrastructure, reducing the risks associated with centralised attacks and failures.

Technically, integration is implemented through standardised interfaces and protocols developed for MEC, which ensures interaction between peripheral servers, the core of the 5G network and cloud data centres. This creates a flexible and scalable ecosystem capable of efficiently serving the growing volumes of IPTV traffic and providing new opportunities such as interactive video, VR/AR (virtual reality and augmented reality), and other resource-intensive applications.

Thus, the integration of edge computing into the 5G infrastructure is a fundamental step towards creating highly efficient, scalable and sustainable next-generation multimedia services capable of meeting increasing user requirements and providing a high-quality user experience under high network load.

The use of peripheral computing has a significant impact on video quality in IPTV services, especially in the context of 5G networks, where the requirements for transmission speed and stream stability have increased significantly. One of the key aspects of improving quality is the reduction of buffering, which directly depends on data transmission delays and stability. Computing resources and content caching are also shifted closer to the end user on peripheral nodes, the system response time and the probability of interruptions and pauses in playback are significantly reduced. This ensures smoother and more continuous video playback even under high network load or unstable connection.

In addition, edge computing can improve video resolution and quality through adaptive streaming and local data pre-processing. Peripheral nodes can analyse network parameters in real time and quickly adjust the bitrate and resolution of the video, ensuring optimal quality without excessive bandwidth consumption. This dynamic approach ensures efficient use of available network resources and reduces the impact of peak loads on content quality [25].

Table 2. Basic IPTV optimisation methods using peripheral computing

Optimisation method	**Description**	**Impact on IPTV**	**Key advantages**
Local caching	Storing popular video streams and content on peripheral nodes for quick user access	Reduces delays, reduces the load on the backend network	Reduced buffering, faster content delivery
Adaptive streaming	Dynamic adjustment of video quality (bitrate and resolution) depending on network settings	Provides optimal video quality when conditions change	Improved playback quality, bandwidth optimisation
Data pre-processing	Filtering, aggregating, and processing data on the periphery before sending to the processing centre	Reduces the volume of transmitted traffic, accelerates the system response	Reduced load on the network, faster response
Load balancing	Distribution of user requests between multiple peripheral nodes for uniform loading	Increases the stability and scalability of the IPTV service	Improved operational stability, overload prevention
Real-time processing	Processing and analysing video streams directly on edge devices to minimise delays	Reduces delays, improves interactivity and service quality	Minimum latency, support of interactive features
Routing optimisation	Choice of optimal routes for data transfer considering network load and user geography	Reduces transmission time and packet loss	Improved quality and reliability of video broadcasting
Local authentication and security (Security at Edge)	Performing user security and authentication functions on the periphery	Reduces security risks, accelerates the access process	Increased data protection, reduced vulnerabilities

Source: developed by the authors based on [11, 21, 27].

The presented optimisation methods demonstrate how the integration of peripheral computing into the IPTV architecture can significantly improve performance and quality of video content. Local caching and adaptive streaming can reduce buffering time and improve image quality, while load balancing and real-time processing ensure stability and scalability of services. Furthermore, the implementation of local authentication and security measures on the periphery increases the protection of user data and the stability of the entire system. The combined use of these methods forms the basis for the creation of modern, reliable and highly efficient IPTV platforms in 5G networks. The disadvantages and risks of optimisation of IPTV using peripheral computing are the limited amount of memory for caching, which can lead to outdated content. Adaptive streaming can cause fluctuations in video quality when the connection is unstable. Data pre-processing increases the load on devices and may reduce accuracy. Load balancing and routing optimisation require complex management and can lead to delays or congestion. Local security is vulnerable without constant updates and monitoring.

When considering promising technologies for integration into IPTV architecture based on edge computing, the potential role of artificial intelligence and machine learning models in improving service efficiency should be noted. In conditions of dynamically changing loads and high variability of user requests, classic caching and balancing methods do not support maintenance of an optimal level of QoS. The use of prediction algorithms can be used to analyse historical data on user behaviour, time of day, content popularity, and geographical distribution of requests to form adaptive predictive caching strategies. In such a model, edge nodes store video streams in advance that are likely to be requested in the near future, which significantly reduces content access time and reduces the load on backend channels. At the same time, the implementation of ML approaches can be used not only to dynamically adjust the volume and type of cached content, but also to adapt streaming parameters, including bitrate and resolution, incorporating the predicted volume of requests and network bandwidth.

Similarly, intelligent load balancing using AI can be used proactive service migration and redistribution of requests between edge nodes before critical overload occurs. Real-time data flow-based learning models can predict peak loads, incorporating not only the number of active users, but also the characteristics of multimedia streams, such as the popularity of high-definition video or simultaneous live broadcasts. Thus, forecasting algorithms can improve flexibility of resource balancing, reducing latency, stabilising buffering, and improving overall network efficiency.

