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An Optimized and Cost - Effective Resource Management Model for Multi - Tier 5G Wireless Mobile Networks

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Abstract

Wireless Mobile Networks (WMN) is a pivotal technology that can advance the development of the future digital economy. WMN delivers pervasive computational power via the multitier installation of computers, ensuring reduced latencies and enhanced interaction with multi-tier 5G networks, ledgers, and machine learning. This research presents a novel methodology for improving equipment resource management for edge nodes within a multitier WMN architecture. Alongside a centralized unit, the study evaluates active radio and dispersed units integrated with edge terminals with varying computing capabilities. A customizable Bayesian optimization is employed for hardware resource management to enhance the total computing capability of a 5G-based WMN technology. Simulation findings indicate that, under specified budget limitations, the suggested strategy surpasses pseudorandom resource management for the completion rate of computing jobs. The attainable increases range from 20% to 40%, contingent upon job difficulty and the chosen budget criterion.

Keywords: Resource Management, Wireless Mobile Networks, 5G, Optimisation.

1 Introduction

The expansion of 5G mobile networks facilitates the integration of immersive offerings, like Virtual Reality (VR), Augmented Reality (AR) (Al-Ansi et al., 2023), omnipresent computation, multiplayer online games, and the Internet of Things (IoT) (Laghari et al., 2021) into everyday activities. Given that most of these offerings need the transfer of substantial data quantities and intricate information

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processing on the webservers, the present networks and computing platforms are expected to experience significant strain shortly.

Server locations are often far from User Equipments (UEs) in multi-tier 5G (Ding et al., 2021). Requests from user equipment are transmitted to a distant server via many portions of the transportation network's framework. Given the substantial volume of traffic from the server systems to each UE, the transportation network readily obstructs forthcoming immersive services. These distant servers are reachable by billions of user entities, resulting in a significant likelihood of bottlenecks in both connection and computation segments. The queuing technique employed for demand handling directly influences the efficiency of mobile cloud computing systems.

The innovative framework of Wireless Mobile Networks (WMN) has been established to address the constraints of cloud computing on mobile devices (Ram & Chakraborty, 2024; Mocanu et al., 2020). The principal concept of WMN is to position the computer structures nearer to consumers, enabling queries to be handled locally rather than sent to distant server locations. The requisite regional servers, including base stations and backend units, can be assimilated with the current mobile network facilities. WMN offers several critical advantages over traditional computer systems. Initially, it diminishes round-trip delay by situating servers near end consumers. Secondly, by facilitating the local processing of most traffic, WMN decreases the volume of data transported across long distances via the transportation system multi-tier 5G (Malathi, 2024). Regional server farms are better for context-oriented solutions since they retain pertinent information specific to a region and cache crucial content based on local patterns.

An extra degree of autonomy in the optimal paradigm is the existence of an external dynamic in the framework, as indicated by the mobility of users (Zijlstra et al., 2020). Unlike earlier studies, the research captures the immediate locations of consumers to assess the demand for the server cluster during every simulated session. Thus, the research represents the comprehensive spatio-temporal computational requirements, enabling us to enhance the hardware capability of each tier inside the WMN network with multi-tier 5G (Scanzio et al., 2021). To streamline the optimization issue, this study omits a comprehensive analysis of the physical layer characteristics of the 5G networks, as their effect on service delay is significantly less than that of the computing capacity of the WMN systems.

This study presents a method for enhancing the computing capability of a multitier WMN structure, considering specified financial limitations and user activity patterns. The primary contributions of the research are outlined below:

- The research presents a strategy for optimum hardware installation under financial limitations for a multi-tier WMN construction, whereby servers are incorporated into critical components of the multi-tier 5G network like Distributed Unit (DU), Central Unit (CU), and Active Antenna Unit (AAU).
- The research models the process computing effectiveness in a WMN utilizing operation characteristics derived from empirical data on online gaming network clients' behavior.

2 Related Studies

The authors suggested a queuing delay concept for front-haul networking measuring in 5G systems to satisfy the latency standards of the cloud-based radio access network (Bassoli et al., 2021). The authors utilized Kingman's hyperbolic rule of overcrowding to assess the wait time on the front-haul.

A maximum-revenue resource management optimization problem was developed for virtual networks within a two-tier heterogeneous system. The researchers used pre-allocated radio bandwidth to the corresponding base stations or access points to address this issue. A flexible resource-sharing framework for single-tier homogenous multi-tenancy was suggested (Bor-Yaliniz, 2020). Considering the renters ' needs, a network utility maximization issue was established. The proposed two-step sub-optimal strategy enhanced network utility; nevertheless, consumers were not classified according to their slice needs.

