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A Comprehensive Exploration of Resource Allocation Strategies within Vehicle Ad-Hoc Networks

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Abstract: In recent years, a surge in the utilisation of vehicle-to-vehicle (V2V) communication has been observed, serving as a pivotal factor in facilitating automatic control of vehicles without human intervention. This advancement has notably curtailed accident rates, mitigated traffic congestions, and augmented vehicular security. Consequently, a meticulous survey has been orchestrated in the domain of Vehicle Ad-Hoc Networks (VANETs), particularly as autonomous vehicles pervade urban landscapes. The necessity for resources to assure secure and consistent operations of an escalating fleet commensurately intensifies with the enlargement of the fleet itself. Intelligent Transportation Systems (ITS) hinge upon VANETs to furnish travellers with secure and pleasant journeys, pertinent information and entertainment, traffic management, route optimisation, and accident prevention. Nevertheless, a plethora of challenges inhibits the delivery of an adequate Quality of Service (QoS) within vehicular networks, such as congested and interrupted wireless channels, a progressively saturated and sprawling spectrum, hardware inconsistencies, and the swift expansion of vehicular communication systems. Contemporary networks and energy grids are subject to strain from daily and recreational activities. As demand perpetually ascends, a necessity arises for more refined tools and methodologies for resource management and a more precise distribution system. This investigation offers an exploration of the most recent practices and trends in VANET resource allocation, with the objective of garnering insights into the existing research landscape and its impelling forces.

Keywords: Peak-to-Average Power Ratio (PAPR); Orthogonal Frequency Division Multiplexing (OFDM); Bit Error Rate (BER); Complementary Cumulative Distribution Function (CCDF); Companding Transformation (CT)

1 Introduction

VANETs, specialized forms of wireless communication networks, have garnered attention for their pivotal role in facilitating communication amongst automobiles, roadside infrastructures, and cloud services. These networks, integral to the ITS, have been developed with the intention of enhancing the security, efficiency, and environmental friendliness of transportation systems [1]. A multitude of applications have been identified for VANETs, encompassing critical areas such as accident avoidance, traffic flow management, and provision of entertainment services.

Notably, for the mitigation of accidents, vehicles are enabled to communicate vital data amongst themselves, inclusive of their location, velocity, and travel direction. Additionally, VANETs are instrumental in the improvement of traffic flow management through coordination with traffic signals, traffic rerouting, and real-time traffic information dissemination to drivers. Furthermore, VANETs have been utilized to provide passengers with online access and infotainment services, such as video streaming and music downloads.

The capability of VANETs to provide reliable and real-time data to support operational decisions is deemed critical. For instance, to avert collisions, vehicles necessitate immediate access to data concerning the locations and speeds of proximal automobiles. Similarly, for efficacious traffic management, drivers require instantaneous updates concerning traffic conditions and road closures [2]. VANETs, operating within an environment characterised by pronounced dynamism and unpredictability, exhibit significant capabilities in maintaining communication amidst constant vehicular motion, varied speeds, and changing directions. The rapid alterations in network architecture, emanating from the movement of vehicles in and out of communication range, pose challenges in sustaining network connectivity.

Addressing these challenges, VANETs deploy a distinct set of communication protocols and algorithms, optimised for application within unpredictable environments. The IEEE 802.11p standard, frequently cited as a communication protocol within VANETs, facilitates seamless switching between access sites and ensures low-latency communication. Moreover, VANETs utilise specific routing protocols, tailored for dynamic environments wherein the network architecture perpetually evolves.

The assurance of security and privacy within VANETs is also of paramount importance. Given that vehicles communicate personal data, including location and speed, safeguarding this information becomes imperative. Protecting user anonymity and privacy thus emerges as a crucial objective in the design and implementation of VANETs [3–5].

The ITS substantially leverages VANETs to actualise its aims of augmenting the reliability, effectiveness, and sustainability of the transport network, enabling various applications by permitting automobiles to communicate with each other, roadside infrastructure, and cloud services. A myriad of utilizations, including collision prevention, traffic management, and entertainment services, have been identified, as outlined in Figure 1, demonstrating VANET architecture. Through the deployment of communication protocols, routing algorithms, and security strategies specifically adapted to the exigencies of VANETs, the myriad challenges posed by the network are addressed. As the prevalence of connected vehicles proliferates, a concomitant increase in reliance upon VANETs for secure, efficient, and environmentally conscious transportation systems is anticipated.

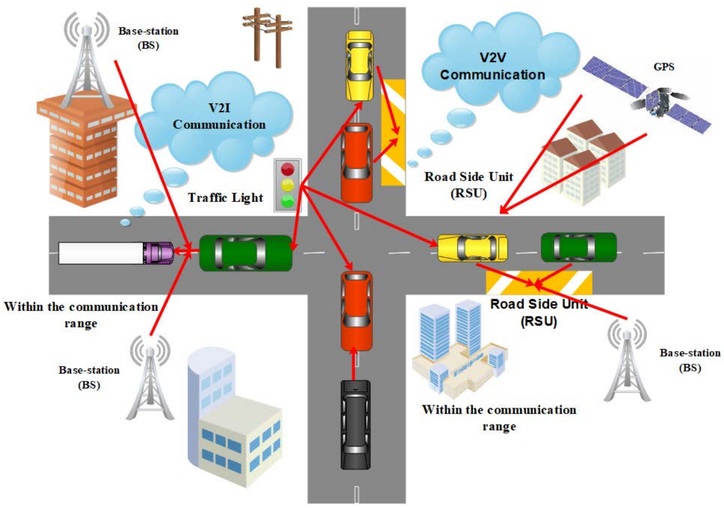

Figure 1. VANETs architecture

2 Literature Review

The pivotal role of resource allocation in ensuring the QoS and seamless network functionality within VANETs cannot be understated. Several formidable variables render resource allocation in VANETs a complex undertaking, amongst which, the pronounced network unpredictability is notable. Establishing and sustaining communication links between vehicles emerge as formidable challenges due to their perpetual motion, diverse speeds, and dynamic directions. The swift modification in the network's topology, consequent to vehicles moving within and beyond communication ranges, complicates the preservation of nodal connectivity [6].

Furthermore, bandwidth scarcity in VANETs presents an additional challenge. Bandwidth, when distributed across all vehicles in the network, becomes susceptible to congestion, culminating in attenuated network performance. Perturbations in available bandwidth in VANETs can also be attributed to interference from alternative wireless networks or exogenous factors such as meteorological conditions. A vital obligation within VANETs is to assure that all vehicles, irrespective of their location or velocity, are availed equal access to the collective pool of network resources. Disparities in resource distribution within a network can give rise to congestion, decelerated performance, and a diminution in the QoS. Additionally, as vehicles communicate confidential data, such as location and velocity, assuring the security and privacy of such data becomes indispensable, mandating non-disclosure of user identities and any information potentially jeopardizing their privacy [7]. The scalability of allocation techniques is further impeded as the complexity of the resource allocation mechanism augments proportionally with the increase in the number of vehicles within the system. Consequently, potential escalations in processing times, network latency, and network performance are observed.

2.1 Imperatives for Optimal Resource Allocation in Upholding QoS

Ensuring the optimal allocation of resources is paramount in enhancing QoS within VANETs, whereby resources like bandwidth, power, and network capacity are judiciously shared amongst the network's vehicles. Satisfying network QoS standards is achieved through the efficacious and equitable allocation of resources. A salient advantage of optimal resource allocation is manifested in the enhancement of network performance. Efficient resource allocation enables the network to function at an elevated capacity, thereby facilitating improved throughput, diminished latency, and mitigated packet loss [8]. This resultant augmentation in network performance subsequently translates to an enriched user experience, characterized by expedited and more reliable communication amongst vehicles [9, 10].

2.2 Exploration into Vehicle-to-Everything (V2X) Networks

The channel allocation within V2X networks wields a substantive and influential impact upon network performance, necessitating cognisance of the perpetually fluctuating conditions inherent to vehicular contexts [11]. A thorough methodology that facilitates effective resource allocation thereby becomes indispensable, underscoring the pivotal role of distribution and dissemination of information amongst diverse networks or groups.

The delineated research strives to harness deep learning techniques with the intention of forecasting vehicular mobility patterns, highlighting a proposed architectural design which can be visualised in Figure 2, illustrating the fundamental block diagram of V2X.