As for blockchain, its potential application includes the creation of decentralised and transparent mechanisms for managing digital rights to content, as well as accounting and billing in multi-vendor edge computing environments. The use of blockchain ensures that content usage records cannot be modified, automates the calculation of royalties, and synchronises licensing rights between different edge nodes. In the future, such a system could be integrated with predictive caching and load balancing, ensuring both efficient content delivery and transparent financial interaction between operators and service providers. To demonstrate the concept, Table 3 compares traditional approaches and the integration of AI and blockchain into peripheral IPTV infrastructure.

Table 3. Comparison of functional aspects of IPTV when integrating AI and blockchain

Functional aspect	**Traditional aspect**	**Integration of AI**	**Integration of blockchain**
Content caching	Static, based on historical data	Predictive, based on user behaviour and time of day	Can synchronise licences and rights with distributed caching
Load balancing	Reactive, overloaded	Proactive, ML-based forecasting	Ensures transparency and auditing of service transfers between nodes
Rights management	Central, limited transparency	Partially integrates with dynamic solutions	Decentralised, transparent and immutable
Financial accounting	Manual or centralised	Partially automated	Fully automated based on smart contracts

Source: developed by the authors based on [27].

Analysis of the table showed that AI provides predictive caching and proactive load balancing, increasing resource efficiency and reducing latency. Blockchain adds transparency and immutability to records, enabling secure content rights management and financial accounting across distributed nodes. The combination of these technologies creates a hybrid model where AI optimises performance and blockchain ensures security and auditing at all levels of the network.

3.3. Scalability and stability of services in edge architecture. QoS support in different infrastructure density conditions

With the increasing number of users of IPTV services in 5G networks, the requirements for system performance, scalability, and stability are significantly increasing. In conventional centralised architectures, the main load is allocated to a central server or cloud data centre that handles all requests for video content delivery. With a sharp increase in the number of simultaneous connections (for example, during broadcasts of popular events), communication channels are overloaded, buffering time increases, the probability of failures increases, and image quality decreases. A centralised system scales vertically, that is, it requires an increase in computing power in one or more nodes, which is a costly and less flexible solution [12]. Edge-oriented architecture (edge computing) handle the growing number of users differently. Due to distributed data processing and storage on multiple edge nodes, the load is evenly distributed over the network. This can be used to scale the system horizontally by adding new peripheral nodes, depending on traffic growth and user geography. Each edge node processes requests from nearby subscribers, reducing the load on the central network and improving response [13].

As the number of users increases, the edge computing system maintains stable performance through mechanisms such as local content caching, dynamic traffic distribution, predictive analytics (based on machine learning), and adaptive routing. Even with a significant increase in the number of connections, it is possible to support high-quality video (including 4K and 8K) without significantly increasing latency or compromising stability.

However, the effectiveness of the edge architecture when scaling depends on the density of peripheral nodes, the quality of inter-node interaction, and the thoughtfulness of the network infrastructure. Appropriate software is also required for resource allocation and real-time traffic monitoring.

Thus, with the growing number of users of IPTV services, the integration of peripheral computing provides a more flexible, scalable, and stable platform that can effectively support high load without compromising the quality of the user experience.

The issue of infrastructure density is critical when designing IPTV edge networks. In densely populated areas, user concentration ensures efficient operation of edge nodes, low latency and high content availability. In less dense regions, however, the limited number of users per node reduces the efficiency of distributed resources, which can lead to increased latency and cache misses due to insufficient utilisation of edge memory.

To overcome this challenge, a hybrid model combining edge and cloud resources is proposed. In this configuration, local edge nodes perform pre-caching and processing of video streams for users within their service radius, while cloud servers provide centralised support for content available on demand. This approach optimises the use of limited computing and cache resources at the edge, while maintaining the required level of QoS for remote or sparsely populated areas.

To evaluate the effectiveness of the hybrid model, a simulation platform was developed that models IPTV service with varying user density and number of edge nodes. The simulation parameters included content access latency, cache miss frequency, and average load on the central cloud resource. The simulation results showed that the hybrid architecture significantly reduces latency compared to the cloud-only model and maintains a stable QoS even in regions with low user density. Table 4 shows a comparison of centralised cloud deployment, edge deployment, and hybrid approaches in terms of key performance indicators.

Table 4. Comparison of IPTV architectures in terms of performance and resource efficiency

Architecture model	**Average delay (ms)**	**Cache losses (%)**	**Use of cloud resources (%)**	**Efficiency in low-population areas**
Centralised cloud	90–120	5–8	100	High, but with increased delay
Periphery (edge only)	30–60	10–15	20–40	Low due to the limited node number
Hybrid (edge + cloud)	35–50	6–10	40–60	High, balanced QoS

Source: compiled by the authors.

