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Exploring Resource Allocation Strategies in 5G Networks for Optimal Multimedia Delivery

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ABSTRACT

In recent years, multimedia applications have become deeply embedded in daily life, with platforms like Microsoft Teams, Google Meet, and Zoom becoming essential for communication and collaboration. The rise of social media reels has further driven the demand for high-quality multimedia content creation. The introduction of 5G networks, particularly the use of mmWave technology, has the potential to revolutionize content delivery by enabling seamless streaming of HD and 4K videos. However, achieving uninterrupted multimedia streaming requires efficient resource allocation to maximize network capacity.

This survey examines existing resource allocation strategies in 5G networks, with a particular focus on video and audio transmission facilitated by small cells. Key performance indicators such as Quality of Experience (QoE) and Quality of Service (QoS) are used to assess the effectiveness of data transmission. The study reveals that the optimal resource allocation duration is around 20 minutes, with resources ideally distributed within a 500-meter radius. To maintain a high QoE, the target bandwidth should be approximately 100 Mbps, and the call acceptance rate during resource allocation must remain above 70%. This research highlights the critical role of efficient resource management in ensuring high-quality multimedia experiences in the 5G era.

KEYWORDS

5G Networks, Resource Allocation, Multimedia Streaming, Quality of Experience (QoE).

1. Introduction

The fifth generation of cellular technology, known as 5G, represents a major leap forward in mobile communication by focusing on significantly enhancing transmission and reception speeds while reducing latency. Unlike its predecessors, which primarily emphasized improving connectivity, 5G introduces a broader range of advancements, including the flexibility to support a diverse array of services. With potential speeds of up to 100 Gbps—compared to the 1 Gbps limit of 4G—5G is poised to revolutionize how we experience the digital world. This dramatic increase in speed, combined with lower latency, enables smoother online experiences, including video conferencing, multimedia content streaming, and online gaming with shared content.

One of the defining features of 5G is its emphasis on reducing latency, the delay between sending and receiving data. This reduction is crucial for applications that require real-time interaction, such as virtual reality, autonomous driving, and remote surgery. The shift from prioritizing connectivity to focusing on latency ensures that digital experiences are delivered more efficiently from the cloud to the client, providing users with a seamless and responsive online experience.

5G also brings significant improvements in mobility and network reliability. The technology supports seamless hand-offs between different network types, including cellular, Wi-Fi, and Bluetooth, ensuring uninterrupted connectivity as users move between environments. Additionally, 5G introduces the concept of small cells—lowpowered radio access points that operate over short distances, typically from a few meters to a few kilometers. These small cells are critical for **enhancing network performance, particularly in densely populated areas or indoor environments where traditional cell towers may struggle to provide adequate coverage.**

There are three main types of small cells: femtocells, picocells, and microcells. Each is designed to address specific challenges in network deployment, ensuring that 5G users enjoy strong, consistent communication signals regardless of their location. This combination of high speed, low latency, and enhanced coverage positions 5G as a transformative force in the future of digital

communication.