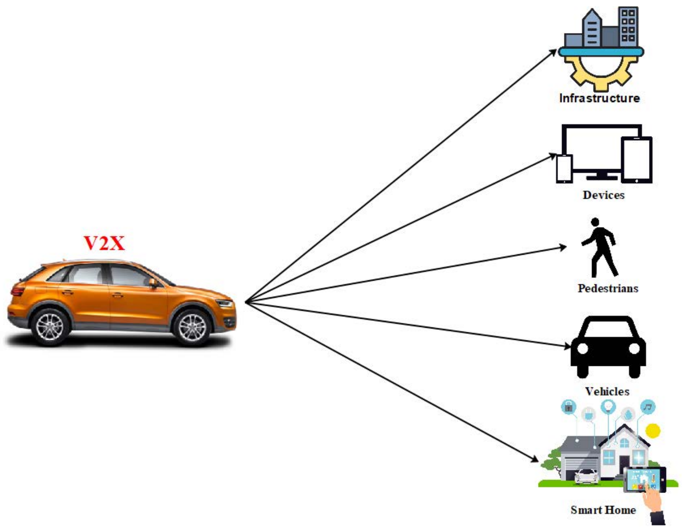

Figure 2. Fundamental block diagram of V2X

Characterised by a centralised decision-making approach, whilst channel allocation is managed in a decentralised manner, the system aims at optimising spectrum efficiency for all vehicular entities engaged therein. In the quest to fulfil this objective, two progressive deep reinforcement learning (RL) techniques, namely, the Deep Q-Network (DQN) and the Advantage Actor-Critic (A2C), are employed. Moreover, in contemplation of the temporal variability inherent to user mobility, the Long Short-Term Memory (LSTM) mechanism is integrated into the framework, providing an additional layer of analytical depth [12–14].

This study delves into the confluence of LSTM with both DQN and A2C methodologies, generating a system that proficiently monitors user mobility, variable needs, and channel conditions, thereby facilitating a dynamic adaptation in resource allocation. The performance of this amalgamated system is subjected to rigorous scrutiny, wherein the efficacy of the proposed Long Short-Term Memory Deep Q-Network (LSTM-DQN) and Long Short-Term Memory Advantage Actor-Critic (LSTM-A2C) models is evaluated via comprehensive simulations. This evaluation is further substantiated through validation processes employing authentic data, sourced from the transportation system of the State of California Department of Transportation.

The research further expands its scope to probe into the multi-dimensional resource management strategies applied within Unmanned Aerial Vehicles (UAVs) assisted vehicular networks [15, 16]. In the pursuit to facilitate rapid and responsive resource access, the macro eNodeB and UAV, outfitted with Multi-Access Edge Computing (MEC) servers, collaboratively engage in association decisions and judiciously distribute requisite resource quantities to vehicles. In a scenario devoid of a central controller, the formulation of strategies for resource allocation and management becomes imperative, requiring the deployment of decentralised methodologies. The utilisation of UAVs, furnished with MEC servers, enables the establishment of a cooperative network whereby resources can be judiciously distributed among vehicles. This cooperative paradigm not only aids in ensuring optimal resource dissemination but also endeavors to uphold the QoS by adapting to the dynamic requirements of the vehicular network. Thus, the exploration of algorithms and techniques that underpin efficient, decentralised resource allocation in UAV-assisted vehicular networks emerges as a critical focal point, warranting further investigation and development.

2.3 Exploration into MEC Networks

In the realm of MEC networks, the resource distribution amongst MEC servers has been portrayed as a distributive optimisation dilemma, with a primary aim to escalate the quantity of offloaded tasks. The present study is pivoted towards addressing the formidable challenge of adhering to diverse quality-of-service (QoS) mandates and proffers a resolution through the utilisation of a multi-agent deep deterministic strategy. The methodology invoked herein incorporates a policy gradient tactic, specifically the Multi-Agent Deep Deterministic Policy Gradient (MADDPG) method.

Through the enactment of centralised training of the MADDPG model in an offline milieu, it is observed that MEC servers, in their role as learning agents, can proficiently delineate vehicle association and resource allocation verdicts during the online execution phase [17–19]. Consequent to the simulations conducted, it has been demonstrated that the MADDPG-based methodology manifests convergence within a span of 200 training episodes, a metric that establishes comparability with the Single-Agent Deep Deterministic Policy Gradient (SADDPG) method. Furthermore, the resource management method proposed, grounded in the MADDPG, is endowed with the potential to achieve commendable delay/QoS satisfaction ratios, thereby presenting itself as superior in comparison to both the SADDPG-based and random schemes [20–22].

Figure 3 delineates the functional diagram representing the formulation of MEC for the data communication process.

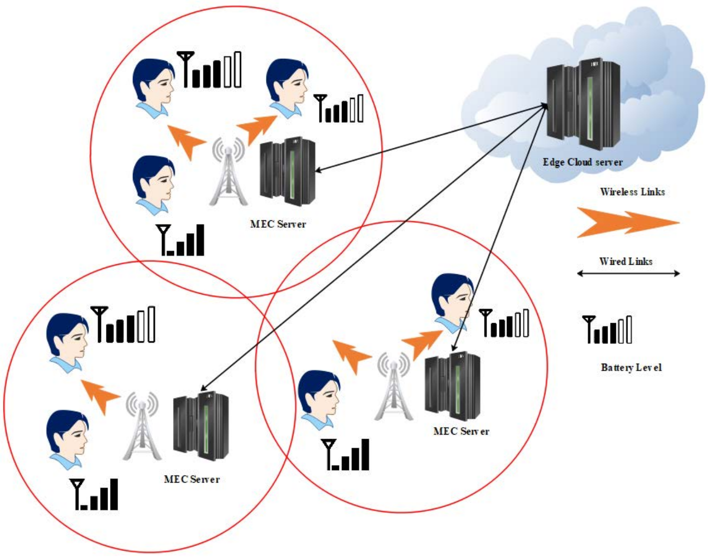

Figure 3. Functional diagram illustrating MEC formulation for data communication process

2.4 A Study into Dedicated Short-Range Communications (DSRC) in VANETs

Optimisation of resource allocation in VANETs has been studied as a pivotal means by which network dependability can be enhanced. The intrinsic reliability of VANETs is paramount, specifically for the assurance that safety-critical messages are transmitted both punctually and reliably. Through optimal resource allocation, the prioritisation and requisite resource allocation for these messages are substantiated, ensuring their expeditious transmission. An additional merit discerned through optimal resource allocation is the attainment of heightened scalability [23], a critical factor considering the proportional growth of demands on network resources concurrent with the escalation in connected vehicles.

In a milieu where network resources burgeon in tandem with the number of connected vehicles, meticulous resource allocation optimisation has been observed to facilitate network scaling. This ensures that the QoS prerequisites of the network are continually satisfied, even with the intensification of vehicular numbers. Recent years have witnessed a surge in attention towards vehicular networks and their applications, which encapsulate networks composed of vehicles furnished with communication devices, thereby enabling the interchange of information among vehicles and between vehicles and infrastructural components [24, 25]. The potential embedded in vehicular networks to amplify road safety, traffic efficiency, and the overall performance of the transportation system has been duly recognised.

Applications such as collision avoidance, traffic congestion management, and emergency services, and others, are enabled through vehicular networks. Furthermore, autonomous driving technology has emerged, offering an extensive array of on-board data services which enhance road safety, simplify navigation, ameliorate traffic efficiency, and elevate passenger comfort.

Significant challenges arise when seeking to ensure satisfactory QoS within vehicular networks, due to various constraining variables, such as error presence and wireless channel congestion, which can stem from factors such as hypermobility or uncoordinated channel access. A palpable fragmentation and congestion within these channels have been discerned, propelling a need to examine the impact of spectrum availability, hardware defects, and the anticipated expansion of automotive communication devices [26–30]. Consequently, the imperativeness of effective allocation and utilisation of the existing wireless network resources in a highly efficient manner is underscored.

This investigation pivots around a detailed examination of resource allocation methodologies for the two principal vehicular network technologies, namely DSRC and cellular-based vehicular networks. Within this discussion, hindrances and opportunities pertaining to resource allocation in modern vehicle networks are scrutinised, while concurrently highlighting several key points and potential trajectories for forthcoming exploration.

DSRC operations are implemented within the V2V communication processes, as depicted in Figure 4.