The authors introduced an adaptive radio resources slicing framework for a two-tier diverse wireless connection (Khodapanah et al., 2020). An alternating concave search method was developed to address the most significant networking utility optimization issue. The two-tier heterogeneous system, owing to its basic framework, inadequately encapsulates a 5G network architecture characterized by many tiers of connection networks necessary to satisfy the continually escalating user needs. The authors neglected to discuss the notion of multiple tenants, which is essential in 5G systems (Gaurav et al., 2018).

The authors examined the dynamic management of radio resources within a network-slicing context (Lieto et al., 2020). An auction game-theoretic technique was devised to distribute resources efficiently. The authors should have addressed the issue of latency limits inside the resource management framework. While the researchers acknowledged multi-tenancy, they did not account for the multi-tier and multi-slice characteristics of the 5G system in their research.

An effective radio channel slicing technique for a diverse network incorporating Vehicle to Everything (V2X) applications was examined (Cui et al., 2024). The authors suggested an offline reinforcement learning framework that assigns radio bandwidth to the V2X use cases to maximize system resource consumption. The latency needs of the V2X application were not considered. The model does not incorporate the small-scale fading variables that substantially impact rapidly moving machinery and automobiles.

A single-tier system was evaluated, which fails to fully represent a 5G system that is anticipated to be a multi-tenant, multi-tier architecture (Batista Jr et al., 2021). The authors examined several strategies to implement for V2X connections. The authors employed the Media Access Control (MAC) layer technique’s significant deviation theory architecture (successful bandwidth or capacities). The authors presented a cooperative connectivity technique utilizing mean bit errors to improve the efficiency of IoT communication networks (Nguyen et al., 2020). The methodology depends on the proficiency of the back-propagation neural networks to forecast the ABEP efficiency of the analyzed system.

The aim was to identify the trade-off between energy usage and associated delay across different offloading situations. The Time-Division Multiple Accessibility (Shayo et al., 2020) and omnidirectional Frequency-Division Multiple Accessibility (Zhai et al., 2021) methodologies were evaluated for the radio modules. The scientists assessed and modeled the power usage for offloading and computation in a multi-tier scenario. The researchers assessed the power consumption associated with complicated operations and examined possible enhancements in safety and confidentiality for transferring tasks to a web server (Sun, 2020).

Their study determined that the issue is Multiobjective optimizing problems (MOOP) addressed by Pareto optimality, wherein the objective is to identify an answer such that no alternative option enhances any of the goals (Li et al., 2023). To attain the Pareto optimizing model, the research proposed a biased-sum approach to decrease computer complexity significantly. The examined system comprised a single full-duplex base station with a web server, and it had many WMN consumers and numerous customers.

The researchers suggested a system to minimize concurrent upload and download energy consumption when ensuring personal information transfer with specified Quality Of Services (QoS) (Touil et al., 2021). The research employed the balanced Tchebycheff approach to develop the task management method.

Considering energy efficiency and QoS, the combined optimization of computing power and wireless connections was suggested (Rajesh et al., 2023; Sreevidya & Supriya, 2024). The researchers presented a Devices-To-Devices (D2D) (Gismalla et al., 2022) design for WMN, intending to optimize the user equipment's computation power. The research articulated the task management challenges across several situations in the WMN platform. A concave relaxation-based technique was presented to address the difficulties described.

3 Proposed Model for Resource Management and Optimisation

1) Pricing and Economic Model

The mobility of UE results in fast fluctuations in the number of connected UEs to each Base Station (BS) and the resources accessible. Different approaches, including game-theoretic or auction techniques, can establish a pricing system in a context with restricted resources. In these tactics, often one side prevails in rivalry, or if equilibrium is attained, one market participant achieves greater profitability—the research utilizes clever and flexible pricing strategies to achieve a system grounded in justice. Given the constrained resources, a dynamic pricing strategy can augment the motivation to supply the required assets. This section establishes a unit price to represent and formulate the suggested system paradigm. Due to fluctuations in network data flow as time passes, it can adjust its unit costs dynamically.

Advantageous and effective pricing significantly optimizes Management and Orchestration (MNOs) profitability over time. The research utilizes two activities: price fluctuation and resource management. Figure 1 depicts the pricing and resource management procedures executed by MANO. During each time slot, the UEs assess and provide the Reference Signal Received Quality (RSRQ) to the BSs.

Following the handover procedure and first phase, E2E MANO commences the costing and resource management operations. It sells services to the MNOs and supplies them with necessary assets. During the fourth to sixth phases, the MNOs collaboratively provide the essentials for the UEs. In the seventh stage, allotted assets are relinquished when each UE departs from a BS.

