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Research Efforts in Mobile Edge Network Environments

Amine Abouaomar

Abstract—Mobile Edge Computing (MEC) has emerged in recent years as a way to reduce data transmission, decrease service latency, and reduce the load on the core network. MEC is expected to play a significant role in future communications networks, especially in providing services for new applications that involve high mobility or require high reliability and low latency communications. Edge computing relies on other technologies to achieve the desired performance, including network softwareization technologies (e.g., software-defined networking (SDN), network functions virtualization (NFV), and network slicing). Edge computing also enables edge intelligence, by hosting artificial intelligence (AI) and machine learning (ML) technologies, either to improve its own operation or to provide services to end users. Various MEC-related research efforts are underway in these areas as well as in the area of security and privacy in relation to MEC. This report provides an overview of some recent works in the area of MEC.

Index Terms—Edge computing, software defined networks, vehicular communication, federated learning, resource allocation, edge security.

I. INTRODUCTION

Edge computing, a new extension of cloud computing, moves application placement out of centralized data centers to the edge of the network, close to users and data producers [1]. While Edge computing is an overarching concept, MEC is seen a telecommunications standard that provides computing and storage capabilities at the edge of the service provider's network. MEC allows processing close to the source, therefore achieving many benefits such as low latency, high bandwidth, and reduced backhaul bottlenecks. MEC is not only a technology tool for achieving key performance indicators (KPIs), but also plays a key role in the transformation of the sector [2]. Indeed, telecom networks are becoming multi-purpose service platforms for industry and other specific customer sectors. Edge computing is driving this transformation, as it opens the network edge to third-party applications and services. In a broader perspective, the edge represents a whole new environment and a new value proposition. Operators and infrastructure providers are able to open their Radio Access Network (RAN) to independent and authorized entities, enabling them to deploy innovative services and applications in a fast and flexible manner. Some of the areas that can be improved through edge computing are edge analytic, location-based services, augmented reality, and vehicle-related services. To achieve the desired improvement in these areas, it is crucial to design solutions and schemes to effectively manage edge resources. It is well known that the edge is a highly heterogeneous environment where equipment is not only from different manufacturers and of different types, but also has limited resources. Such constraints have raised

challenges in terms of resource management at the edge. In addition, it is essential to study the composition and placement of services at the edge under resource constraints [3].

Another concept that gathered a lot of interest in the research community is Edge intelligence. Edge intelligence refers to the extension of artificial intelligence to the edge of the network [4], [5]. This definition is not restricted to running AI models on servers/devices at the network edge, but also includes collaboration between the edge and the cloud, as well as leveraging AI to improve MEC. By adapting robust models to resource-constrained devices, AI will unlock the true potential of MEC. Previous work on AI has focused on deploying pre-trained models at the edge for inference. Nevertheless, privacy issues have generated a pressing need to push the training task toward the edge. In order to address these issues, federated learning emerged as a machine learning approach to train AI models using the user's data and devices without sharing the data with third parties [6]. FL only allows sharing the trained model, which is presented in the following sections of this paper.

The security of edge computing networks has risen to the forefront of industry and academic concerns [1], [7]. MEC security challenges originate from the fact that MEC networks involve various parties employing different security policy requirements and measures [8], [9]. Security management deficiencies among these parties can lead to potential security attacks. Therefore, security solutions must be designed to secure deployments of various MEC verticals such as Internet of Things (IoT) and Industry 4.0, etc. The interdependencies between MECs and network-based environments imply certain standardized requirements in terms of integrity, security, availability and confidentiality. It is therefore essential to design methods to secure MEC models and architectures, e.g., by predicting and detecting corrupted data injections.

Safety is among most critical factors in vehicular communication. Accordingly, the design of a vehicular ecosystem aims to provide adequate resources to ensure safety on the road [10]. Vehicular communication systems integrate many diverse enabling technologies, including sensing, localization awareness, and decision making. With such constraints, many challenges are encountered in the design of vehicular communication systems. Indeed, these challenges arise from the requirement to process massive amounts of data from a wide range of real-time on-board sensors. Another challenge to consider is the high mobility of vehicles that imposes other types of requirements in terms of service continuity, latency and energy consumption (e.g., charging schedule for electric vehicles), as well as services migration [11]. Finally, safety cannot be ensured when the infrastructure's security is

threatened/attacked. Therefore, it is imperative to protect the vehicle communication infrastructure from attacks at various levels of the sensing and computation pipeline.