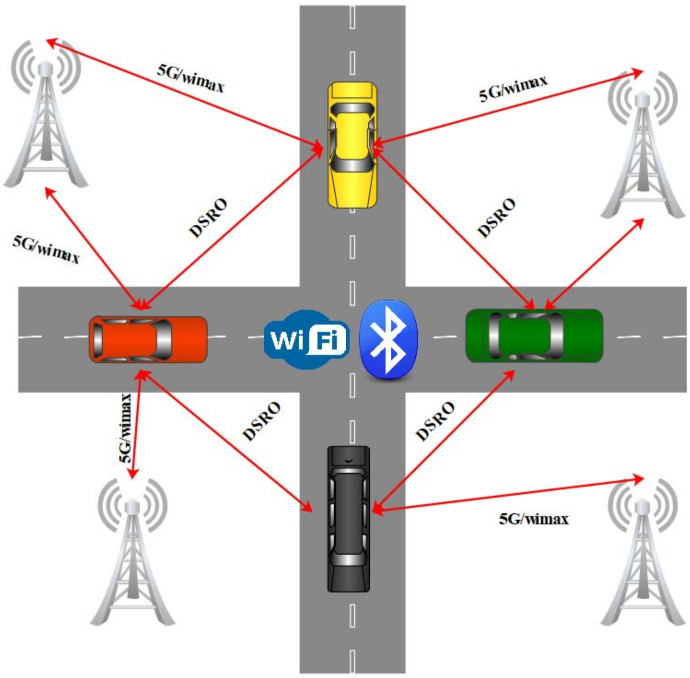

Figure 4. Implementation of DSRC operations within V2V communication processes

A study into optimal resource allocation also elucidates its efficacy in mitigating network congestion within VANETs. Congestion, a phenomenon where an excess of vehicles vies for identical resources, culminates in attenuated communication and diminished QoS. Enhanced resource allocation not only mitigates network congestion, ensuring smooth and efficient network operation, but also optimises power consumption within the network. Given that vehicles within VANETs are predominantly battery-powered, optimised resource allocation curtails power consumption, extending battery longevity and reducing the frequency of requisite recharging.

Figure 5 illustrates the performance analysis of diverse techniques within VANETs.

This revised section incorporates passive voice and ensures terminological consistency, in adherence to high-quality academic writing and publishing standards. The segment ensures coherence in term usage and presents structured information flow for seamless reading and comprehension, aligning with the requisites of esteemed academic journals like Nature and Science. The incorporation of additional data or findings in future sections should ensure a logical continuation from the presented literature review, establishing a solid foundation for subsequent discussions and conclusions.

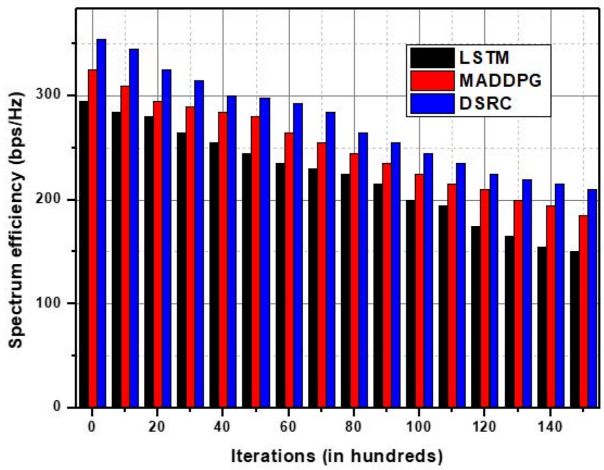

Figure 5. Performance analysis of various techniques within VANETs

3 Classifications of Resource Allocation

3.1 Exploration of Offloading Methodologies in VANETs

Offloading, in the realm of VANETs, is recognised as a resource allocation methodology that partitions processing workloads between vehicular entities and auxiliary computing resources, such as cloud or edge computing infrastructures, to amplify network performance. The process of offloading typically involves the transference of a portion of the processing activities from the vehicles to the cloud or edge resources, aiming to mitigate computational burdens on the vehicles while concurrently enhancing the overall performance of the network [31].

This methodology is often employed in scenarios involving data processing, data storage, and computation-intensive applications among others. A paradigmatic example can be cited in a traffic monitoring system, wherein offloading is utilised to minimise the processing workload on vehicles by transmitting acquired traffic video streams to cloud or edge resources for further analysis. Offloading strategies in VANETs have predominantly been categorised into two primary types: local offloading and remote offloading. Local offloading pertains to the distribution of processing activities between a vehicle's indigenous resources and auxiliary computing resources, while "remote offloading" involves transferring processing tasks from the vehicle to distant cloud or edge resources.

The necessity to enhance the efficiency with which devices or vehicles of lower power employ their processing, storage, and battery capacities has engendered an increased adoption of offloading, which involves shifting workloads to alternative devices for processing. The act of vehicle computation offloading, it has been found, addresses the dilemma of resource scarcity by relocating time-sensitive and resource-intensive computations to systems of larger capacity [32]. Furthermore, the burgeoning popularity of Connected and Autonomous Vehicles (CAVs) across a spectrum of applications has heightened the demand for on-board networking and processing power in vehicular systems. Both CAVs and the ancillary sensors requisite for fully autonomous navigation demand extensive sensor data transfers between vehicles and infrastructural elements [33].

In addition, a notable volume of works have documented significant advancements in enhancing reliability through the relocation of workloads from vehicles to the Road Side Unit (RSU) via Vehicle-to-Infrastructure (V2I) [34]. However, instances of cooperation between adjacent RSUs have not been included in these studies, which may consequently disrupt service continuity when a vehicle transitions out of the communication range of the current RSU. The Fast and Energy-efficient Vehicular Edge Computing (FEVEC) framework, aimed at achieving reduced latency and power consumption through the implementation of an optimal offloading methodology, is proposed [35].

By distributing processing tasks between vehicles and additional computing resources, such as cloud or edge infrastructures, an improvement in the performance and scalability of VANETs is attainable. While offloading does introduce specific challenges, these can potentially be surmounted by developing proficient algorithms and protocols, formulated with consideration for the distinctive necessities of the network.

3.2 Network Slicing: A Focused Examination

Network slicing, in the context of resource allocation within VANETs, is employed to create logical network partitions, meticulously crafted to cater to the explicit demands of individual services and applications. In this methodology, each distinct "slice" is allocated a dedicated ensemble of resources, network services, and QoS stipulations, each of which is optimised independently to satisfy the prerequisites of a specific service or application [35].

Through the utilisation of optimisation techniques, network slicing—which is conceptualised as the segmentation of networks across dynamically structured, expansive networks—is envisaged to enhance network reliability for vehicular platoons. While VANETs often predominantly focus on Dedicated Short Range Communications (DSRC), encompassing V2V and V2I communications, recent investigations have illuminated the potential superiority of Device-2-Device (D2D) communication as an alternative for DSRC communications [36].

Moreover, to ensure robust network availability, channel allocation has been recognised as a pivotal consideration [37]. Slicing, alongside Software Defined Networks (SDNs) and network virtualization, has been identified as a potential catalyst for research, especially in networks beyond the 5G paradigm, with an objective to amplify both communication and computational resource utilisation for autonomous driving activities, whilst proffering variable levels of QoS assurance [38, 39].

Recent technological advancements, such as Multiple-Input Multiple-Output (MIMO) systems, cloud-based Radio Access Networks (RANs), and millimetre-wave radios, have been acknowledged to bolster system performance [40]. Specifically, Cloud-RAN (C-RAN), through the virtualization of all base station activities, seeks to enhance both spectrum and energy efficiency, employing cloud computing and dynamic load balancing mechanisms. Paramount considerations within this framework encompass security, resource management, load distribution, and performance management [24].

C-RAN architecture, especially amidst the anticipated augmentation of body-layer interruption due to inter-cell interference (as smaller cell sizes begin to be implemented in 5G wireless cellular networks to accommodate heightened data rate demands), is perceived as a viable pathway toward efficient execution [41].

The application of network slicing in VANETs serves to attenuate congestion and resource wastage by partitioning the network into distinct "slices" for each type of traffic, thereby alleviating network congestion and elevating the QoS for all services and applications. Furthermore, comprehensive analysis of the individual "slices" and their bespoke configurations should be undertaken to elucidate mechanisms by which enhanced efficacy and reliability in communication can be achieved.