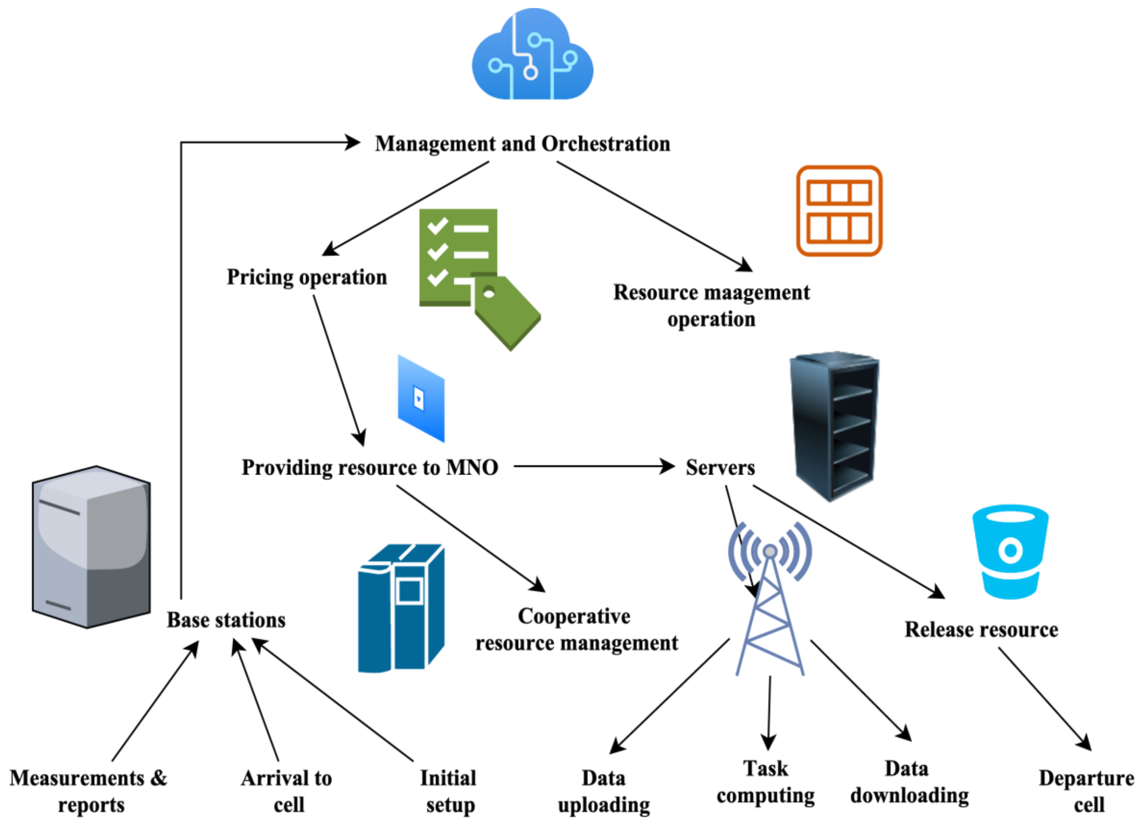

Figure 1: Workflow of the 5G Model

2) Latency Modeling

Three primary factors contributing to delay are identified for WMN. These improvements align with the three primary phases of the assignment life phase:

The first stage involves task offloading, wherein delay arises from communicating the job to the designated network node for execution.

Stage two is the execution of the task, wherein delay arises from the execution of the assignment by specific Central Processing Units (CPU) and is affected by the workload from concurrent processes.

Stage three is task downloading, when the job is transmitted from the intended destination to the consumer to finish, contributing to the ultimate delay. Subsequent sections will provide a more detailed description of each step.

The research officially denote the entire delay for T_x and the equation (1) is given as,

$$T_{t,x} = T_{ol,x} + T_{p,x} + T_{d,x} \quad (1)$$

In the system model, to simulate several concurrently interacting network facets and duties sets with an equitable distribution of concurrently shared assets among the responsibilities, which are components of the processing sets, are added. Each node in the network has three categories to represent the allocation of capacity of upload and download communication and the distribution of computing assets between the set components: upload_group, download_group, and computing_group.

Phase 1

The duties are promptly categorized into upload_groups by the UEs upon their generation. upload_group emulates the communication of an assignment to a device at a superior stage, with all concurrent operations inside an identical set utilizing the communication channel capabilities collectively. Downlink_ group denotes communication from the WMN stations to the UEs. The offloading period $T_{ol,x}$ is articulated and the equation (2) is given as,

$$T_{ol,x} = T_{w,x} + T_{F,x} + T_{M,x} \tag{2}$$

$T_{w,x}$ represents the duration of wireless communication among the UE and the AAU, $T_{F,x}$signifies the fronthaul communication duration among the AAU and the DU, and $T_{M,x}$ defined by the mid-haul transmission duration from source to destination. For the multi-tier 5G connection $T_{w,x}$, consider c_w represent the link increase in energy for unloading; hence, the required offloading speed is expressed and the equation (3) is given as,

$$R_x^{ol} = B_W^{ol} \log\left(1 + \frac{P_W^{ol} c_W}{\alpha_W^2}\right) \tag{3}$$