This report summarizes most relevant research efforts in edge-cloud network environments related to (i) multi-access edge computing, (ii) edge intelligence through federated learning, (iii) softwarization of the networks and (iv) network slicing, and finally, (v) security and privacy preserving at the edge.

II. MULTI-ACCESS EDGE COMPUTING

In [12], a resource allocation scheme for fog computing was proposed with the aim of reducing the latency of applications and the fog resource consumption. Fog computing appeared as a promising paradigm for dealing with latency-critical applications, by keeping the data processing and analysis nearer to their sources. Owing to the heterogeneous nature of devices in fog, this work aims to cope with such issues. The resources types and the capabilities of the fog devices were represented in a uniform manner. The resource information then is being fed to a resource allocation scheme through the ETSI MEC API development, which is based on Lyapunov framework. Within a fog computing context, the work in [13] investigated the users-fog assignment under latency and resource consumption context. The problem was framed as a correspondence/matching game between the users and the fog infrastructures. The game was solved through the multi-stage deferred acceptance algorithm (Gale & Shapely). Additionally, the equilibrium of the game was proved. The work in [7] extends the work in [12] to consider not only the resource representation, but the queuing dynamic and the resource allocation frequency. The resource representation is exposed to the supervisor of the network, which have the role of shaping the resource allocation schemes. The queuing dynamic was studied through the optimization of Lyapunov and the drift-plus-penalties framework. The resource allocation frequency is based on the load of the edge nodes in terms of resources. Simulation in this work were conducted on a testbed. The work in the paper [14] addresses the problem of clustering, scheduling and provisioning of online users in Internet of Things networks beyond cellular 5G. The NOMA method has been adopted to accommodate many devices within the same wireless resources, mainly as a result of the massive number of devices that seek to access the network. Contrary to most prior work, we aim to maximize the number of served devices while simultaneously having to allocate their transmit power to fulfill both their real-time demands and their limited operational power. Initially, the problem was formulated as a mixed-integer nonlinear program (MINLP) that can be easily relaxed into a MILP for particular scenarios. Subsequently, the work examined the problem's computational complexity by identifying the NP-hardness of the particular scenarios. Finally, through splitting up the problem into multiple NOMA clustering and scheduling subproblems, the work has proposed an efficient online competitive algorithm. Finally, the work has shown possible paths for using these online algorithms and bringing their solutions into a reinforced learning environment

to reach energy provisioning and thus solve the global problem.

The work in [15] has studied the problem of massive Internet of Things (IoT) access in 5th generation (5G) networks using non-orthogonal multiple access (NOMA) techniques. This problem requires massive clustering of IoT devices and power supply to satisfy the low latency as well as limited operating energy of IoT devices. The objective function considered is different from the traditional throughput and sum objective functions, given that it maximizes the incoming IoT packets. Firstly, the problem is decomposed into various NOMA clustering subproblems. Secondly, the work has proposed an efficient online competitive algorithm to solve each sub-problem. Finally, a novel reinforcement learning (RL) framework has been proposed to overcome the power allocation problem. In this framework, an RL agent is trained to utilize the competitive algorithm as a black box and combines the obtained solutions for every sub-problem to decide the power provisioning for each NOMA cluster.

The work by [16] has presented a matching-based service offload scheme for computer-less IoT networks. This work has adopted the matching theory to match service offloading to suitable edge servers. The framework proposed represents a vertical many-to-many offloading scheme which focuses on offloading the frequently requested and reusable services to appropriate edge servers. This has been extended to support horizontal sharing of one-to-many computation reuse between the edge servers, which allows less computation to be pushed to the cloud.

The work of [17] have investigated the feasibility of delivering location-based services for conditional access control in mobile cloud. Specifically, this paper proposed an attribute-based multi-authority-controlled access policy to handle co-existence of multiple authorities, then, to ensure users' anonymity, and finally, to safeguard their identities from untrusted authorities. The solution proposed in this work uses the dynamic location of users as a context-centric information, leverages the location constraints as a policy in attribute-based encryption, and authorizes users whose dynamic location satisfies the access policies. The proposed attribute-based encryption is integrated with re-encryption at the proxy level to, first, transform secret valuable information from various authorities and protect the identities of mobile users from begin leaked on the cloud side, and then, outsource the computation to a cloud infrastructure with "infinite" computing resources. This improves efficiency and reduces computational overhead for mobile users with limited resources.