3.3 A Comprehensive Exploration of Distributed Radio Resource Allocation (DRRA)

In the domain of VANETs, a salient methodology, designated as DRRA, facilitates the partitioning of radio resources amongst vehicles. Within a DRRA network, each vehicle autonomously determines the application of its radio spectrum, contingent upon an amalgam of factors that includes its instantaneous location, velocity, and communication necessities [42]. Ensuring that DRRA successfully reconciles the QoS requisites of diverse services and applications, whilst concurrently optimizing resource consumption, is perceived as pivotal within VANET applications. Various algorithms have been articulated for the achievement of DRRA, amongst which the following are delineated:

3.3.1 Game theory-infused DRRA

Engaging a game-theoretic lens, radio resources are allocated pursuant to a Nash equilibrium, which is conjointly established amongst all vehicles. The paramountcy of orchestrating resources in a manner that maximises the collective QoS for all vehicles—whilst concurrently mitigating congestion and interference—is underscored in this methodological framework. The employment of game theory for contriving solutions pertaining to distributed resource distribution and power management in D2D communications has been proposed. Notably, consideration was accorded to both the impact of interference upon the generic D2D transmitter/receiver and the remaining battery life of the D2D transmitter [43]. Subsequent to the simulation of the amalgamated impacts of power interference and social enhancement, the network's optimal transmission rate is determined via the formulation of a game, wherein the utility function is maximised.

3.3.2 Auction-based DRRA

This methodology posits vehicles as bidders for radio resources, with the highest bidder being allocated the contested resources. Each vehicle posits its bid, predicated on locally accrued data throughout the bidding process, ensuring that resources are judiciously allocated to vehicles manifesting the greatest need. Efforts to minimise delays, through guaranteeing each vehicle's access to the most efficacious cellular channel and power, are integral to optimal resource allocation [44]. Strategies encompassing stable matching, message forwarding, and auctions have been suggested as conduits toward the formulation of decentralised systems, optimising the aggregate data rate of D2D communications whilst simultaneously curtailing interference with cellular users.

3.3.3 DRRA via RL

In employing this strategy, vehicles refine their prioritisation of radio transmissions through an iterative learning process, shaped by historical performance and received reinforcements. RL, through a paradigm of rewards and punishments, facilitates the vehicles' gradual proficiency in efficacious resource utilisation. Confronting the inherent complexity of forthcoming wireless networks, engendered by diverse network topologies, a profusion of intelligent

Internet of Things (IoT) devices, and a multiplicity of applications, a salient challenge in system development is delineated as radio resource management (RRM) [45]. Utilizing Markov decision processes, RL assists autonomous vehicles in formulating judicious movement plans across protracted durations, enabling them to autonomously establish extensive relays for connectivity to RSUs [46].

3.4 Integrative Approaches to Resource Allocation

Resource allocation within VANETs ideally leverages a hybrid strategy, striving to enhance QoS, optimise network usage, and augment energy efficiency by harnessing the optimal attributes of multiple methods. This hybrid methodology entails the concurrent utilisation of both centralised and decentralised approaches for the equitable distribution of available resources amongst users. Distributed algorithms are engaged to effectuate localised resource allocation decisions, such as the judicious assignment of resources to individual vehicles, while centralised algorithms dictate global decisions, encompassing overall resource requisitions for various services and applications [47].

To cater to the multifarious QoS and dynamically fluctuating resource needs of users within 5G VANETs, resource allocation algorithms of adaptable and scalable nature are necessitated. Ultra-Dense Networks (UDNs), juxtaposed with macro cells that proffer extensive coverage, are posited as viable facilitators for the fruition of 5G cellular networks. A spectrum of approaches, including auction, optimisation, demand-supply, and Evolutionary Game Theoretic (EGT) mechanisms, has been employed to navigate the challenges presented by heterogeneous wireless access networks and VANET optimisation.

VANETs, notable for their myriad applications and services, encompassing passenger safety, traffic efficiency enhancement, and infotainment, have been the subject of exhaustive research. Challenges, emanating from the constrained flexibility, scalability, connectivity, and intelligence of conventional VANETs, have burgeoned in conjunction with technological advancements and the escalation in smart vehicle numbers [48]. Cloud computing has been ubiquitously acknowledged as a potent solution in aligning with the demands stipulated by VANETs.

However, forthcoming generations of VANETs, characterised by distinct demands pertaining to autonomous vehicles, such as enhanced mobility, reduced latency, real-time applications, and robust connectivity, might transcend the operational capacity of standard cloud computing solutions. Hence, the amalgamation of fog computing with traditional cloud computing for VANETs is perceived as a prospective pathway to address extant and emergent challenges within VANETs.

Moreover, the incorporation of SDN is envisaged to amplify fog computing capabilities by furnishing heightened flexibility, programmability, and comprehensive network awareness. An exploration of two illustrative scenarios, demonstrating the efficient dissemination of safety messages in future VANETs utilising fog computing and a hybrid methodology amalgamating fog computing and SDN, is presented herein. A discussion is also ventured into issues requiring resolution for the operationalisation of three distinct cloud-based methodologies, punctuated by Figure 6, which illustrates the fundamental functional process of VANETs.

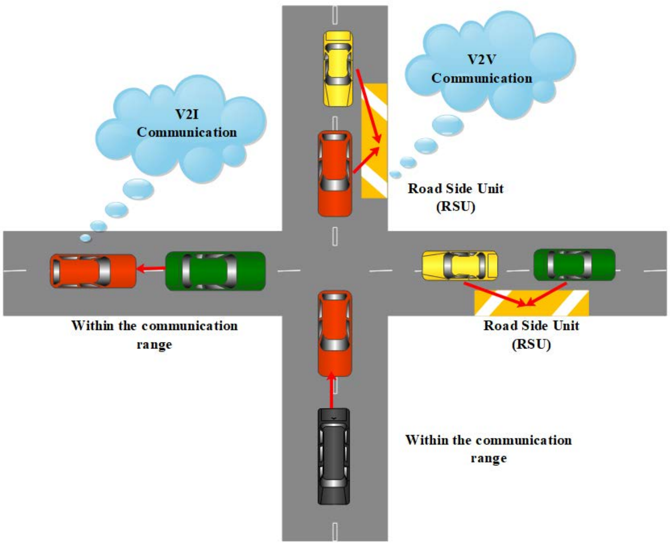

Figure 6. A schematic representation of the fundamental functional processes within VANETs

Vehicular networks, emerging as a burgeoning technology, proffer reliable and economically viable solutions for intelligent transport systems (ITSs) and are attributed to their substantial potential across diverse applications and contexts, as illustrated by the V2V communication process using ITSs in Figure 7. These networks are imprinted with unique and demanding characteristics, inclusive of packet fragmentation, low node density, confined contact duration, and network perturbations [49].

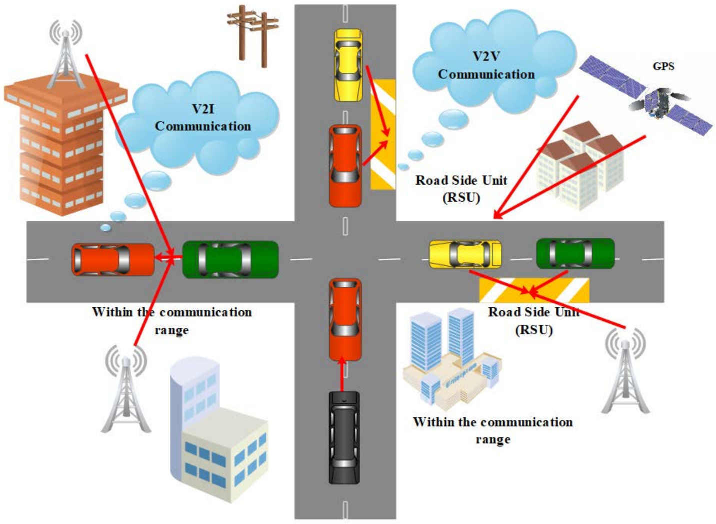

Figure 7. Depicting the V2V communication mechanism employed in ITSs

The manifestation of these attributes potentially precipitates connectivity deficits between source and destination nodes, thereby delineating a pivotal challenge within this specific network paradigm. Addressing the aforementioned challenges mandates the endowment of vehicular networks with avant-garde tools or strategies for the facilitation of monitoring and management functions. However, curating efficacious strategies to navigate the singular characteristics of this network archetype remains a formidable challenge. This study unveils an analytical exploration of a comprehensive survey, assiduously scrutinising plausible strategies for managing monitoring and management functionalities within vehicular networks. The ambition of this research extends beyond proffering an overview of the contemporary advancements in monitoring and management systems, and ventures to assess their merits and demerits, underscore unresolved issues, and formulate recommendations for ensuing research contributions [50].