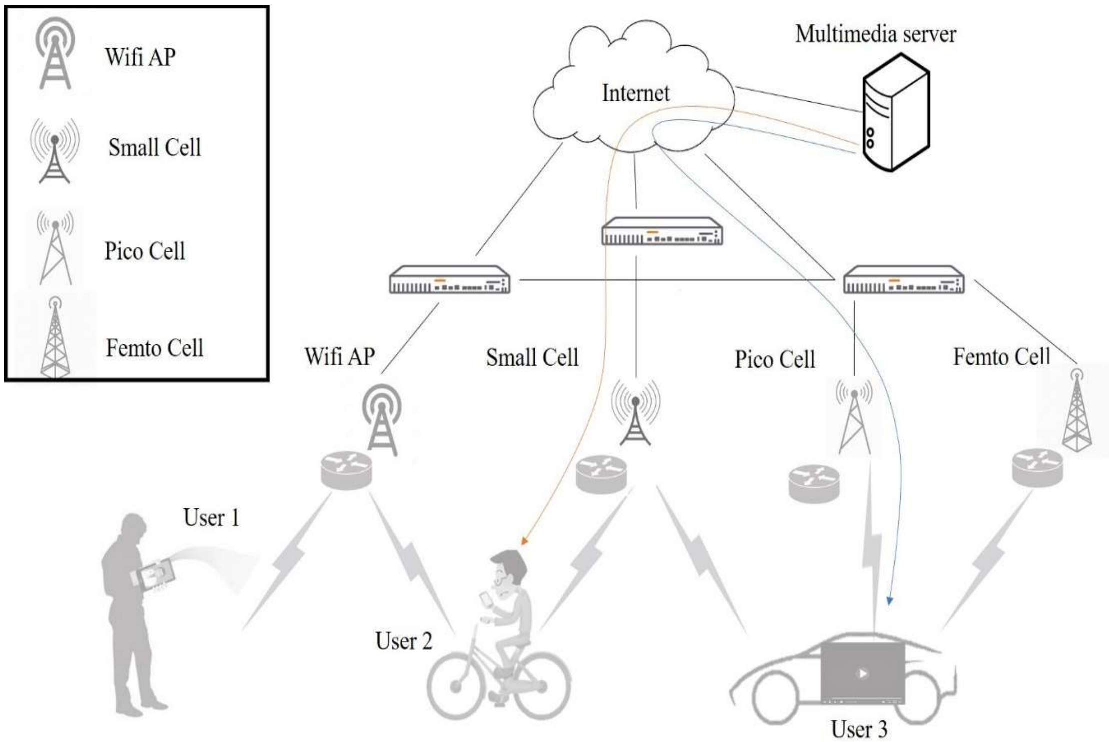

Fig. 1 Elements of a 5G network with different multimedia users. User 1 is trying to communicate through a video call via a wifi access point that goes through optical fiber backhaul to 5G internet service where we connect to a multimedia server via a high-speed wired network. User 2 is moving at a slow speed and has dual connectivity with WiFi AP and one of the small cells. The small cells can be Micro-cell or Femtocell or Picocells. The connectivity information for user 2 is shared on an optical fiber back-haul. User 3 shown needs the maximum bandwidth as the user is trying to watch a movie on a high- speed moving vehicle. The user needs at least one of the 3 small cell communication to work which are micro-cell, picocell, and femtocell. Typically moving vehicles always try to connect to microcells as the range is maximum compared to other small cells. Also, the optical back-haul is trying to maintain the speed that the user needs to have error-free communication

Femtocells are the household units installed and have the highest speed. Picocells have a larger range (roughly 200 meters) compared to fem- tocells (roughly 10 meters). Microcells are the biggest small cells and they can go up to a few kilometers also. Small cells are the derived improvements of cellular boosters available with the 4G technology. Small cells are preferred when the multimedia contents are streamed with a user seating in one place, for example, watching a movie. For people who walk during a telephonic conversation, there are chances that they might continuously switch between 2 femtocells caus- ing inefficient communication. Macrocells are the alternatives to small cells and can carry signals through large distances. Small cells used in 5 G are useful for internal usage whereas macrocells can be useful for outdoor users. There are a lot of challenges in maintaining a throughput when a user moves from indoor to outdoor.

The outer connectivity still heavily relies on macrocells with optical fiber as a black hole. It is expected that

5G technology will not only improve the speed in the megacities, it can also be reached the rural parts and even provide on- demand content to remote villages. 5G network works with a distributed access architecture that enables faster data processing. Most of the 5G architecture is software controlled and hence net- work functioning can be maximized with the help of algorithms. The advancement in the current telecom industry allows defining of sub-networks, the creation of network slices, and beamforming from the antennas.

5G technology focuses on enhancing the digital experiences with AI-based recommendation sys- tems. An automated content suggestion will allow a user to spend more time in multi-media services increasing the requirement for infrastructure and enhancing bandwidth.