In [18] a new algorithm was proposed to optimize edge resource allocation techniques for edge infrastructure based on the optimization of stochastic networks. The primary focus of this approach is to minimize the power consumption at the cloud datacenter level while simultaneously achieving resource elasticity to meet users' requirements and guarantee a high-availability computing platform. This works selected overclocking techniques to enhance server capabilities and Lyapunov optimization to provide a stable design and minimize energy cost. More extensive work was presented in [19], that aimed at minimizing the user's requests delay and to

simultaneously improve the resource availability. A Lyapunov drift plus penalty-based optimization was proposed to ensure design stability and to minimize the delay cost function.

The work in [20] addresses the assignment of channels for users in cloud networks according to the information from the application layer. This work assumes a multi-user driven network where services requested by users are classified into delay-tolerant and real-time services. The suggested approach allocates each wireless channel to a user requesting a real-time service. Taking inspiration from the cognitive networks, this work aims to allocate the very same channel to another user requesting the delay-tolerant service, while at the same time reducing the interference. The goal is to make such allocations simultaneously so that the SNR of the less favored user is maximized. Such allocation is much more efficient than allocating channels separately to real-time users and then to delay-tolerant users. The resulting allocation problem is shown to be NP-hard. This work proposed a straightforward algorithm to solve this problem. Additionally, the proposed scheme is proved that the proposed algorithm gives near-optimal results.

III. FEDERATED EDGE LEARNING

Federated learning is a technique for distributed machine learning, where every device is contributing to a learning model through independent computation of gradient over its local learning data [6], [21]. Such technique has recently risen to the forefront of research, since it promises several improvements in terms of data privacy and scalability. However, it is challenging to implement federated learning at the network edge given the heterogeneity of the data, the systems, and the resources. The existing challenges and tradeoffs in federated learning at the edge were investigated in [6]. The design of federated edge learning algorithms for resource efficient learning poses a number of challenges. Essentially, multidisciplinary-related nature of the problem. Since data is the core of the learning process, this work requires a new set of criterions regarding the properties of data for wireless scheduling algorithms in federated learning. Therefore, this work provides a comprehensive framework for data-aware scheduling that provides a guideline for future directions in federated learning research. Work [22] unlike previous work in which data aspects were barely studied, this work takes into account the characteristics of the data in the proposed algorithm of scheduling. For this purpose, this work has provided a scheduling algorithm for non-independent and identically distributed and non-balanced sets of data. In the proposed algorithm, the work has taken into account data and resource perspectives. In addition to minimizing the federated learning time of completion by the edge along with the transmit energy of the involved devices, this algorithm gives preference to devices having diverse and rich set of datasets. This work has defined a comprehensive data aware scheduling framework, as well as the main lines and requisites for assessing diversity. Then, the work has addressed the aspects of diversity and some processes and measures that can be exploited. In the same context, however, under constraints of high communication rates, federated learning at the edge

must be tailored to constrained communication resources. In addition, the heterogeneity of local data distributions as well as the uncertainty in data quality raise very interesting challenges for training convergence. Therefore, the participating devices should be carefully selected, and an equivalent bandwidth provisioning is required. Always on federated learning, the work in [23] proposed a scheduling algorithm based on the quality of data. This scheme put devices that are considered to be reliable in priority due to their diversity and rich datasets. The proposed work has defined the various elements of the learning algorithm and the evaluation of the data quality.

Although the hype in the federated edge learning-related research, few works actually investigated it through a precise use case. [5] Within a smart grid scenario and precisely data from 200 houses from the state of Texas in the united states, where considerable amounts of electrical consumption data were used for models' training for applications to monitor demands and loads responses. This work evaluated using federated learning at the network edge, as a machine learning scheme in a decentralized fashion. Such an approach allows increasing both diversity and volume of the used sets of data in the training process of deep learning models with corrupting the data privacy. This work is considered as one of the very few works to achieve promising results in using federated learning to forecast household electrical loads. In the context of use cases, the work in [4] investigated the prosumer communities to achieve collective objectives regarding the energy consumption in the smart grid. Individual consumer decisions are driven by individual livelihood goals. Consequently, the framework gives priority to consumers' individual decisions and relies on the 5G network to provide coordination among different community members.

The work in [24] investigated communication and computation problem in the network edge by highlighting the privacy of data in smart household use case. This work has resulted in an architecture that includes federated learning at the edge to ensure the confidentiality of data and a weighted node elimination scheme to choose suitable candidate devices with high quality data, which improves training and reduces communication costs. Additionally, The work employ long-term memory to proactively forecast and store future tasks at the edge level. This work includes the reuse of computations to address incoming tasks with small or zero computations, thus excluding recurring computations and reducing the cost of computations.