B_W^{ol} (in Hz) represents the transmitting bandwidth, P_W^{ol} signifies the transmitting power allocated for jobs, and c_W symbolizes the Additive White Gaussian Noises (AWGN). In a multi-tier 5G context, the information rate is defined and the equation (4) is given as,

$$R_x^{ol}(t) = \frac{R_W^{ol}}{N_x(t)} \tag{4}$$

$R_x^{ol}(t)$ is a temporal variable owing to the fluctuating amount of concurrent jobs $N_x(t)$. An operation is deemed assigned upon the fulfillment the following expression. The equation (5) is given as,

$$D_x \leq \sum_{i=0}^{N} R_x^{ol}(t)\Delta t \tag{5}$$

The transmission duration for T_x is calculated and the equation (6) is given as,

$$T_x = \left(T_{end,x} - T_{start,x}\right)\Delta t \tag{6}$$

The communication times for fronthaul and midhaul cable lines are computed similarly, as both utilize fiber optics. To prevent redundancy, the terminology employed above needs to differentiate between upstream and downstream in multi-tier 5G networks.

Phase 2

In the suggested solution discrete-event modeling, all jobs on a particular core at a specific time step must share the core's available instruction frames per unit of duration. The duration of every activity is contingent upon the interactions of other activities at each specific interval. Given that the operations in the study are similar, an equitable distribution of computing resources among those activities on a particular core fulfills the equality criterion. For a specific assignment, the time-varying periodicity allocated during time slot t is determined and the equation (7) is given as,

$$f_x(t) = \frac{f_{CPU}}{N_{pt}(x,t)} \tag{7}$$

$N_{pt}(x,t)$ represents the concurrent operations executed on the same processor as the assignment. Multiple processors will be implemented on a single node, each including various cores; hence, the aggregate value of activities on one device over a designated interval t is represented by $N_C(t)$, and $N_{pt}(x,t)$ is calculated and the equation (8) is given as,

$$N_{pt}(x,t) = \frac{N_t(n,t)}{N_c(nt)} \tag{8}$$

A limitation exists on the number of concurrent jobs a single CPU can manage; nevertheless, this figure is relatively high since a CPU can transition between tasks rapidly, rendering this limitation almost negligible. The computing set is contingent upon the processors allocated at every node, as every processor distributes jobs uniformly.

Upon transmission to its designated node, a job is categorized into the computing_group and starts processing. The mathematical framework employed for simulating the procedure at the points has been delineated in the preceding sections. During the simulation, the elapsed computation cycles and the number of concurrent jobs are monitored at each exercise stage for each assignment. A job is deemed completed when the total amount of delayed periods meets or exceeds the task's demand, as outlined below. The equation (9) is given as,

$$D_x I_x \leq \sum_{i=0}^{N} f_x(t)\Delta t \quad (9)$$

$T_{start,x}$ and $T_{end,x}$ denoting the time intervals during that the operation initiates and concludes computation accordingly; hence, the real computing duration for operation x is computed and the equation (10) is given as,

$$T_{proc,x} = \left(T_{end,x} - T_{start,x}\right)\Delta t \quad (10)$$

Phase 3

Upon completing a job, the result will be sent to download_group for transmission to the user equipment. The collaboration system for the download dissemination set mirrors that of the uplink communication set: the information size for transmission is determined by the number of concurrent users/tasks at every stage of transmission, and an assignment is deemed passed on once the provided information size meets or exceeds the task size.

Job routing is unambiguous when elevating a job throughout the network tree structure for computation by the desired node, as every node possesses a singular parent; hence, identifying the goal level index suffices for routing the assignment. When transmitting a computed result along the hierarchy to the UE that demanded it, the route back across the internet to this UE has to be unequivocally established. Due to the absence of IP addresses and routes in the framework, a simple approach utilizing a stack of information specific to each job is employed to document all devices traversed by an operation en route to the destination.

3) Continuous Genetic Algorithm

The research addresses the altered variable resource management issue in a multi-tenant, multi-tier network inside a network slicing context using the Continuous Genetic Approach (CGA).

The research employs the Genetic Algorithm (GA) to address the maximization problem due to its resilience and efficacy in identifying global optimum solutions compared to other heuristic approaches. Thus, the GA can address any optimization issues and all limitations, including both linear and non-linear. The CGA is renowned for its excellent accuracy in describing solutions without excessively lengthy chromosomal strings, resulting in minimal computing complexity, reduced storage requirements, and increased performance.