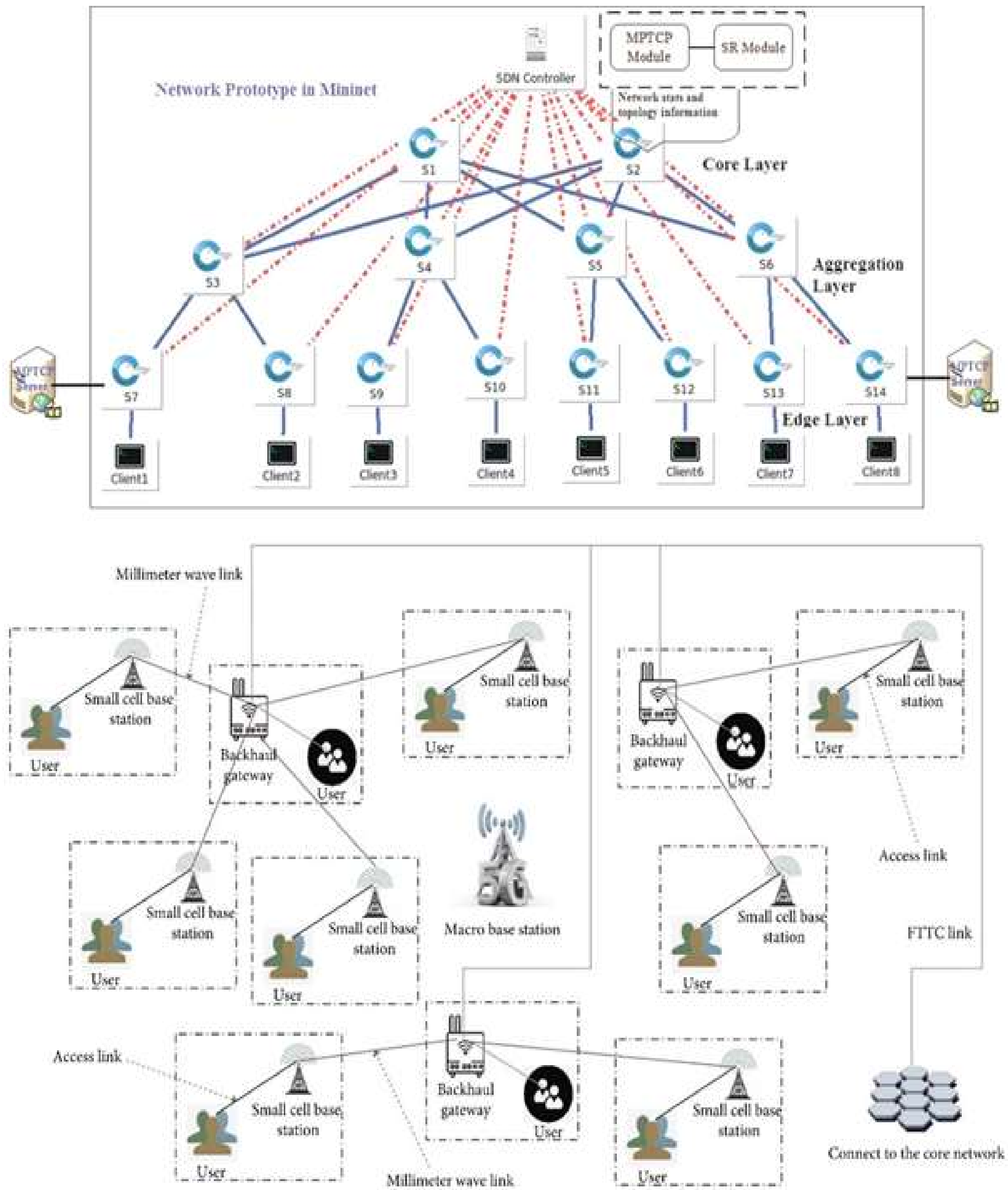

Fig. 2 (a) Network prototype in mininet. The architecture consists of a centralized SDN controller that connects to different clients through different nodes starting from S1 to S14. The mini net is based on 3 layer architecture where the core layer takes care of all the network stacks and topology information. The aggregation layer collects all the data from the edge layer. All the clients with their parent nodes are considered as the edge layer of the network. (b) 5G architecture with FTTC link and millimeter-wave link. Here individual user is connected to its corresponding small cell base station and the backhaul gateway is connected to the individual small cell base station. All the information collected from a backhaul gateway is sent to the FTTC link to the core network. The macro base station is used only when the user has difficulty in a small cell base station.