IV. SDN/NFV ROLE IN EDGE-CLOUD NETWORKS

As an edge computing key enablers, emerging from the virtualization technologies. Software defined networks and network function virtualization reshaped the environment not only on the cloud but at the edge also. Function can now be abstracted into software pieces allowing easy, efficient and scalable deployment of the equipment with lower cost [11], [25]–[28].

To ensure the scalability of SDN-based edge computing networks, the work in [28] proposes a preemptive mechanism to balance the load in an SDN control plane distributed architecture. The proposed mechanism uses an LSTM-based long-term

prediction model for SDN controllers loads. Accordingly, the controller load predictions of long-term order enable preemptive detection of the load nature (i.e., balanced/unbalanced) in the control plane. Based on the forecasting results, data plane migrations can be in advance scheduled. To improve the efficiency of migration operations, the load balancing problem was formed as an optimization problem willing to find the tradeoff between load balancing factors and migrations cost. To solve this problem, a reinforcement learning (RL) algorithm is proposed. When the load becomes imbalanced in the control plane, an RL agent efficiently selects data plane components to be migrated and the location of the migrations.

In [27], a prediction-based data plane component migration scheduling algorithm is designed to balance the load among SDN controllers in a 5G network. The proposed algorithm leverages an auto-regressive integrated moving average (ARIMA) multi-step prediction model to forecast the load of SDN controllers. Then, when a controller overload is predicted, a data plane component is chosen to be migrated from the overloaded controller to a less loaded controller. This proactive algorithm ensures that the load in a distributed SDN control plane remains permanently balanced.

In [11] the problem of service function chain resource allocation at the edge. An SFC is a set of VNFs chained to shape a service. The problem consists in solving three subproblems, namely, the VNFs placing, VNFs chaining, and VNFs scheduling. The first two subproblems (i.e., placing and chaining) is tackled under the same formulation, while the third subproblem (i.e., VNFs scheduling) is tackled as a single formulation. The first formulation was formulated as a mean-field game, for which the equilibrium was analyzed mathematically and analytically. The game was solved through iterative learning. The scheduling problem was formulated as a matching game (many-to-one) to match edge resources to VNFs requirements. This work investigated additionally, to the latency and the consumption of resources, the execution time of the proposed scheme themselves, which turn out to be very low compared to other schemes from literature. Within a context where the services are not only to be placed or chained, but to be migrated from an infrastructure to another. In [29], a service migration scheme was proposed having the role of guaranteeing the continuity of the services while offering a lower latency. The work leveraged the deep reinforcement learning to offer efficient solutions. The problem was modeled as a multi-agent Markov decision process and solved through deep reinforcement learning algorithm, which allows a proactive migration of services and simultaneously enabling the continuity of services within high mobility use cases.

The manufacturing processes are becoming more automated and it is now recognised that both the manufacturing process and the objects it produces can be interconnected in the post-manufacturing stage. Based on this requirement, a chatty factory is about making products that can send data back to the production and manufacturing landscape as they are used, while ensuring the protection of their users' privacy. The expected utilization of a product during its designing is sometimes quite different than its actual utilization. By under-

standing the purpose of this data to sustain ongoing product refinement and by understanding how the fabrication processes can be adjusted dynamically according to the availability of the data, a number of opportunities exist. The work [30] describes how collected product usage data can be leveraged to: categorize product usage; match a label to product usage through the use of unsupervised learning; and feed this data into a cloud-based environment in which labels can be mapped to multiple products of the same type. Federated learning policies are leveraged across all devices to ensure that all data captured from a given product may be analyzed on a local basis, thereby maintaining confidentiality of the data.

Vehicles have embedded software for a variety of functionalities ranging from driver assistance to entertainment. Automobile manufacturers are often required to update embedded software on their vehicles. Software updates are available through the vehicle manufacturer to provide patches or requested by vehicle proprietors to upgrade some functionality. The work [31] proposed an architecture to distribute software updates to vehicles through SDN and cloud computing. It is shown that using SDN in providing on-demand network programmability, allows substantial flexibility for deploying in-car software updates. Alternatives for modeling vehicle networks are presented, particularly in the format of a connectivity map which can be used as an entry into the SDN infrastructure. This work presented an SDN-driven approach in which multiple frequencies are assigned to various edges of the network to enhance performance of the network.

V. EDGE COMPUTING FOR VEHICULAR COMMUNICATION

Work [32] proposed RSUs as an approach to deliver unsecured QoS-aware VANETs applications. The architecture of cloud-based RSUs is composed of legacy RSUs, dedicated micro-datacenters, and VMs using SDN. But frequently changing service hosting decreases the services delivery and increases the costs of service providers. This work employed Mininet as an analysis tools to quantify the reconfiguration of the overhead. The proposed scheme minimizes the reconfiguration overhead, the costs of service deployment, and routing delay at the infrastructure side jointly. This work was considered as the first of its kind to use this approach. The work benchmarked the purist approach's performance against an ILP scheme and an innovative heuristic for the proposed technique.