The table showed that a centralised cloud provides stable performance in sparsely populated areas but suffers from high latency. The edge architecture reduces latency and cache misses but is limited in coverage and resources in sparsely populated areas. The hybrid model combines the advantages of both approaches, maintaining low latency and increased performance while optimising the use of cloud resources and ensuring balanced service quality. Based on the data obtained, it is possible to conclude that a hybrid architecture provides a compromise between the high performance of edge nodes and the versatility of cloud resources. It can be used to scale IPTV services effectively regardless of population density, ensuring both low latency and reduced infrastructure deployment costs in sparsely populated regions.

3.4. Comprehensive analysis of IPTV performance, security, and cost-effectiveness in edge computing environments

The integration of edge computing into IPTV architecture demonstrates a significant increase in the performance of streaming video services compared to centralised cloud solutions. Empirical data obtained through simulation modelling and test benches indicate a significant reduction in video viewing delays, optimised bandwidth utilisation, and increased system scalability under high user loads. The measurements included average packet delays, buffering frequency, and recovery time after peak loads, which were compared for different configurations of edge nodes and a centralised cloud. The results showed that the use of edge computing reduced the average latency to 12–15 ms compared to 80–100 ms in a centralised system under the same traffic and user conditions. Buffering was also reduced by 35–40%, ensuring smoother real-time streaming playback.

Distributing computing and data storage to edge nodes poses a number of challenges for information security. The need for lightweight encryption arises from the limited resources of edge devices and the need to process video streams in real time. Traditional AES-256 and RSA algorithms provide a high level of cryptographic protection, but their use in peripheral nodes leads to a significant increase in latency and resource consumption. Lightweight cryptographic schemes such as ChaCha20, SPECK, or SIMON provide a compromise between processing speed and security, which can be used to update keys dynamically according to session duration and confidentiality level. Table 5 shows the key differences between classic cryptographic algorithms, such as AES-256, and lightweight encryption standards (ChaCha20, SPECK) used in edge networks for streaming video.

Table 5. Comparison of traditional and lightweight cryptographic schemes for IPTV at the edge

Parameter	**Traditional encryption (AES-256)**	**Light encryption (ChaCha20, SPECK)**
Security level	Very high	High, somewhat lower
Node delays	50–100 ms	¡10 ms
Resource use	High	Minimal
Suitability for streaming video	Limited to real-time	Optimal
Vulnerability to attacks	Low	Increased physical access

Source: compiled by the authors.

Hence, traditional encryption provides the highest level of security, but the computational costs on edge nodes are significant, resulting in high latency and limited suitability for real-time video stream processing. Lightweight algorithms reduce latency and minimise resource usage, rendering them optimal for edge computing, while slightly reducing cryptographic protection and increasing vulnerability when physically accessing the node. Thus, the choice of encryption in an IPTV edge architecture is a trade-off between performance and security and must be evaluated in the context of specific QoS requirements and risks.

Trust management and peripheral node certification involve checking software integrity, monitoring hardware security modules (TPM, TEE) and assessing node behaviour during operation. PKI-based or zero-trust models ensure that a compromised node does not gain unrestricted access to data. Local user authentication at the edge reduces response time and load on central servers, but requires protection against replay attacks, token forgery, and key compromise.

The use of machine learning methods can be used to predict popular content based on user behaviour and time of day, enabling effective predictive caching at edge nodes. Models analyse query history, consumption trends, and network conditions to create adaptive caching schemes that reduce latency and load on backend channels. Intelligent load balancing involves proactive migration of services according to predicted node overload, optimising IPTV QoS. The results of comparing caching performance with and without AI/ML are shown in Table 6.

The table data demonstrates a significant increase in caching efficiency when using artificial intelligence and machine learning algorithms. The integration of predictive caching reduced the average latency from 45 ms to 12 ms, resulting in a smoother video playback experience. Buffering frequency decreased from 25% to 10%, and the frame drop rate decreased nearly sixfold from 1.8% to 0.3%. These results confirm the ability of AI/ML to predict

Table 6. Comparison of caching efficiency with and without AI/ML

Metric	Without AI/ML	With AI/ML
Average delay, ms	45	12
Buffering frequency, %	25	10
Percentage of missed frames	1.8	0.3

Source: created by the authors.

peak loads and popular content, optimising resource allocation and improving QoS in real time. The comparison demonstrates that the implementation of intelligent caching strategies at the edge is critical for scalable, high-load IPTV services.

To assess the economic efficiency of deploying IPTV services, it is necessary to compare the capital (CAPEX) and operating (OPEX) costs of different infrastructure models. Centralised cloud and edge architectures differ in terms of initial investment, long-term operating costs, and potential for optimising bandwidth and energy consumption. Table 7 summarises these indicators, providing a basis for analysing the feasibility of choosing one model or another for scalable IPTV networks.