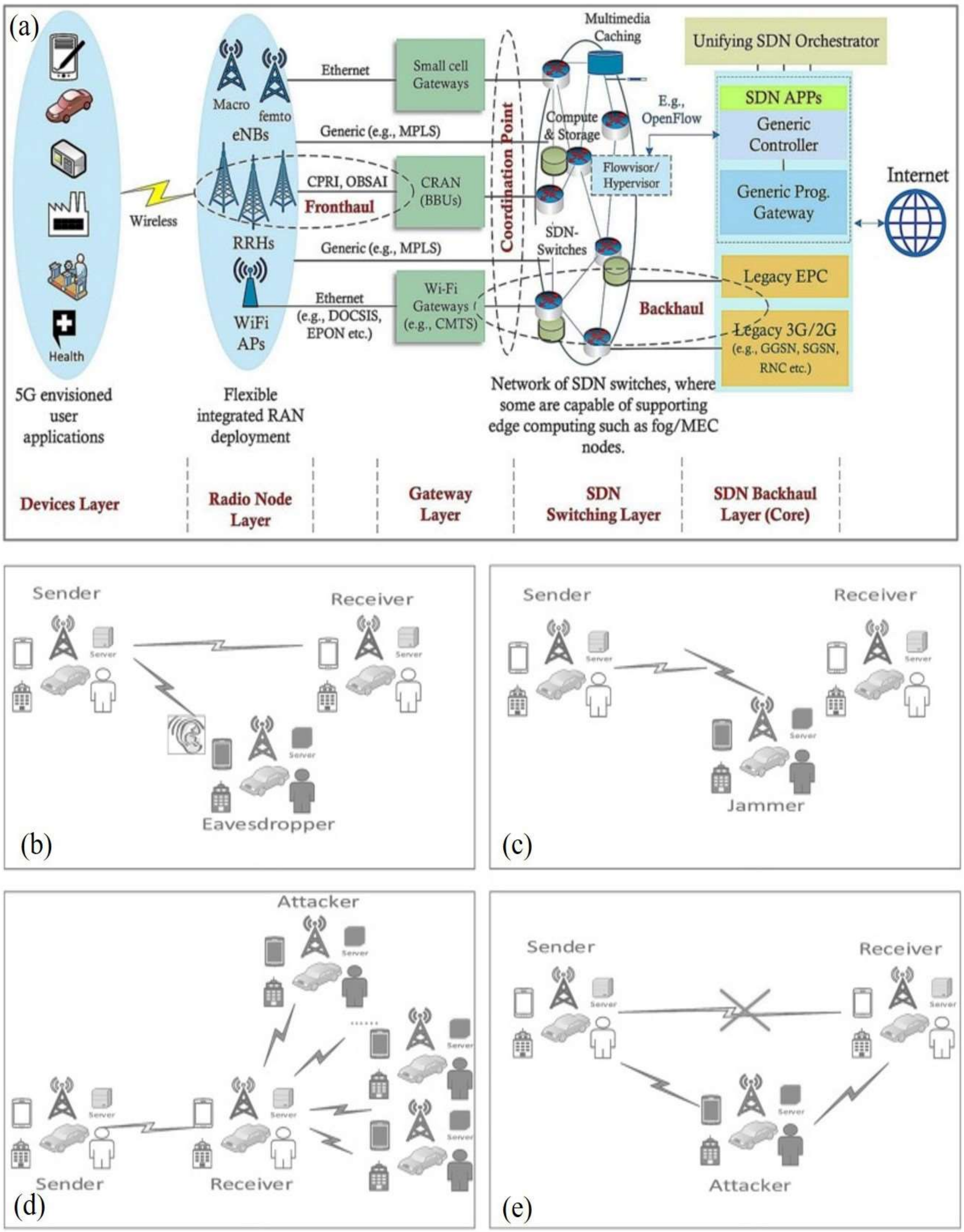

Fig. 3 (a) 5G network architecture proposed with unified SDN Orchestrator where the devices are switched using software design network and all the gateway layers are controlled by SDN switching layer. The 5G user applications data goes from device layer to radio layer and based on the requirements it is processed on the fronthaul or backhaul. All the backhaul- related data goes to SDN Switch whereas all the fronthaul data goes on a wireless link via CRAN 5G. (b) It shows a condition where 5G data is sent from sender to receiver and Eavesdropper listens to the private communication between the sender and the receiver. (c) A scene shows a data sent from the sender is blocked by a jammer and never reached the receiver. (d) A scenario where communication between a sender and a receiver is successful but different attackers continuously try to communicate with the receiver with garbage data. (e) A scenario where a sender data is captured by the attacker modified and further transmitted to the receiver.

Resource management in IoT networks, a form of complex distributed systems, is crucial due to the dynamic and heterogeneous nature of IoT resources and the diverse requirements of applications. The primary objective of resource management is to determine optimal resource allocation to efficiently serve a large number of clients. This involves key activities such as resource allocation and scheduling, which are essential for achieving this goal. Additionally, resource management includes supporting operations like resource modeling, discovery, estimation, and monitoring.

A multimedia service is one that combines more than one type of media (e.g., voice, still frame, video, data) and delivers it to the receiver. There are two types of multimedia services mainly interactive and distributed.

The interactive multimedia service allows users to interact with the environment such as, chang- ing the color content inside a live video stream or adjusting the sound filters applied in real-time music. Multimedia services do focus on real-time processing of images audio and text and hence it is important to have network optimization of 5G mobile networks when we are streaming mul- timedia. Nowadays people are more focused on, distributed multimedia systems where the con- tent gets delivered to the user and is stored on multiple servers. It is important to connect the user to its nearest multimedia video server via the best gateway so that un-buffered multime- dia content can be delivered. While analyzing the performance of multimedia content the bit rate is an important parameter one should con- sider. Bit rate allows users to establish the speed at which data is flowing and can vary between a