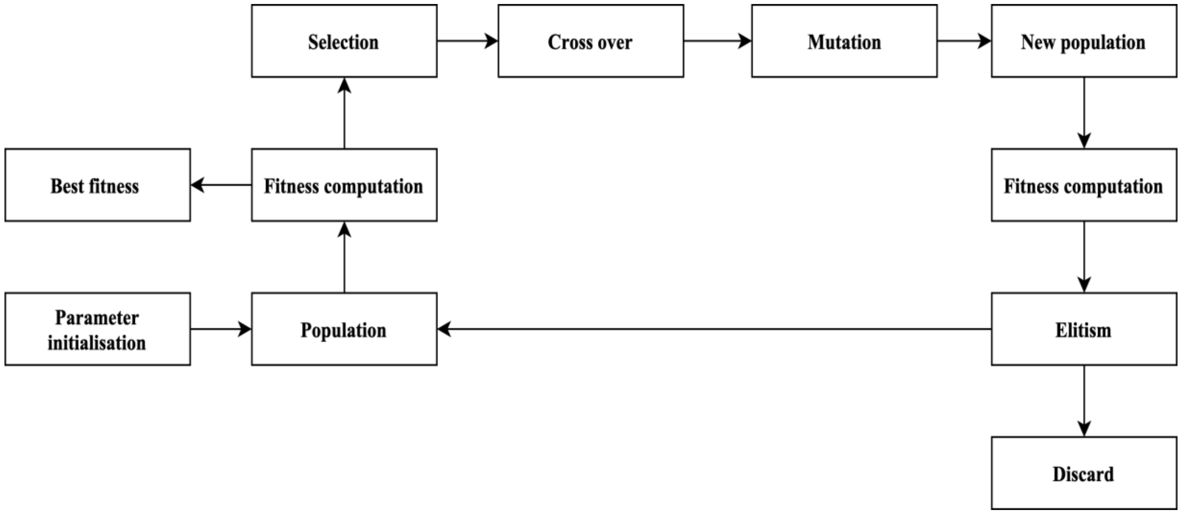

Figure 2: Workflow of the Optimization Model

It is a randomized search method grounded in the principles of natural choosing, reproduction in nature, and genomics. The process starts with a randomly selected collection of solutions, the sample. The population adheres to the boundaries of the optimization problem. Each entity in a group is referred to as a chromosome. A chromosome is a conventional depiction of solutions, sometimes called genetics. The genetic algorithm evaluates the fitness of every chromosome in a group using an objective value. This study used the roulette wheel approach to choose chromosomes with optimal fitness standards, generating pairings designated as fathers for crossover, predominantly influenced by the crossover likelihood. The crossover mehcanism generates novel chromosomes, referred to as offspring. To replicate the procedure of natural development, the offspring's genes are altered at birth, resulting in another population. The health of the newly formed group is assessed, and through elitism, a select portion of the top people from the prior group is preserved in the new people while the remainder is eliminated. This procedure is depicted in Figure 2.

4 Simulation Analysis and Discussions

This section evaluates the efficacy of the suggested GA innovative latency-aware resource management system using Monte Carlo-based simulations conducted in a Matlab setting. The research examined a multi-tier, multi-tenant system of MNOs functioning within a 950-meter radius of interest. The large station was positioned centrally, encircled by femtocells and tiny cells, covering a corresponding radius of 50 meters and 250 meters. The multi-tier network comprised seven fetal cells, four small cells, and five clustering fetal cells for each picocell.

Transmitting power budgets of 10, 20, 30, and 40, dBm were evaluated for Vehicle to vehicle (V2V) transmission mode, the fem, tiny cells, and the macrocell. Different kinds of slice consumers were assigned randomly throughout access indicates at all levels.