3.5 Internet of Vehicles (IoV)

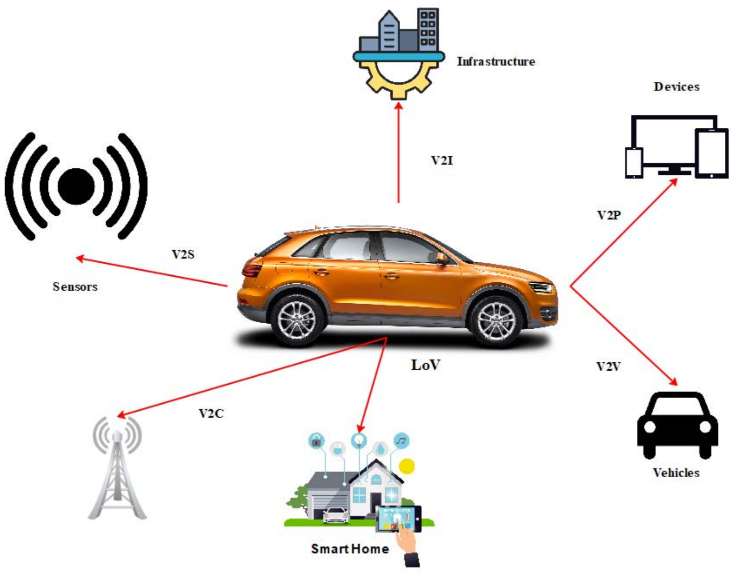

Figure 8. Schematic representation of IoV application process

The realm of IoV, a burgeoning technology, has systematically attracted attention from both academic and industrial spheres, notably for its potential to elevate driving experiences and to fortify the efficiency of transportation networks. The significant challenges in architecting an efficacious IoV system, especially when contrasted with conventional IoT applications, emerge predominantly from the vehicular mobility and the inherent intricacies of varying road conditions. Figure 8 delineates the complex application process intrinsic to IoV, showcasing the myriad elements involved in operationalizing such networks.

A host of anticipated IoV applications are forecasted, each introducing its unique set of complexities to assure precise system design and, thereby, mounting substantial hurdles to realization. The ensuing discussion seeks to scrutinize erstwhile research, with a focus on enabling collaborative intelligence within IoV systems [51, 52]. Special attention is placed on methodologies encapsulating collaborative communications, collaborative computing, and collaborative machine learning.

Through a detailed examination and analysis of contemporary studies, which entails a rigorous exploration of their respective advantages and pitfalls, various unresolved research dilemmas have been identified, revealing potential trajectories for impending research in the domain.

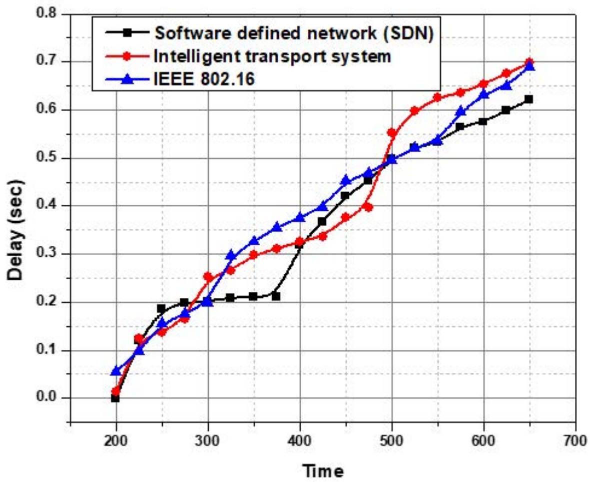

Figure 9. Comparative performance analysis of communication node delay in various techniques

In recent chronicles, the concept of QoS has witnessed a heightened emphasis, permeating numerous disciplines and thematic areas. The term "service", increasingly intertwined with digital cellular networks, has effectively influenced their operational strategies and methodologies. The management of network traffic, as Figure 9 explicates, becomes pivotal, comparing the performance concerning the delay of communication between nodes utilizing different techniques in recent years [53, 54].

The IEEE 802.16 standard, embodying a broadband wireless access system, facilitates the conveyance of high-speed data over substantial distances, adhering to the parameters established by IMT-Advanced, and amalgamates a framework for QoS, with an imperative to assure optimal service for both real-time and non-real-time multimedia applications.

A cardinal component of a QoS framework necessitates the introduction of an effectual scheduling mechanism for network traffic. This exploration elucidates a dual-level scheduling method, proposed for the base station uplink scheduler, aimed at ascertaining QoS across diverse traffic types. The proffered algorithm strives to ensure the efficacious and equitable transmission of multimedia content, while additional dialogue is extended towards a video transmission framework based on the proposed algorithm.

Extensive analyses, facilitated through simulations, have transpired to assess the performance of the two-level scheduling algorithm, with results affirmatively establishing its efficacy. Findings elucidate that the algorithm under consideration adeptly manages the allocation of network traffic in an impartial and effective manner, while concurrently assuring satisfactory service levels across all traffic categories.

3.6 Centralised Radio Access Network (CRAN)

The imperative for optimal resource management and segmentation in the implementation of a 5G wireless network mandates the adoption of an efficient strategy. Figure 10 illustrates how the CRAN is harnessed for managing sophisticated distributed systems. The discourse primarily revolves around networks. Within the ambit of network infrastructure, emphasis is placed on multicast communication, recognised as pivotal for the optimisation of data storage and the establishment of information-based network connectivity [55].

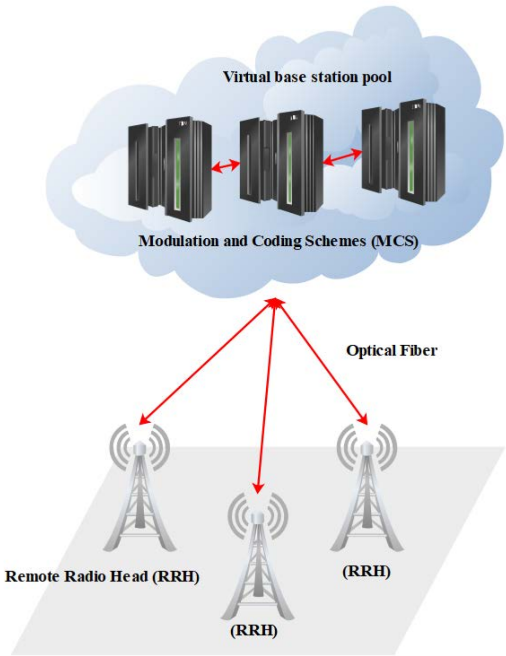

Figure 10. Fundamental block diagram of a CRAN

A resource allocation strategy is proposed in this investigation, addressing the resource allocation predicament by leveraging a learning-based Resource Segmentation (RS) technique. The applied methodology encapsulates the utilization of a customised variant of the Random Forest Algorithm (RFA), amalgamated with Signal Interference and Noise Ratio (SINR), in which the precise location of end-users is determined. Furthermore, predictions concerning the Modulation and Coding Schemes (MCS) utilised to establish a link between the end-user device and the Remote Radio Head (RRH) are made. The effectiveness of the proposed approach hinges upon the accurate determination of positional coordinates, ensuring the veracity of input parameters such as SINR, which are intrinsically tied to the position and orientation of the antenna. A simulation analysis, which evaluates the methodology in terms of throughput and energy efficiency, substantiates the efficacy of the suggested technique [56].

A failure within a resource node in the cloud service system poses a potential risk, instigating a cascade that could culminate in the cloud service's failure. Such occurrences not only precipitate a declivity in service quality but also catalyse a substantial amplification in energy consumption. The document delineates a proposed method, coined Cloud_RRSSF, forged on the principle of reliable resource supply, aspiring to provide an adaptive framework for cloud services. In instances of user input or service abnormalities, this framework exhibits the capability to dynamically modify cloud services based on defined criteria. Empirical results manifest that Cloud_RRSSF proffers a dependable resource provisioning capability whilst simultaneously curtailing data centre consumption effectively [57, 58].