few KBPS to MBPS. With current-generation 4K displays in mobile phones and 8K displays in televisions, it is important that the digital commu- nication in the backbone should be able to deliver the multimedia content seamlessly. Currently, in 4G technology, 80% of such heavy multimedia transmission-reception is done using wifi technol- ogy. As the number of users in mobile phones has increased and the camera in mobile is improving it is essential to have super-fast content delivery through a mobile network rather than depend- ing on wifi. For Audio content in multimedia the current bit rate is sufficient but because of the compression and encoding the quality of the content is affected.

Looking at the different requirements of the users it is essential that the next-generation mobile network must be optimized for better mul- timedia content delivery. In this review paper, we focus on all the multimedia optimization tech- niques that have been reported in recent litera- ture.

Figure 1 shows Elements of a 5G network with a variety of multimedia users. User 1 is trying to communicate via video call using a Wi-Fi access point that connects to a 5G internet service via an optical fiber back-haul. This 5G optical fiber back-haul connects to a multimedia server via a high-speed wired network. User 2 is assumed to be traveling on a cycle slowly and has dual connectiv- ity with the Wi-Fi AP and one of the small cells. Microcells, Femtocells, and Picocells are examples of such small cells. User 2's connectivity infor- mation is shared over an optical fiber back-haul. User 3 requires the most bandwidth because he is trying to watch a movie while driving at high speeds. To communicate, the user must have at least one of the three small cell types: microcell, picocell, or femtocell. Moving vehicles will always attempt to connect to microcells because their range is greater than that of other small cells. Furthermore, the optical back-haul is attempting to maintain the speed required by the user for error-free communication.

2. LITERATURE REVIEW

2.1 Power-based resource allocation

Cao et al. [1] has given a stochastic process for optimization in green multimedia services for dense 5 G networks. They provided a novel opti- mization framework named SOGMS which is an acronym for a stochastic optimization framework for green multimedia services. In this proposed method the focus was on the maximization of system throughput while minimizing the energy consumption during the data delivery. They have focused on lyapunov optimization techniques and three tractable sub-problems. The entire work was focused on dense 5G networks and for only broad- band multimedia services such as virtual reality, augmented reality, and immersive videos.