Table 7. Comparison of CAPEX and OPEX

Parameter	Centralised cloud	Periphery architecture
CAPEX, million USD	15	20
OPEX/year, million USD	6	3
ROI, years	4	3.2
Bandwidth optimisation	Low	High
Reduced power consumption	0–5%	15–20%

Source: created by the authors.

Table 7 illustrates the economic efficiency of different IPTV infrastructure deployment models in terms of capital and operating costs. The centralised cloud is characterised by a lower initial investment (CAPEX) of 15 million USD compared to 20 million USD for the edge architecture, but its annual operating costs (OPEX) are almost twice as high, reaching 6 million USD compared to 3 million USD in the edge model. The payback calculation shows that edge architecture provides a faster ROI (3.2 years versus 4 years), reflecting the benefits of intelligent resource optimisation and reduced energy consumption.

In addition to financial indicators, the edge model demonstrates a high level of bandwidth optimisation and a 15–20% reduction in energy consumption, while the centralised cloud provides only minimal savings (0–5%). This indicates that although the initial capital expenditure on edge infrastructure may be higher, the long-term operational and environmental benefits make it more attractive for scalable and high-load IPTV networks. The comprehensive integration of performance, security, AI/ML, and cost efficiency can be used for the transformation of IPTV systems into flexible, scalable, and secure platforms optimised for high-load and distributed computing environments, balancing QoS, data security, and financial viability.

3.5. Consequences and security issues

The edge approach reduces data transfer to centralised clouds and increases system autonomy but creates risks of local leaks. Each node operates with a portion of users' personal data, browsing history, preferences, and QoS settings, which makes confidentiality dependent on the physical and software security of the node. Potential vulnerabilities include malicious applications, unauthorised access to the cache, and attacks on internal routing channels. To reduce risks, anonymisation or pseudonymisation methods, request encryption, and distributed metadata storage are used. Balancing between minimising delays and ensuring a high level of privacy is critical to maintaining IPTV QoS.

Local authentication involves verification of the user without contacting the central server, which reduces response time and load on central systems. Potential vulnerabilities include token forgery on compromised nodes, replay attacks, and local malicious code injections. To mitigate these risks, hardware key encryption, periodic key synchronisation with the central server, multi-factor authentication, and local certificate expiration limits are used. Figure 1 illustrates a comprehensive approach to IPTV security in an edge computing environment. It demonstrates a sequence of processes that ensure user data protection and trust in edge nodes by integrating lightweight encryption methods, local authentication, and node attestation into a single architectural model.

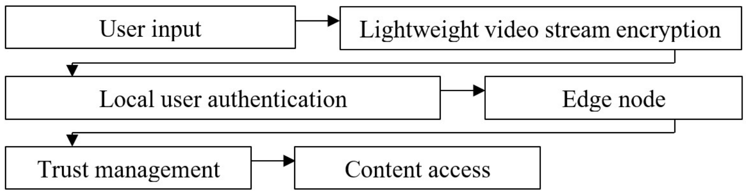

Figure 1. IPTV security at the periphery.

The diagram shows how security is ensured at each stage of data processing. User input data is encrypted using lightweight cryptographic algorithms, which minimises delays while maintaining a sufficient level of protection. The next stage, local authentication, is used by edge nodes to verify user rights without involving central servers, reducing delays and increasing the system's resistance to communication channel disruptions. Node certification ensures integrity and compliance with security standards, while trust management coordinates access to content and controls interaction between nodes, preventing potential attacks and data leaks. Together, this model creates multi-layered protection that optimally combines performance and security in high-load IPTV networks. Table 8 shows a comparison of traditional centralised approaches to IPTV security with edge-oriented solutions that integrate lightweight encryption, local authentication, and node attestation. It summarises key aspects of data protection and operational processes, highlighting the trade-offs between performance and security.

Table 8. Comparison of traditional and edge-oriented approaches

Security aspect	**Traditional aspect**	**Edge-oriented solution**	**Benefits/limitations**
Video stream encryption	AES-256/TLS, centralised	Lightweight cryptography (ChaCha20, SPECK) on edge	Reduced latency, possible reduction in cryptographic protection
User authentication	Central server	Local authentication with periodic synchronisation	Fast authentication, risk of node compromise
Node certification	Limited	Cryptographic verification and integrity control of TPM/TEE	Increased trust in edge nodes, need for resources
Data confidentiality	Transfer to a centralised cloud	Anonymisation, local encryption and pseudonymisation	Minimisation of leaks, balancing delays and protection

Source: created by the authors.