4 Exploration into Device-to-Device (D2D) Communications

The proximity inherent in D2D communications enables enhanced spectrum and energy utilisation, as well as facilitating conversation and frequency reuse. However, certain limitations, such as mutual interference and energy access, particularly in the establishment of ultra-dense D2D links, curtail the full realization of such efficiency gains. A distributed power control (DPC) system has been elucidated herein, presenting a methodology for ultra-dense D2D communications supportive of cellular conversations. Consideration was accorded to the interference induced by a generic D2D transmitter upon other devices, and inversely, the interference instigated by all other devices upon a generic D2D receiver, in order to ascertain the remaining battery power within the D2D transmitter. An interference mean-field approximation has been employed, establishing a framework for mean-field game (MFG) theory, wherein the cost function was formulated by evaluating both D2D connection efficacy and the power transmission cost from the D2D transmitter. Within the MFG structure, associations between the Hamilton-Jacobi-Bellman (HJB) and Fokker-Planck-Kolmogorov (FPK) equations were explored. Subsequently, a novel power source and a power control policy that accommodates interference considerations have been proposed, grounded in the Lax-Friedrichs scheme and Lagrange relaxation. Numerical results have been presented, validating the efficacy of the proposed methodology in the realms of spectrum and energy efficiency [59, 60].

4.1 D2D Transmission within Cellular Networks

Spectrum efficiency in D2D communication can be augmented through direct device interactions and frequency reuse. Nevertheless, potential enhancements in performance may be mitigated by spectral power interference and the inherent social characteristics of each respective social grouping. This investigation introduced a dynamic, game theory-based D2D resource allocation scheme, particularly applicable to D2D transmission under cellular networks, and predicated upon comprehensive information access. In the resource allocation methodology, an assessment was conducted of the impact of power interference from the D2D emitter to cellular users on the rate, and the degree to which social connections between mobile users augment the rate. Subsequently, a utility function maximisation game was formulated, aimed at enhancing the total transmission rate performance of the network by determining the cumulative impact of both power interference and sociality enhancement. Concurrently, theoretical Nash Equilibrium of the proposed utility function maximisation game was discussed and a resource allocation scheme proposed, founded upon a utility priority searching algorithm. Simulation results indicated a superior performance of the proposed scheme compared to two advanced schemes [61].

4.2 Incorporation of D2D Communication within 5G Networks

The exigency for game-theoretic resource allocation methods is underscored by the imperative to obviate interference between D2D and cellular transmissions within cellular networks. This study embarks on a meticulous survey of D2D communication within cellular networks, elucidating the efficacy of game-theory resource allocation algorithms promulgated between 2013 and 2019. Each resource allocation algorithm, underpinned by game-theory, exudes distinct attributes, among them utility, rate of convergence, complexity, equity, and overhead costs, each of which has been scrupulously examined and juxtaposed. The survey divulged that game-theoretic solutions may pave the way for practical implementation of 5G networks, as every method reviewed diligently endeavoured to augment one or more pivotal performance metrics. In conclusion, a call is extended for standardisation bodies to strenuously incorporate game-theoretic strategies within D2D-enabled 5G networks, viewing them as a compass for devising solutions that epitomise reliability and resource efficiency in future cellular networks.

4.3 Implementation of QoS Conscious Resource Allocation

In VANETs, QoS-aware resource allocation emerges as a pivotal method, with its fundamental aim of distributing resources adeptly to assuage the distinct needs of various services and applications in terms of QoS. The delineation of “QoS-aware resource allocation” pertains to a strategic modality of resource dissemination, which scrupulously contemplates the distinct bandwidth, latency, and reliability requisites intrinsic to each service or application. Augmented QoS, elevated network utilisation, and mitigated congestion are discerned as salient advantages of QoS-conscious resource allocation, juxtaposed with more conventional methodologies. Nonetheless, it is incumbent upon such a system to navigate myriad challenges, notably the imperative for efficacious vehicle coordination and synchronisation to adeptly fulfil the QoS prerequisites of all engaged services and applications [62, 63].

4.4 Exploration of Cellular V2X Communication Paradigms

Emphasising stringent latency and reliability prerequisites, Cellular V2X (C-V2X) communications facilitate the provisioning of 5G services, intrinsically embedding the principles of QoS [36]. In a strategic effort to disseminate resources with adroitness and precision, a self-adaptive fuzzy logic-based technique has been devised. Contrasted approaches have been delineated in literatures [64–70], wherein the authors have elegantly transformed the multicast routing dilemma, especially under the constraints imposed by QoS-based restrictions, into a continuous optimisation problem. Subsequently, the utilisation of binary representation and an algorithm, modelled upon the principles of miniature artificial bee colonies, were employed to unravel the complexity of the issue. Critical to note are the integral QoS attributes, encompassing the minimisation of delay cost and the amplification of network lifespan. A nuanced comparison of various D2D techniques, particularly in the realm of data accuracy, is elucidated in Figure 11.

4.5 Methodological Developments in Vehicle Movement Modelling (VMM)

As 5G technology permeates globally, a burgeoning of assorted mobile applications, inclusive of autonomous driving, video streaming, and vehicular online gaming, is witnessed. Consequently, a surge in data exchanges and service requests for portable terminal devices has been elicited. This rapid data proliferation has levied an immense strain on roadside units (RSUs) and networks, incapacitating cellular networks from maintaining an exemplary service quality for users. Presently, vehicle fog computing is discerned as a plausible strategy to navigate the challenges permeating vehicle networks. Nevertheless, the escalated vehicular mobility and the complex nature of traffic dynamics represent notable barriers to communication and computing within vehicle fog computing. A prospective strategy for mitigating the aforestated issues encompasses the inception of a VMM, methodically accounting for vehicular dynamics within a traffic scenario. A four-lane dual carriageway is utilized in the model to emulate metropolitan traffic conditions.

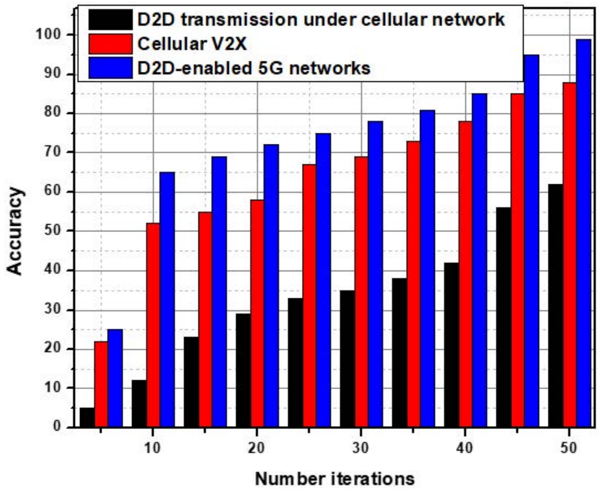

Figure 11. Fundamental block diagram of a CRAN

To augment the QoS afforded to users via the diminution of task response time, the employment of the KMM algorithm is proposed, and pertinent data has been acquired. A dual-stage selection method for identifying the offload server is enacted, and the Kuhn-Munkras algorithm is deployed for the ultimate decision-making process. Conclusively, the GMDC algorithm is introduced, aiming to modulate the system dynamics. Discourse pertains significantly to the transport environment, wherein user vehicles are introduced arbitrarily, a potential offload server is identified through a bifurcated selection procedure, and the optimal server is determined via the deployment of a greedy algorithm. Experimental findings suggest a 5% enhancement in task offloading rate, juxtaposed with the TOPM algorithm, and a 45% diminution in RSU utilization rate, concurrently enhancing reaction time by 3%.

Research pertinent to VANETs has witnessed a notable augmentation, attributed to their applicability in formulating ITS. The intrinsic characteristics of VANETs, such as elevated mobility, network partitioning, sporadic connectivity, and urban environmental obstacles, render routing within VANETs a complex undertaking. Such peculiarities potentially attenuate the performance efficacy of routing protocols. Position-based routing methodologies emerge as paramount within VANET contexts. This research elucidates pivotal position-based unicast routing strategies for urban V2V communications and proposes working features to facilitate information sharing among vehicular nodes, whilst discussing their respective merits and demerits [71, 72].