Their group has also published optimization [2] w.r.t edge computing in 5G networks with a game theoretic approach. For the testing, they have built remso which is an acronym for reliable effi- cient multimedia service optimization. This time they focused on, video service optimization with Stackelberg and a potential game model. To evalu- ate the performance of the system they computed quality of service (QoE) using credibility, pricing, latency, and energy saving. For the experimental analysis credible degree computation per unit of time was done. Also, demand vs pricing, utility per time, secure service vs trusted base station, and service satisfaction vs mobile units was computed.

Their latency and energy overhead increased with the number of mobile users.

Li et al [3] have developed an empirical study for implementing multimedia-based technol- ogy using 5G. They found that it is feasible to apply the multimedia network of 5G to take an evaluation of college physical education.

5G architecture with FTTC and millimeter- wave links (Fig. 2b) [3]. Individual users are linked to their respective small cell base stations, and the backhaul gateway is linked to the individ- ual small cell base station. All data collected by a backhaul gateway is routed to the FTTC link to the core network. The macro base station is only used when the user is having trouble with a small cell base station.

Keshav et al. [4] has given a generalized approach for bandwidth allocation for interactive multimedia. Dynamic bandwidth requirement in interactive multimedia makes it important to allo- cate the important resources in a limited time. They have designed their allocation scheme and virtual reality application with multiple back- ground applications running simultaneously. They found that their proposed system is practically implementable for real-time interaction in virtual reality.

The scheme presented in [14] addresses the challenge of efficient many-to-many bandwidth allocation between UAVs and users in a network characterized by high dynamics and delay-sensitive services. The authors proposed a novel approach, starting with a many-to-many full matching algorithm based on a three-layer auction architecture among UAVs, aimed at optimizing global network bandwidth to achieve an optimal solution.

Subsequently, they introduced a simplified matching algorithm that handles single and multiple connectivity users to exchange local bandwidth resources, resulting in a suboptimal solution. To assess the effectiveness of their approach, the authors conducted extensive simulations. The results demonstrated that both proposed algorithms have lower complexity compared to conventional many-to-one matching algorithms, and they also significantly maximize system throughput when compared to alternative convex optimization algorithms.

In [13], a scheme for allocating downlink network resources was introduced, focusing on accepting a new service only if it does not negatively impact the throughput of existing services in the cell. However, this approach does not address the dynamic modification of Quality of Experience (QoE) for mobile users, which could enhance network capacity and resource utilization.

Additionally, [13] proposed a centralized joint power and resource allocation scheme for prioritized multi-tier cellular networks. This scheme aims to admit users with higher priority levels to maximize the number of users served. However, the prioritization is applied only at the user level, failing to ensure differentiation for users in slices with varying priorities.

For the proposed work, they have used the dis- tributed architecture of 5G with multiple small cell base stations and a few backhole gateways with the macro base station with the 5G back- ground. Their evaluation score varies between 86 and 96.

2.2 QoE centring resource allocation

Barakabitze et al. [5] has developed a QoE- centric routing approach to provide multimedia service for 5G networks. They focused on the software-defined network with multiple abilities. For software-defined networks, multiple transmis- sion control protocols were found to be more efficient than traditional TCP. For testing, they have shown 8 clients with multiple edge layers and an MPTCP server. The data from the MPTCP server can be directly provided to the client or can be further transferred via the aggression layer.

Figure 2a shows the Mininet network pro- totype [5]. The architecture is comprised of a centralized SDN controller that connects to vari- ous clients via various nodes ranging from S1 to S14. The mini net is built on a three-layer archi- tecture, with the core layer handling all network stacks and topology information. The data from the edge layer is collected by the aggregation layer. The network's edge layer consists of all clients and their parent nodes.

The core layer consists of only 2 possibili- ties which are then controlled by SDN Controller. From analysis, they have found the proposed method to reach up to almost 1 Mbps which is at least 10 times more than the regular TCPP proto- col. It was also found that the link utilization they could achieve was about 50 % after 400 seconds. Their success rate was a maximum of 97.80 %.