Analysis shows that the edge approach significantly reduces latency through local encryption of video streams and user authentication, while increasing trust in edge nodes through cryptographic attestation. However, it requires additional resources to support control processes and may have slightly increased vulnerability when nodes are physically accessible. Local encryption and data pseudonymisation minimise information leaks, striking a balance between latency and confidentiality that is critical for high-load streaming services. Thus, the comprehensive integration of these elements transforms the IPTV edge architecture into a flexible, scalable, and secure platform, balancing performance, real-time stream processing speed, and user data security, which is critical for 5G networks and high-load environments.

4. Discussion

One of the key factors for effective IPTV operation in a 5G environment is to reduce latency and buffering time. These parameters have a direct impact on the quality of broadcasts, especially in cases of interactive video or viewing in VoD format. Delay optimisation can ensure smoother playback of content and mitigate stream fragmentation. Martín-Pérez et al. [28] demonstrated that the introduction of edge computing reduces the average latency in mobile IPTV services. This significantly improves the quality of service in high-load scenarios. Compared to centralised models, this also reduced buffering time and improved broadcast stability. In contrast to a study, which addressed only mobile networks, presented article covered the full-fledged architecture of IPTV in 5G networks, including both fixed and mobile users. In addition to reducing latency, a substantial milestone is the stability of the quality of service during peak loads. In conventional centralised systems, QoS often deteriorates with a large number of simultaneous connections.

Li et al. [29] noted that the use of edge computing increases resistance to peak loads by distributing processing to local nodes. In the author's experiments, the QoS remained stable even under high thread load. This result was consistent with the current one: the edge architecture of IPTV made it possible to avoid overloading centralised channels during peak hours, especially when broadcasting popular events. However, the study addressed only the quantitative metric of QoS, whereas presented article also evaluated the parameters of buffering, frame loss and reaction time.

The implementation of specific technical solutions such as local caching, adaptive streaming, and load balancing are substantial in improvement of the efficiency of IPTV. These methods help unload the backend network and increase fault tolerance. Li et al. [30] proved that the combination of local caching with query balancing reduces traffic and improves video delivery time. Presented research also highlighted substantial efficiency of similar methods. In particular, due to caching and balancing, it was possible not only to reduce the load, but also to ensure the autonomy of edge nodes when disconnected from the central network. The difference is that the study did not investigate cloud failure scenarios, whereas the presented article explicitly states the advantages of the offline mode of edge components.

Another substantial aspect is the infrastructure requirements for deployment of edge architectures. Without sufficient node density and efficient routing, the expected benefits may be negated. Masoudi and Cavdar [31] noted that the efficiency of edge computing decreases with the interval between nodes, as the advantage in access time is lost. The results indicate that a dense grid of edge nodes is critical for the stable operation of IPTV in 5G, especially under heavy load conditions. However, the study did not consider the role of intelligent traffic management, whereas in the presented article, it was one of the key factors in the adaptability of the system.

Another promising area is the personalisation of video services based on peripheral data processing. This approach can adapt the content to a specific user in real time. Khamoushi [32] emphasised that local analytics can be used for the implementation of intelligent recommendations and regional advertising, reducing delays in accessing personalised content. Presented results also confirmed this effect, in particular, in aspects of dynamic image quality management depending on bandwidth. However, the study emphasised the commercial component, while presented research addressed personalisation in combination with QoS. As the number of users increases, the issue of scaling the system becomes relevant. Centralised solutions tend to scale vertically, which is associated with increased costs.

Peripheral IPTV nodes have several hardware limitations that directly affect streaming performance. One of the most relevant factors is limited cache memory, which leads to frequent requests to central servers and increased delays in video content playback. This drawback makes it difficult to maintain low response times and high-quality service for users during peak loads. Cache replacement algorithms are used to mitigate computing and cache memory limitations. Classic approaches, such as LRU (Least Recently Used), remove the least recently used items, efficiently retaining popular content within limited memory. The LFU (Least Frequently Used) algorithm, in turn, is based on the frequency of data access and ensures that the most requested content is retained, reducing cache misses and improving system efficiency during long viewing sessions.

Wang et al. [33] demonstrated that horizontal scaling through the edge architecture can efficiently support an increase in the number of simultaneous connections without loss of performance, the study confirms these conclusions: with increasing load, the edge computing-based IPTV system maintained 4K stream stability, which was impossible in conditions of centralised processing. However, the study did not explore the flexibility of caching and adaptive routing, which in the presented case have become key factors in maintaining quality.