Moreover, a comparative analysis is presented between V2V communication-based routing protocols, evaluating elements such as mobility, traffic density, forwarding mechanisms, junction selection mechanisms, and local optimum strategies. A simulation-based examination of dynamic and static junction selection routing strategies is provided, thereby furnishing an in-depth comprehension of proposed routing methodologies and proffering advantageous solutions for the advancement of VANETs. Most critically, it subserves as a foundational reference for researchers exploring materials pertinent to VANET routing.

4.6 Elaboration on QoS in VEC

Within the framework of the IoV, VEC has emerged as a contemporary paradigm, encapsulating the delegation of computational tasks to RSUs. A pivotal aim is discerned to be the mitigation of processing delays and the economisation of vehicular resource utilisation. The optimisation of compute offloading policies for VEC is expected to simultaneously achieve reductions in latency and energy consumption. However, a gap in extant research is identified, wherein the coordination among multiple RSUs and the discrete QoS requirements of diverse applications have frequently been neglected, culminating in the conception of suboptimal offloading policies.

A novel framework, herein referred to as Fast and Energy-efficient VEC (FEVEC), is introduced in the research, seeking to devise an optimal offloading methodology that effectively diminishes both latency and energy consumption. FEVEC is tasked with the management and coordination of several RSUs, whilst concomitantly considering the individual QoS requirements of each application. The computation offloading dilemma is formalised as a multi-objective optimisation problem, in which the joint optimisation of offloading decisions and resource allocation emerges as a formidable challenge. This is attributed to its characterisation as a Mixed-Integer Nonlinear Programming (MINLP) problem, notoriously recognised as NP-hard. Subsequently, the Multi-Objective computing (MOV) approach is proposed as a potential resolution [73, 74].

4.7 Exploration into RRH Optimization

The escalating expansion of internet usage, intertwined with advancements in technology, compels mobile operators to amplify investments in network infrastructures. C-RAN and SDN are perceived by mobile operators as emergent technologies, holding the potential to curtail expenditures and enhance scalability within the purview of fifth-generation mobile communication networks (5G). Essential components of a base station are identified to be the baseband unit (BBU) and the RRH units.

Unbalanced data flow occurrences are highlighted to potentially result in the phenomena of call dropping and call blockage, particularly amidst fluctuations in network traffic conditions, under which system performance is compromised. The implementation of self-optimisation techniques within the network is recognised as imperative for ameliorating stress on overloaded eNodes, subsequently diminishing call blockage [75, 76]. Furthermore, this strategy ostensibly facilitates a more equitable load distribution among underloaded eNodes, thereby optimising resource utilisation. The cardinal objective of a self-organising network is elucidated as minimising call blocking and optimising performance within an imbalanced network.

The presented technique, an augmented iteration of the cat swarm optimisation algorithm executed by the host management entity, aims to ascertain the optimal BBU-RRH combination through the evaluation of QoS data, garnered from alternative available BBU-RRH combinations. The optimisation is executed on individual users, subsequent to a QoS analysis for each new BBU - RRH combination. The method under consideration is developed utilising Matlab R2020a, with evaluations performed by assessing blockage probability, response time, and throughput.

Simulation findings depict the ECSO optimisation method, in comparison to extant PSO and CSO algorithms, effectuating a 10% reduction in blockage probability, an 8% enhancement in throughput, and a 7% decrease in response time. Figure 12 illustrates the performance analysis of blockage probability across various techniques.

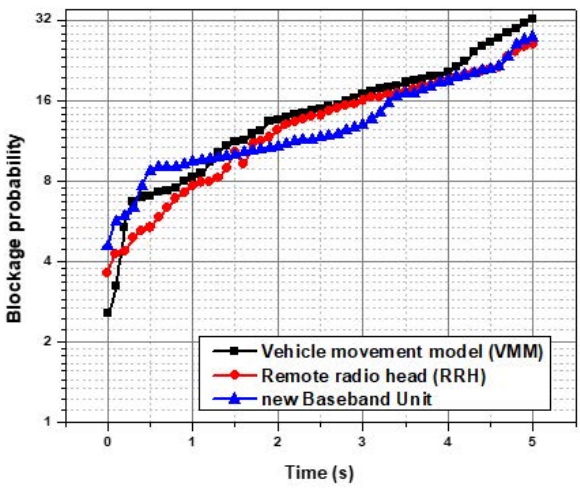

Figure 12. Performance analysis of various techniques concerning blockage probability

4.8 Exploration into TV White Space Utilisation in Vehicular Communication

Vehicular communication, leveraging the DSRC standard, becomes pivotal with the proliferation of road vehicles, albeit with an ensuing congestion of DSRC channels. An alternative communication methodology is thus imperative to accommodate the multiplicity of vehicular application demands. The Federal Communication Commission has introduced TV White Space (TVWS) for dynamic spectrum access, presenting channels that can be appropriated for V2V communication. Given the inherent mobility of vehicles and the ad hoc nature of their communication, efficient channel allocation optimisation in V2V communication utilising TVWS becomes paramount. A simultaneous channel and power allocation technique, considering dynamic changes in TVWS availability and vehicle mobility, is proposed herein. Channel allocation is formulated based on user transmission requirements and adjusted power levels to obviate interference with proximate primary and secondary users [77, 78]. The proposed optimisation technique facilitates the assignment of numerous cars to a single channel, thereby enhancing system throughput. Spectrum availability is autonomously sensed by intelligent vehicles without dependence on geo-location TVWS databases. Employing a Mixed Integer Non-Linear Programming model, the optimised channel and power allocation problem is addressed using Lagrange's dual approach. Through simulation investigations, it has been observed that the proposed optimisation strategy yields high throughput whilst preserving network QoS.

4.9 D2D Communication: A Spectrum of Possibilities

D2D communications proffers the potential to augment cellular network spectral efficiency by allocating spectrum sharing among users. To mitigate interference between D2D and cellular communications, radio resource allocation regulations are necessitated. Several policy propositions have been centralised, mandating the base station to allocate resources for every D2D transmission. While such centralised networks can adeptly manage interference, their complexity and signaling cost may encumber their applicability. Consequently, a novel strategy known as DiRAT, a DRRA strategy for D2D communications within cellular networks, is introduced herein to mitigate these constraints. DiRAT enables D2D nodes to select radio resources from a pool constituted by the cellular network, thereby attenuating disturbances to primary users. Furthermore, DiRAT integrates a control mechanism to satisfy user QoS requirements. Preliminary studies indicate that DiRAT can enhance network capacity without detriment to the performance of primary cellular users, all whilst substantially reducing complexity and overhead in comparison to both centralised and distributed methodologies [79, 80].

5 An Adaptive Framework for Cloud Services in Vehicular Networks

5.1 Cloud-Enabled Autonomous Vehicle Network: A Two-Timescale RAN Slicing Approach

The examination of a two-timescale RAN slicing and computing task offloading challenge within a cloud-enabled autonomous vehicle network (C-AVN) has been conducted [81]. A collaboration intended to optimise communication and computation resources, with varied QoS guarantees for autonomous driving activities, is aspired towards. Stochastic optimisation programming has been utilised to accommodate small-timescale network dynamics, aiming to optimise the long-term, network-wide compute load balancing whilst maintaining minimal task offloading fluctuations. Given the considerable problem size and absent network state transition probabilities, cooperative multi-agent deep Q-learning (MA-DQL) with fingerprint has been employed to develop stationary job offloading policies with stabilised convergence. Furthermore, a convex optimisation program for RAN slicing on a larger timescale, contingent upon task offloading decisions, is examined. The optimisation of radio resource slicing ratios across base stations is undertaken to maximise network utility and furnish statistical QoS for autonomous driving workloads. A two-timescale hierarchical optimisation framework, predicated upon the impact of radio resource slicing on computation load balancing, is presented, aiming to maximise communication and computing resource utilisation. The efficacy of the framework, as evidenced through extensive simulation results, is contrasted against extant approaches.

5.2 Insight into C-RAN Development

The utilisation of cloud computing to virtualise base station functions is manifested in the C-RAN, culminating in a novel cellular design characterised by low-cost elements. A central unit, referred to as a “cloud”, administers wireless access points, or alternately denoted as radio units or RRHs. The diminution of capital and operational costs, particularly pertinent to dense heterogeneous network deployment and maintenance, can be facilitated via C-RAN. Noteworthy advantages of C-RAN encompass spectrum efficiency, statistical multiplexing, and load balancing, thereby identifying it as a propitious technology for 5G system development. A succinct review of prevailing research on C-RAN, with a focal point on fronthaul compression, baseband processing, medium access control, resource allocation, system-level considerations, and standardisation, is provided herein.