1) Network Capacity Analysis

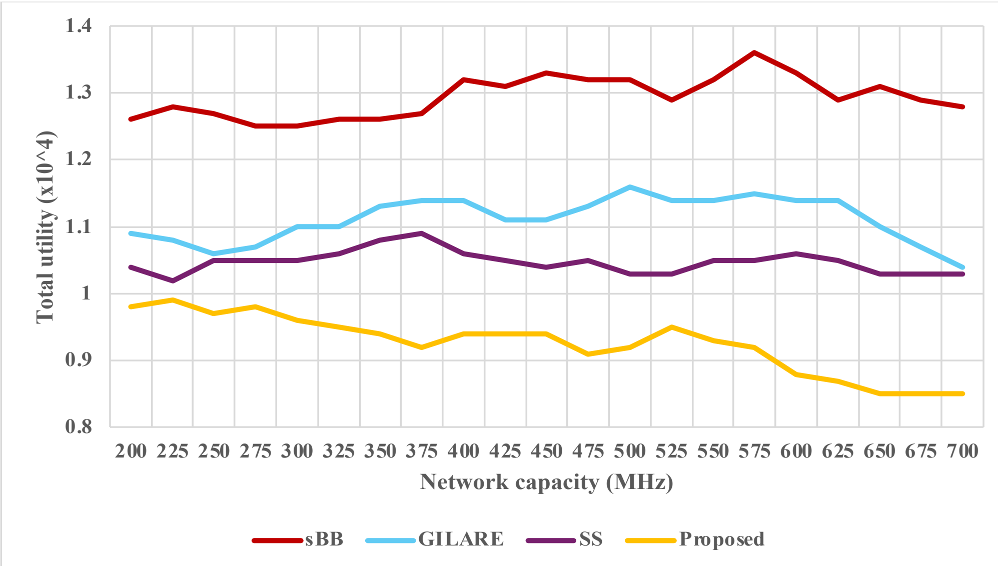

Figure 3: Network Capacity Analysis

Figure 3 illustrates the impact of the system's total capacity on network efficiency. The research adjusted the total network capacity from 200 MHz to 700 MHz, maintaining a user density of five individuals and a delay constraint of 1 ms. Figure 3 illustrates how networking utility escalates with a rise in overall capacity. This is due to the increased usefulness when additional resources become accessible to the networking slice consumers. The delay constraint is established at 10ms with a user concentration of 5 customers. The network's utility escalates with a rise in the total capacity of the entire network. With a relaxed delay limit restriction of 10ms, the system's utility significantly surpasses the other methods, although at the expense of Quality of Experience (QoE).

2) Delay Limit Analysis

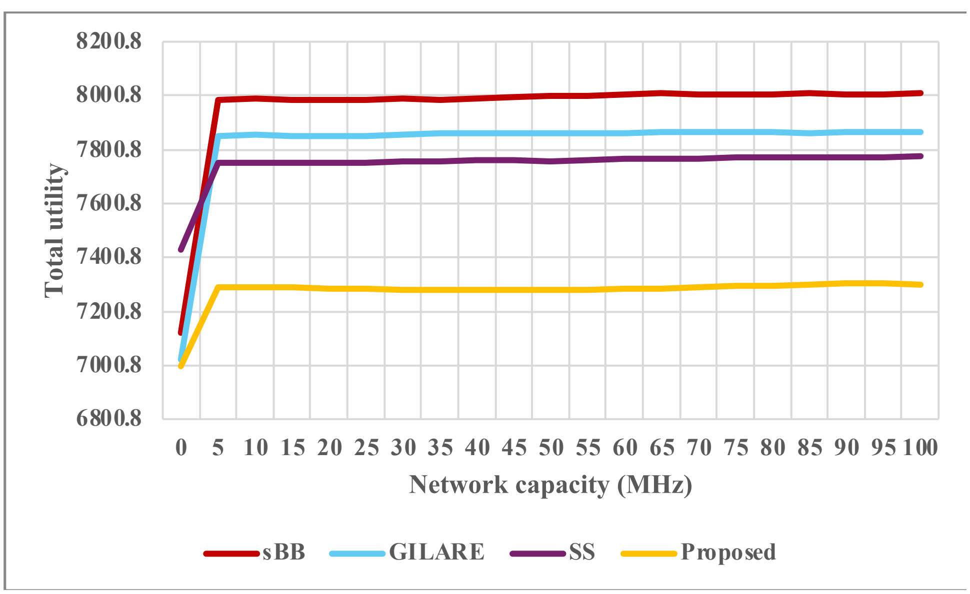

Figure 4: Delay Limit Analysis

Figure 4 illustrate the impact of the delay constraint on network usefulness and adequate capacity. It illustrates the effect of the delay constraint on channel utility, given a user density of 2 users and an internet capacity of 100 MHz. There is a swift augmentation of networking utility when the delay restriction is relaxed from Ims to 10ms; nevertheless, with constrained network resources, the benefit stays static despite the escalation in the delay limit. Figure 4 illustrates the impact of the delay limit on the actual capacity. The actual bandwidth significantly influences the data received rate of consumers in the slices, as indicated by limitations. The researcher that when the highest delay limit escalates, the limit diminishes