One of the key challenges in scaling IPTV services is ensuring stable transmission quality under peak load conditions. Nguyen [34] proposed a dynamic traffic balancing model between the core of a 5G network and peripheral nodes. The proposed approach has shown a reduction in average latency compared to centralised systems. However, the limitation was the lack of adaptation mechanisms to the geographical distribution of the load, which made it difficult to maintain stability in conditions of uneven user activity. The presented model used adaptive placement of edge resources depending on subscriber activity, which ensures flexible response to changes in demand in real time. The study by Aladag [35] analysed the effect of bandwidth instability on the quality of IPTV when using caching on the periphery. The study proved that local preservation of popular content can reduce the playback start time by an average of 42%. It is worth noting that the study did not consider the conditions of streaming in real time, where the content cannot be saved beforehand. The model expands these approaches by combining caching with pre-processing of traffic and adaptive routing, which ensures efficiency even in live broadcasts.

Kim et al. [36] addressed the issue of the sustainability of IPTV networks with a rapid growth in the number of subscribers. The simulation model showed the critical overload thresholds for centralised and hybrid systems. Despite this, no mechanisms for automatic scaling of the edge infrastructure were proposed. In contrast to this approach, this study implements dynamic deployment of edge nodes following a spatiotemporal load analysis, which ensures resilience to sudden peak loads. The study by Tang [37] considered the use of artificial intelligence algorithms for routing IPTV traffic through edge networks. The models demonstrated an improvement in QoE in urban areas with high user density. However, the complexity of the system's installation and the need for large computing power limited its use in wide areas. In the presented solution, these limitations were addressed by the use of lightweight pre-routing algorithms and calculations at the MEC gateway level, which ensures a balance between quality and computational efficiency.

The results of the study may indicate significant advantages of using peripheral computing in the architecture of IPTV services in 5G networks, especially in terms of reduction of delays, buffering time, and improvement of the stability of service quality during peak loads. The data obtained are consistent with the conclusions of most modern studies, however, this paper additionally highlights the issues of the autonomy of edge nodes and the possibility of adaptive traffic management in real time, which contributes to the research of the potential of this technology. Overall, the integration of edge computing into 5G-based IPTV seems to be a strategically relevant area for providing high-quality multimedia services in the context of increasing demands and traffic volumes.

5. Conclusions

A comprehensive assessment of the impact of peripheral computing on the quality, scalability, and sustainability of IPTV services in fifth-generation networks was conducted. The key parameters critical for IPTV were analysed – data transmission delay, buffering time, bandwidth, peak load stability, and security. The results confirmed that the edge computing-based architecture significantly reduces latency (3-5 times compared to centralised systems), reduces buffering time, and reduces the load on network backend channels through local caching and adaptive traffic allocation. This is relevant for interactive video services, live broadcasts, and personalised content, where performance and quality requirements are high.

The study showed that the peripheral architecture of IPTV in 5G networks reduces latency to 10-50 ms compared to 100-250 ms in a centralised architecture. This helps improve the quality-of-service QoS, which in a centralised architecture becomes unstable at peak load. The use of local caching has reduced video buffering, and load balancing and routing have increased the stability of the system under high load. In addition, the use of adaptive streaming has optimised the quality of video transmission, ensuring stable transmission of high-resolution content, including 4K and 8K, even at peak demand. Local authentication and peripheral security have reduced the risks of data leaks and accelerated the process of user access to the service. These indicators confirm the effectiveness of using peripheral computing to optimise IPTV services in modern 5G networks.

The study demonstrated that distributed data processing on peripheral nodes provides higher fault tolerance and system autonomy – even with a temporary loss of communication with the central cloud, key IPTV functions remain available. Flexible scalability is achieved by horizontal expansion of the network of peripheral nodes, depending on the growth in the number of users and traffic volumes, which significantly reduces the cost of vertically increasing the computing power of the centre.

The study revealed several technical and organisational challenges related to the need for dense placement of peripheral nodes, efficient routing, coordination between operators and developers, and the development of software platforms for monitoring and resource management in real time. These factors determine the complexity of scaling and implementing edge computing in practice.

Thus, the results of the study confirm that the use of peripheral computing is a key factor in optimising IPTV services in modern high-speed 5G networks. Edge computing provides improved quality of service, stability and scalability of platforms, ensuring operation in the ever-increasing demands of users and the volume of video traffic.

The main limitation of the study was the dependence of edge computing efficiency on the density of peripheral nodes and the quality of the network infrastructure, which requires additional resources and coordination of participants. In the future, it is advisable to investigate optimal algorithms for orchestration and load balancing in the dynamically changing conditions of 5G networks to increase the stability and scalability of IPTV services.