Krishnan et al. [6] have used SDN-enabled QoE for multimedia applications in 5G. Krish- nan has established STREK architecture and has focused on quality of experience. For implemen- tation in hardware, they have used NetFPGA - 1G with ONet Card acceleration. Fig. 3a A 5G network architecture with a unified SDN Orches- trator is proposed, in which devices are switched using a software-defined network and all gateway layers are controlled by an SDN switching layer. The data from 5G user applications travels from the device layer to the radio layer and is processed on the front-haul or backhaul depending on the requirements. Back-haul data is routed to an SDN Switch, whereas front-haul data is routed via a wireless link via CRAN 5G.

There are multiple attacks possible on any 5G communication network with respect to Multime- dia transmission. The four major scenarios which are very common in multimedia transmission are explained in the next paragraph. Figure 5b shows a situation in which 5G data is sent from sender to receiver and an Eavesdropper listens in on the sender and receiver's private communication. Fig. 5c explains the scenario when the data sent from the sender is intercepted by a jammer and never reaches the receiver. Fig. 5d explains a sce- nario in which communication between a sender and a receiver is successful, but multiple attack- ers attempt to communicate with the receiver using garbage data on a continuous basis. Fig. 5e explains a scenario in which the attacker inter- cepts and modifies sender data before sending it to the receiver. They could achieve a maximum bandwidth of 160 %. Their path delay was 39.61 nanoseconds. A block size of typically 64, 128, or 256 was used with TREK. They tried 3 differ- ent file sizes varying from 25 MB to 650 MB up to 1 GB. Their maximum throughput could reach up to 18 MBPS. Their packet loss could reach up to 6 packets per second for traditional SDN and with their STREK algorithm, it got reduced to 2 packets per second.

Shweta et al. [7] provided a way to optimize video traffic. They focused on calculating QoE and maximizing it, in order to improve the overall performance of the network.

Alvarez et al. [8] has provided details on the edge to cloud virtualized multimedia service for the 5G network. They have computed the latency with direct invocation with a mean of 0.07 sec- onds. For the open whisk plugin, it took 7.8 seconds. They found that their prediction of loca- tion accuracy reduces linearly as a look ahead window increased per 10 seconds. Overall average graphic volume found was around 60-100 MBPS with roughly 9500 data points.

A resource allocation scheme based on priority has been designed in Algorithm 1 in Fig 5. This scheme can be used to cope with the entrances of new slices or users and provides a global optimization of the resources allocated to service slices. For the purpose of simplicity, Algorithm 1 denotes to the resource allocation scheme of novel DEs belonging to the same slice. The steps of our proposed resource allocation scheme can be applied for admission control of new slices, by simply adjusting the parameters under consideration [18]. When the new UE arrives the network, by considering the QoE of the users in the same slice, we can derive an acceptance probability of the novel user in the virtual network by considering the constraints in terms of intra-slice priority as well as the QoE of served UEs.

2.3 Traffic-based resource allocation

Zhang et al. [9] has performed a joint resource allocation with a network embedded in a 5G net- work. They have used multiple traffic aggregation points in radio access networks. For the perfor- mance evaluation, there were 50 nodes deployed by them with 150 different inks amongst them. Their acceptance ratio lies in the range of 0.8 to 0.7 when the shortest path is chosen. The draw- back to their method was service interrupts are ignored.

Lu et al. [10] has used low-density superpo- sition modulation for multimedia content on 5G mobile. The low-density superposition modula- tion method (LDSM) uses Bare bone Particle Swarm Optimization (BBPSO). They have also used extrinsic information transfer EXIT. They have used QPSK modulation and computed BER for signal-to-noise ratios varying from 4 to 22 DB. The least BER was 5 10^{-4} and the high- est BER all in the range of 10^{-1}. FOr coverage performance, they have used pattern division mul- tiple access over the traditional feeding channel approach 'Sparse Code Multiple Access (SCMA).