3) Packet Loss Analysis

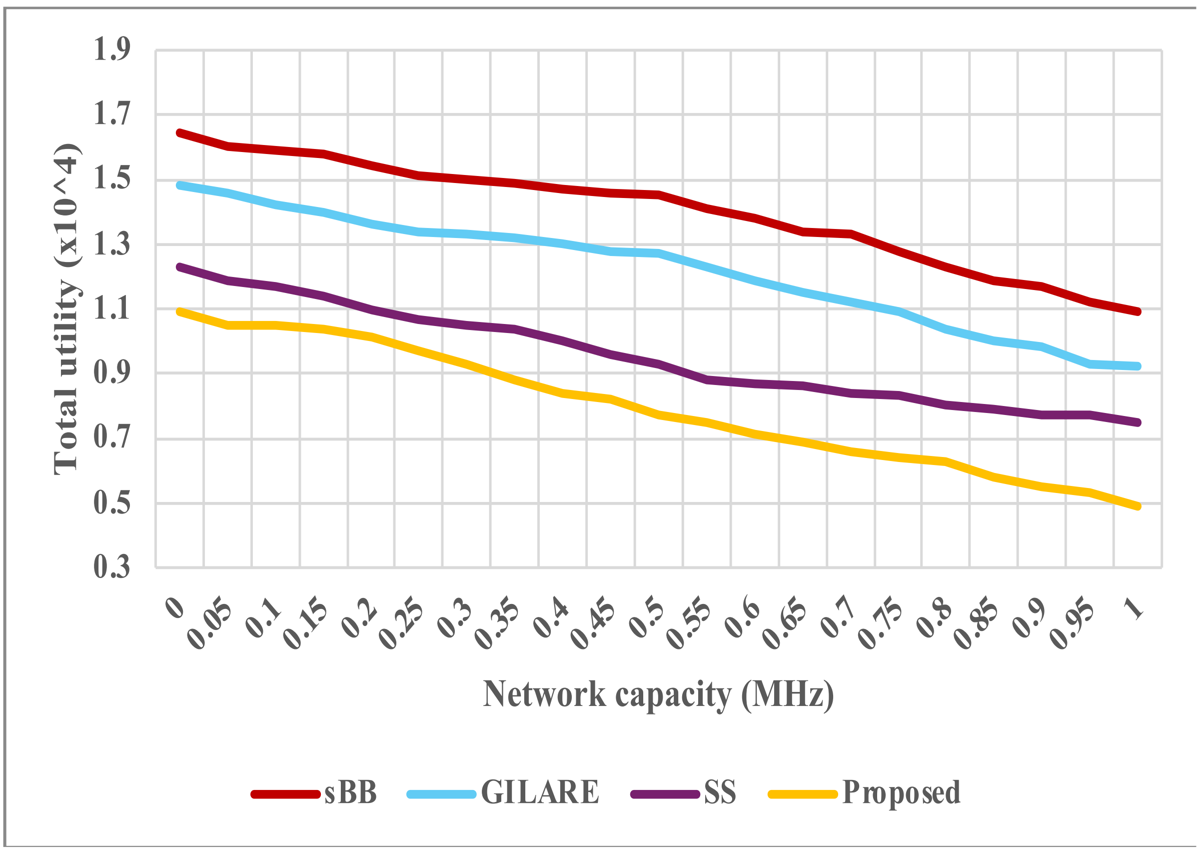

Figure 5: Packet Loss Analysis

Figure 5 illustrates the effect of packet loss likelihood on network efficiency. Packet loss generally includes losses attributable to communication problems, overflowing buffers, and delayed packet deliveries. The packet loss rate is varied from 10^-5 to 10^-1, with a population of 5 consumers, a latency constraint of 10 ms, and a capacity of 200 MHz. Despite the enhancement in networking efficiency with reduced packet loss likelihood, the GI-LARE surpasses the SS and sBB resource management methodologies. A reduced packet loss likelihood correlates with an increased likelihood of packet reception. Enhancing network efficiency is achievable by maintaining a low transmission loss rate. The network income and overall efficiency deteriorate markedly when the packet loss rate exceeds 1.