REFERENCES

1. R. Bruschi, R. Bolla, F. Davoli, A. Zafeiropoulos, and P. Gouvas, *Mobile edge vertical computing over 5G network sliced infrastructures: an insight into integration approaches*, IEEE Communications Magazine, vol. 57, no. 7, pp. 78–84, 2019.
2. H. A. Kholidy, A. Karam, J. L. Sidoran, and M. A. Rahman, *5G core security in edge networks: a vulnerability assessment approach*, in Proceedings of the 2021 IEEE Symposium on Computers and Communications (ISCC), Athens, IEEE, pp. 1–6, 2021.
3. D. V. Nguyen, T. T. H. Tran, A. T. Pham, and T. C. Thang, *An optimal tile-based approach for viewport-adaptive 360-degree video streaming*, IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol. 9, no. 1, pp. 29–42, 2019.
4. M. I. Khattak, H. Yuan, A. Khan, A. Ahmad, I. Ullah, and M. Ahmed, *Evolving multi-access edge computing (MEC) for diverse ubiquitous resources utilization: a survey*, Telecommunication Systems, vol. 88, pp. 71, 2025.
5. Z. Nazemi Absardi, and R. Javidan, *A QoE-driven SDN traffic management for IoT-enabled surveillance systems using deep learning based on edge cloud computing*, The Journal of Supercomputing, vol. 79, pp. 19168–19193, 2023.
6. A. R. Kareem, A. M. Mahmood, and N. Al-Falahy, *Performance evaluation of IPTV zapping time reduction using edge processing of fog RAN*, Mathematical Modelling of Engineering Problems, vol. 9, no. 4, pp. 928–936, 2022.
7. Y. Dong, S. Guo, J. Liu, and Y. Yang, *Energy-efficient fair cooperation fog computing in mobile edge networks for smart city*, IEEE Internet of Things Journal, vol. 6, no. 5, pp. 7543–7554, 2019.
8. K. Khan, *Decentralized identity and user privacy in adaptive video streaming: navigating the blockchain frontier*, International Journal of Multidisciplinary Research and Publications, vol. 6, no. 7, pp. 190–196, 2024.
9. F. Yin, Y. Pan, X. Guo, and X. Feng, *Smart television edge server deployment scheme based on CDN*, in Proceedings of the 12th International Conference on Advanced Infocomm Technology (ICAIT), IEEE, pp. 58–63, 2020.
10. N. Psaromanolakis, V. Theodorou, D. Laskaratos, I. Kalogeropoulos, M.-E. Vlontzou, E. Zarogianni, and G. Samaras, *MLOps meets edge computing: an edge platform with embedded intelligence towards 6G systems*, in Proceedings of the Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit), IEEE, pp. 496–501, 2023.
11. S. T. Thomdapu, P. Katiyar, and K. Rajawat, *Dynamic cache management in content delivery networks*, Computer Networks, vol. 187, p. 107822, 2021.
12. Q. Zhang, L. T. Yang, Z. Chen, and P. Li, *A survey on deep learning for big data*, Information Fusion, vol. 42, pp. 146–157, 2018.
13. G. Giannakopoulos, P. Adegbenro, and M. A. Perez, *The future of IPTV: security, AI integration, 5G, and next-gen streaming*, arXiv preprint arXiv:2503.13450, 2024.
14. E. F. Maleki, W. Ma, L. Mashayekhy, and H. J. La Roche, *QoS-aware content delivery in 5G-enabled edge computing: learning-based approaches*, IEEE Transactions on Mobile Computing, vol. 23, no. 10, pp. 9324–9336, 2024.
15. S. M. Fati, and P. Sumari, *A survey on content awareness challenges in IPTV delivery networks*, Multimedia Tools and Applications, vol. 78, pp. 16817–16842, 2019.
16. J. I. Akerele, A. Uzoka, P. U. Ojukwu, and O. J. Olamijuwon, *Optimizing traffic management for public services during high-demand periods using cloud load balancers*, Computer Science & IT Research Journal, vol. 5, no. 11, pp. 2594–2608, 2024.
17. T. Bai, C. Pan, Y. Deng, M. Elkashlan, A. Nallanathan, and L. Hanzo, *Latency minimization for intelligent reflecting surface aided mobile edge computing*, IEEE Journal on Selected Areas in Communications, vol. 38, no. 11, pp. 2666–2682, 2020.
18. D. Callegaro, M. Levorato, and F. Restuccia, *SeReMAS: self-resilient mobile autonomous systems through predictive edge computing*, in Proceedings of the 18th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON), IEEE, pp. 1–9, 2021.