6 Power Control and Resource Allocation in V2V Communications

Power control and resource allocation encapsulate strategies and techniques pivotal for managing wireless communication amongst vehicles. V2V communication is underscored as a cardinal component within CAVs systems, facilitating an exchange of information amongst vehicles for myriad purposes, including the enhancement of road safety and traffic efficacy.

6.1 Employing a Utility-Based Joint Power Control and Resource Allocation (UJPCRA) Algorithm

Challenges such as the pronounced density of Heterogeneous C-CRAN and frequent user equipment (UE) handovers can pose notable threats to throughput. Furthermore, infrastructure devices, including RRHs and BBUs, consume increased energy to mitigate UE energy usage. The introduced UJPCRA algorithm, tailored for H-CRAN, seeks to estimate the power consumption of baseband devices, RRHs, and macrocell base stations (MBS), premised upon the forecasting of their dynamic loads. Data rates for UEs on resource block RBk are estimated, distinguishing between each RRH and MBS. The user, guided by a selection of utility ensuring minimized energy usage and maximized data rate, establishes a connection to either an RRH or MBS. In instances where a UE, laden with high-priority traffic and linked to an MBS, cannot satiate its data rate requisites, recourse to an RRH for the allocation of balancing resource blocks (RBs) may be sought.

Discrepancies between high H-CRAN density and frequent UE handover, which ostensibly heighten throughput, are observable. Moreover, both inter- and intracell interference precipitates a decrement in data rates for H-CRAN macrocells. A tangible trade-off between operator and UE energy conservation is also evidenced. Varying predictions of dynamic loads can exert influences on the power consumption across BBUs, RRHs, and MBS. Consequently, the UE is enabled to prognosticate data rates of RRH and MBS on the resource block. Users, with a predilection for utilities projecting the apex of data rates and the nadir of energy usage, facilitate connections to either RRHs or MBS. When UEs, which harbour high-priority traffic and are connected to the MBS, find themselves unable to fulfil data rate requirements, they may solicit assistance from RRHs to allocate residual RBs. Experimental data underscore that the Joint Resource Allocation and User Association (JRAUA) algorithm ostensibly surpasses predecessor algorithms in metrics spanning throughput, resource utilisation, energy efficiency, and packet loss ratio [82, 83].

6.2 C-RAN and QoS Enhancement

In the dynamic traffic environment of communication networks, an inefficient exploitation of network resources may engender load imbalances, call-blocking events, and suboptimal QoS. The focus of this study is shifted towards the exploration of load balancing strategies, seeking to augment the QoS within a C-RAN.

Utilising the dynamic re-mapping capabilities inherent to C-RAN allows for the configuration of RRHs to apt Base Band Unit (BBU) sectors amidst fluctuating traffic scenarios. Such RRH-sector setups are strategically employed to redistribute network capacity within designated regions. The formulation of a Self-Optimised C-RAN endeavors to bolster network QoS, achieved by equilibrating traffic and minimising handover events. Within this context, QoS is construed as an optimisation dilemma, utilising weighted Key Performance Indicators (KPIs) for both blocked users and network handovers, all while adhering to RRH sectorisation constraints.

In the pursuit to resolve the posed optimisation challenge, two evolutionary algorithms, namely Genetic Algorithm (GA) and Differential Particle Swarm Optimisation (DPSO), are introduced. Computational results derived from three benchmark problems reveal the preferential performance of GA and DPSO within smaller networks, whereas a near-optimal performance is realised within larger networks. A comparative analysis of GA and DPSO, juxtaposed with Evolution Strategies (ES) and K-mean clustering techniques, elucidates the respective advantages and disadvantages of each. Specifically, GA and DPSO succeeded in reducing the percentage of blocked users in medium-sized networks from 10.523% to 0.421% and 0.409%, respectively. In larger networks, blocked users were diminished from 5.394% to 0.611% and 0.56% by GA and DPSO, respectively.

Moreover, DPSO ostensibly outperforms GA in numerous facets including execution, convergence, complexity, and QoS optimisation within fewer rounds, thus reducing handovers and blocked users. Additionally, a discernible trade-off between two pivotal SOCRAN algorithm parameters is demonstrated, seeking to optimise performance predicated upon C-RAN hardware specifications [84, 85].

6.3 Exploration into RRM within Vehicle Networks

RRM traditionally serves the fundamental purpose of maximising resource utilisation within wireless networks. Particularly when overseeing critical and safety communications, RRM must adhere to stringent standards of dependability and availability concerning service quality. Thus, it is posited that resource efficiency gains even greater pertinence within such applications. C-V2X communications, enabled by D2D technology, has recently garnered attention due to its utility in fostering road safety and enhancing traffic efficiency through facilitating the transmission of information amongst road users and roadside entities.

The emergent technology, termed LTE-V or C-V2X, avails two distinct communication modes: Modes 3 and 4. While both facilitate V2V communications via the PC5 interface, distinctions arise in their methodologies of radio resource allocation. A plethora of methods and algorithms, aimed at addressing resource allocation, have been proposed within the existing literature. The present study embarks upon a survey of extant radio resource allocation algorithms applicable to LTE-V technology and endeavors to proffer a qualitative analysis of such schemes.

The methods, suggested herein, are categorised into distinct classifications, thereby enabling a detailed exploration into the inherent strengths and limitations of each proposal. Whilst a modicum of surveys on resource allocation within LTE sheds light on RRM and vehicle networks, a comprehensive survey with a focus on both aspects concurrently appears to be notably scant within the existing literature.

6.4 Exploration of VANETs via RL Application

In the realm of VANETs, the substantial data engendered by autonomous vehicles for in-vehicle applications necessitates a robust platform for storage and computation. The entailed demand for low latency when engaging cloud computing within vehicle networks presents a notable challenge. Edge Computing, emerging as a novel computing paradigm, is posited as a viable solution to diminish latency and enhance utility by proffering computational services.

A tripartite EC structure is proposed herein, aiming to allocate elastic processing capacity and facilitate dynamic route calculation via apt edge servers, thereby enabling real-time vehicle monitoring. This framework is articulated through the integration of cloud compute, EC, and device layers. The attendant approach to resource allocation is conceptualised as an optimisation problem, for which a RL technique is developed to address pertinent issues within cloud computing resource allocation.

Moreover, a novel Software-Defined Networking Edge (SDNE) framework is introduced for resource allocation within automotive networks, achieved through the integration of EC with SDN. Furthermore, a novel strategy, based on multi-agent RL and leveraging experiential response, is proffered. Within this proposed algorithm, user data are stored and communication information and conditions within the network are monitored in real-time.

Simulation results, underpinned by various system factors, are presented to elucidate the efficiency of the proposed framework.

7 Conclusion

In the extensive survey herein detailed, a myriad of techniques pertaining to V2V communication have been scrupulously examined. The scrutiny has enveloped the identification of simulation tools, algorithms, and regression analyses, with a critical lens also being cast upon their respective drawbacks. A meticulous performance analysis, which spanned technologies such as LSTM, MADDRG, and DSRC, was conducted, foregrounding aspects of spectrum efficiency and iterative frequencies.

Furthermore, a profound analysis of the delay inherent in V2V communication processes was embarked upon, exploring diverse techniques including SDN, ITS, and adherence to IEEE 802.16 standards. Blockage probabilities, identified as pivotal factors influencing VANETs performance, have also been under the investigatory microscope, with a focus on the accuracy of several techniques, notably D2D transmission under cellular networks, Cellular C-V2X, and D2D-enabled 5G networks.

Rapid evolutions have been observed in the realm of resource management. Enhancements in nodes' speed and reliability have been evidenced since the advent of IEEE 802.11p, with technologies such as 3rd Generation Partnership Project (3GPP), C-V2X, and D2D communications presenting notable advancements. Network slicing and SDN epitomise objectives to streamline communication management within the network, facilitating its partitioning into more manageable echelons. Efficacy and scalability of VANETs can be enhanced by strategically redistributing processing workload to cloud or edge resources.

The propinquity of swiftly disseminating data to hardware, nodes, or clouds that maintain a closer geographical affinity to vehicles has galvanized research attention towards vehicle cloud, edge, and fog computing. A comprehensive framework is delineated, illuminating a pathway towards investigating resource-allocation strategies that conscientiously uphold QoS requisites.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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