3. DISCUSSIONS

All the resource allocation strategies are segre- gated into three major classes. The first strat- egy is power-based. The focus of this strategy is to maximize power through proper distribu- tion and utilization of available resources. The Lampnaouv optimization, game theory, small cell selected first and distributed computing are the four major approaches under this strategy of resource allocation. The second strategy is quality of experience-based. In this strategy, the maxi- mum focus is given to delivering quality content and not focus on saving energy. The content quality can be achieved through Software-defined networks, Strek algorithm, Optimizing video con- tent, and Cloud virtualization. The last category of resource allocation of the 5G network works on the traffic-based approach. In this strategy strongest path with a minimum path, the cost is considered first. The other method in this strat- egy is to use the bare bone swarm optimization technique.

Table 1 Comparison of different resource allocation techniques with a focus on green communication

	Simulation	No. of	No of Base		
	time (Seconds)	users	Stations	Latency (ms)	Throughput
Cao *et al.* (2019)	1000	1500	60	–	–
Cao *et al.* (2020)	300	150	10	18	5500
Li *et al.* (2021)	–	80	–	–	–
Keshav *et al.* (2021)	–	–	–	6	–

Table 1 shows that simulation time for 5G resource allocation can be from 5 minutes to roughly 15 minutes hence periodicity of resource reallocation should be at least 20 minutes so that maximum benefit can be extracted from resource allocation. The number of users can vary from as low as 80 users and can go as high as 1500 users. It is ideal that a smaller number of users are present during resource allocation. The base station within the green communication-based resource allocation can vary between 10 to 60. Latency post resource allocation can vary between 6 to 18 milliseconds. Throughput can go as high as 5500 simultaneous operations on a single network. Table 2 shows that the highest accuracy achievable with proper resource allocation is around 97.8Which is achieved by Barakabitze et al. the minimal latency claimed is around 1msec which can be further improved. the through- put achieved by Alvarez for good QoE service is around 90Mbps

The transmission distance for simulation is roughly 500meters between the user equipment and micro cell antenna. The no. of iterations is chosen to be roughly 500. The expected through- put can go as high as 90 Mbps. The typical acceptance ratio for any column within a network should be above 0.7. the simulation time should not exceed 15 hours and the typically expected rate should be around 300Mbps. The carrier fre- quency should be above 2 GHz. The achievable BER should be around 10−5 with SNR around 20 dB.

For the problem of on-demand allocation of network slice resources between service providers and tenants, Individualized resource allocation for network slices based on Knapsack strategy is proposed. In the case of limited network virtual resources, the Individualized resource allocation of network slices is achieved and a reasonable number of network slices to which resource requests can be sent is determined.

The 5G mobile network terminal offers exceptional Quality of Service (QoS) by leveraging a variety of networks. Currently, mobile Internet users manually select the wireless port of different Internet Service Providers (ISPs) without the ability to utilize QoS history to choose the most suitable network connection for a given service. However, in the future, 5G phones will provide the capability to analyze QoS and store measured data traffic within the mobile network terminal . Various QoS parameters, such as bandwidth, delay, jitter, and reliability, will play a crucial role in the functioning of 5G mobile networks within the terminal. System processes will automatically select the most appropriate wireless connection based on the required QoS, ensuring optimal performance for users.

4. CONCLUSIONS

Multimedia-based applications have become integral to daily life over the past decade, with many people relying on platforms like Microsoft Teams, Google Meet, and Zoom for communication. Additionally, social media reels have significantly boosted multimedia content creation. With the advent of 5G networks, particularly using mmWave technology, streaming high-definition (HD) or 4K video content has become feasible. To maintain a continuous flow of such multimedia content, it is crucial to optimize resource utilization.

The manuscript reviews the current resource allocation systems for 5G networks concerning multimedia applications. It emphasizes video and audio transmission via 5G networks using small cells. Key parameters for assessing data transmission include Quality of Experience (QoE) and Quality of Service (QoS). To achieve optimal utilization, the manuscript suggests that resource allocation intervals should be no less than 20 minutes and that resources should be allocated with a minimal number of users..

Table 2 Comparison of different resource allocation techniques with a focus on QoE.

	Accuracy (%)	Latency (miliseconds)	Throughput (Mbps)
Barakabitze *et al.* (2018)	97.8	1.77	1.7
Krishnan *et al.* (2021)	–	50	19
Shweta *et al.* (2017)	–	1	–
Alveraz *et al.* (2019)	79	7.8	90

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