19. A. Erfanian, *Optimizing QoE and latency of live video streaming using edge computing and in-network intelligence*, in Proceedings of the 12th ACM Multimedia Systems Conference (MMSys '21), pp. 373–377, 2021.
20. M. Darwich, and M. Bayoumi, *Edge computing for low-latency video streaming*, in M. Darwich and M. Bayoumi (eds.), Enhancing Video Streaming with AI, Cloud, and Edge Technologies: Optimization Techniques and Frameworks, Springer, Cham, pp. 151–176, 2025.
21. A. L. S. de Moraes, D. D. J. de Macedo, and L. P. Junior, *Video streaming on fog and edge computing layers: a systematic mapping study*, Internet of Things, vol. 28, p. 101359, 2024.
22. M. A. Khan, E. Baccour, Z. Chkirbene, A. Erbad, R. Hamila, M. Hamdi, and M. Gabbouj, *A survey on mobile edge computing for video streaming: opportunities and challenges*, IEEE Access, vol. 10, pp. 120514–120550, 2022.
23. M. Liyanage, P. Porambage, A. Y. Ding, and A. Kalla, *Driving forces for multi-access edge computing (MEC) IoT integration in 5G*, ICT Express, vol. 7, no. 2, pp. 127–137, 2021.
24. Q.-V. Pham, F. Fang, V. N. Ha, M. J. Piran, M. Le, L. B. Le, W.-J. Hwang, and Z. Ding, *A survey of multi-access edge computing in 5G and beyond: fundamentals, technology integration, and state-of-the-art*, IEEE Access, vol. 8, pp. 116974–117017, 2020.
25. X. Ma, Q. Li, L. Zou, J. Peng, J. Zhou, J. Chai, Y. Jiang, and G. M. Muntean, *QAVA: QoE-aware adaptive video bitrate aggregation for HTTP live streaming based on smart edge computing*, IEEE Transactions on Broadcasting, vol. 68, no. 3, pp. 661–676, 2022.
26. W.-Z. Zhang, I. A. Elgendy, M. Hammad, A. M. Iliyasu, X. Du, M. Guizani, and A. A. Abd El-Latif, *Secure and optimized load balancing for multitier IoT and edge-cloud computing systems*, IEEE Internet of Things Journal, vol. 8, no. 10, pp. 8119–8132, 2020.
27. L. Kong, J. Tan, J. Huang, G. Chen, S. Wang, X. Jin, P. Zeng, M. K. Khan, and S. K. Das, *Edge-computing-driven Internet of Things: a survey*, ACM Computing Surveys, vol. 55, no. 8, pp. 1–41, 2022.
28. J. Martín-Pérez, L. Cominardi, C. J. Bernardos, A. de la Oliva, and A. Azcorra, *Modeling mobile edge computing deployments for low latency multimedia services*, IEEE Transactions on Broadcasting, vol. 65, no. 2, pp. 464–474, 2019.
29. S. Li, C. Li, Y. Huang, B. A. Jalaian, Y. T. Hou, and W. Lou, *Enhancing resilience in mobile edge computing under processing uncertainty*, IEEE Journal on Selected Areas in Communications, vol. 41, no. 3, pp. 659–674, 2023.
30. C. Li, J. Zhang, and H. Tang, *Replica-aware task scheduling and load balanced cache placement for delay reduction in multi-cloud environment*, The Journal of Supercomputing, vol. 75, pp. 2805–2836, 2019.
31. M. Masoudi, and C. Cavdar, *Device vs edge computing for mobile services: delay-aware decision making to minimize power consumption*, IEEE Transactions on Mobile Computing, vol. 20, no. 12, pp. 3324–3337, 2020.
32. E. Khamoushi, *AI in food marketing from personalized recommendations to predictive analytics: comparing traditional advertising techniques with AI-driven strategies*, arXiv preprint arXiv:2410.01815, 2024.
33. H. Wang, T. Liu, B. Kim, C.-W. Lin, S. Shiraishi, J. Xie, and Z. Han, *Architectural design alternatives based on cloud/edge/fog computing for connected vehicles*, IEEE Communications Surveys & Tutorials, vol. 22, no. 4, pp. 2349–2377, 2020.
34. V. G. Nguyen, K. J. Grinnemo, J. Taheri, and A. Brunstrom, *Adaptive and latency-aware load balancing for control plane traffic in the 4G/5G core*, in Proceedings of the Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit), IEEE, pp. 365–370, 2021.
35. O. F. Aladag, D. Ugur, M. N. Akcay, and A. C. Begen, *Content-aware playback speed control for low-latency live streaming of sports*, in Proceedings of the 12th ACM Multimedia Systems Conference (MMSys '21), pp. 344–349, 2021.
36. J. Kim, C. Nam, and M. H. Ryu, *IPTV vs. emerging video services: dilemma of telcos to upgrade the broadband*, Telecommunications Policy, vol. 44, no. 4, p. 101889, 2020.
37. F. Tang, B. Mao, Y. Kawamoto, and N. Kato, *Survey on machine learning for intelligent end-to-end communication toward 6G: from network access, routing to traffic control and streaming adaption*, IEEE Communications Surveys & Tutorials, vol. 23, no. 3, pp. 1578–1598, 2021.