4) Coverage Area Analysis

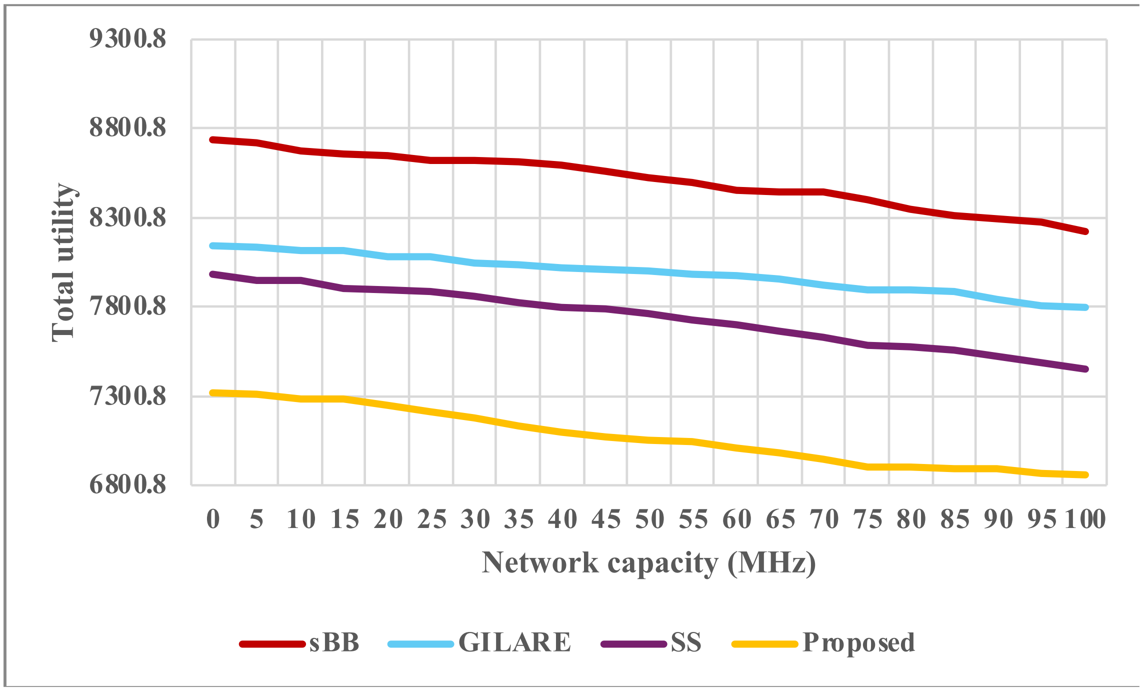

Figure 6: Coverage Area Analysis

Figure 6 illustrates the effect of the covering range of femtocells and tiny cells on network efficiency. The coverage range is adjusted between 10m and 100m, with a delay constraint of 10 ms and an average capacity of 100MHz. The network utility rises as the reach area diminishes. This is attributable to the improved channel settings of the corresponding slice consumers. It analyzes the influence of the covering area of the four picocells on networking efficiency. The research adjusted the detection range from 200 to 300 meters and established a delay constraint of 10 milliseconds. Consistent with the pattern observed in femtocells, network utility improves as the covering area diminishes. But its size is not as substantial as the presence of the femtocells because of the proximity of the femtocells to the cut consumers.

5 Conclusion and Findings

The research has analyzed multitier WMN installation with an ultra-dense 5G wireless network. The primary implications in the analyzed environments are that every passive radio module is outfitted with a lower-energy WMN. In contrast, each dispersed module is supplied with a higher-energy WMN. The research created a method to optimize hardware resource allocation under specified budget constraints. The study has evaluated the efficiency of the suggested system against diverse computing needs and juxtaposed it with traditional pseudorandom resource management. Simulation findings indicate that the optimized approach offers up to 40% more computing capacity than pseudorandom resource management within the same constraint. The research has delineated the prospective significance of WMN improvement in advancing artificial intelligence, blockchain, and 6G innovations.

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Authors Biography

Dr.D.S. John Deva Prasanna, is a dedicated researcher specializing in computer networks, reinforcement learning, and the Internet of Things (IoT). His work focuses on exploring how intelligent systems can optimize communication protocols and data transmission across interconnected devices. With reinforcement learning at the core of his research, Dr. Prasanna develops advanced techniques to enable IoT systems to autonomously improve performance, adapt to dynamic environments, and enhance network efficiency. His contributions are at the intersection of these cutting-edge fields, shaping the future of smart, connected technologies. He completed his Ph.D from Hindustan Institute of Technology and Science in November 2021, and his Post Graduation is from Anna University in the year 2004. With 20 years of teaching experience.

Dr.K. Punitha is working as Associate Professor in School of Computer Science and Engineering, VIT CHENNAI Campus, India. Has 13+ years of experience teaching courses at both undergraduate and postgraduate levels. Has Edited and co-authored contemporary trends in political thought, published over 17 articles in international journals and patented published over 5. Has received best paper awarded for "Intruder Detection System using IoT with Adaptive Face Monitoring and Motion Sensing Algorithm" at the third International conference on Intelligent Computing Instrumentation and Control Technologies (ICICICT).

Dr.G. Shrividya, obtained her B.E (E&C) in the year 1999, from Mangalore University and M.Tech (DEC) (2006) from VTU (Belagavi) and Ph.D from Reva University, Bengaluru in the field of Medical Image Processing in the year 2022 for the thesis "Efficient Schemes for MR Image Reconstruction Using Compressive Sensing " The research was carried out under the guidance of Dr. Bharathi S.H. Dr. Shrividya G. has published 5 papers in the International Journals, 2 papers International Conferences. Shrividya G has 25 years of teaching experience. Her areas of interests are Communication and Image Processing.

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Dr. Priya Vij, is an Assistant Professor in the Department of Computer Science & IT at Kalinga University, Raipur, India. With a solid foundation in computer science, she is actively involved in both teaching and research, focusing on areas such as machine learning, data analytics, and cybersecurity. She is passionate about guiding students and contributing to the growth of the academic community, aiming to bridge the gap between theoretical knowledge and practical applications in the ever-evolving tech landscape.