Smart grid as a collection of operating and management frameworks for electricity provision is an enabler for electrical vehicles. It allows both providers and consumers to better monitor electrical consumption through the two-way communication of electricity and information between grid nodes. With the advent of electrical vehicles (EVs) hitting the roads, and considering the charging time required for batteries, there is a need for wireless-based communication between EVs and the charging stations to check availability and pre-book charging spots. In [33], the authors presented a novel protocol for EV to EVSE communication that provides a reliable reservation process. Within the same context, the smart grid is also called upon to meet the high energy requirements. To address this issue, efficient electrical load scheduling

techniques are needed. In [34] a scheduling protocol with a load control scheme is developed. The scheduling protocol first aims at minimizing the peak loads caused by recharging a number of EVs at homes while applying charging policies. Second, it aims to achieve the tradeoff between charging and discharging in order to achieve cost optimization and improved grid stability. Analytical formulation is provided for the scheduling process problem with a load management policy. A simulation framework for IEEE 802.11p wireless technology in the NS-2 simulator was developed to perform an evaluation of wireless technology for vehicle-based networks [35]. Besides, handover techniques for the early technology were also included into the framework. The framework is intended to reproduce, as closely as practicable, characteristics of the access technology in the simulator and, through scenarios, gives an objective performance overview of the applications for ITS. The framework is being claimed to be the first of its kind open to the research community and developed to support the specifications required for vehicle-to-infrastructure communications, with particular emphasis on the handover process in the IEEE 802.11p infrastructure mode of operation. Urban sensing also have emerged as an important technique for vehicle networks. It provides users with access to a data pool gathered by on-board sensors. Aggregation is an efficient approach towards converting the data collected from the sensing into a utilizable shape. One effective way to aggregate is to partition the network into multiple geographic areas, called aggregation areas. The work of [36] provided a mechanism for constructing aggregation areas based on the location of RSUs. This work has proposed an optimization policy to identify the optimal aggregation region which minimizes vehicular communication delay. M2M concept introduced into the vehicular communication have the potential of improving electric vehicle networking through two-way communication between EVs and the charging suppliers. The work [37] investigated the performance effects of a significant number of connected EVs trying to exploit the random access of LTE-Advanced to transmit information to the network. An effective solution is proposed to overcome the congestion over the channel access in LTE-Advanced for massive EV-to-charging stations communications. In this solution, the work distinguishes two categories of communication service between EVs, prioritizing charging requests over other types of low-priority messages such as promotions, subscriptions, mechanical checks, etc. This work presented an admission control framework to manage machine to machine traffic of electric vehicles over LTE-Advanced and provide QoS to load request messages based on tight delay to prevent higher values of latencies for electric vehicle users and the network load conditions.

In [38], a performance review conducted by means of the WAVE/DSRC standard with the inclusion of pedestrians. In the first stage, the work has proposed a dedicated message format to embed pedestrian and two-wheeler positioning information. Next, a comprehensive collision avoidance scheme at the intersection was proposed. A comparison between two schemes was proposed. The first consists in announcing and transmitting messages on the control channel. The second

consists in using the control channel after announcing the service. Also this work has considered various densities of the network, and provides a study for the operational modes that minimize the congestion and the saturation of the channels. The findings of this work are pertinent to designing data transmission models for avoidance systems of pedestrians at the intersections through VANETs.

In a scenario of a vehicle failure and/or transmission of false information by a malicious vehicle, it is critical to quickly detect the failing/malicious vehicle and adjust the message exchange routine consequently. In [39] a mechanism has been developed which gathers, on a single vehicle basis, data about each adjacent vehicle transmission, as well as extracting the time correlation rules among the vehicles participating in the transmissions in the vicinity. In doing so, faulty or malicious vehicles are detected. This mechanism is referred to as VANETs Association Rules Mining (VARM). A mining operation occurs over an historically constant period of time. The association policies formulated during the mining process are employed to identify faulty or maleficent vehicles. To respond after such a fault detection, a 1:N technique has been employed as a safeguard to recover the precision of the data collection operation among the communicating vehicles.

In [40], a distributed clustering approach was proposed. Referred to as DCEV, it is constructing multi-hop clusters. DCEV sorts vehicles through the feature of non-overlapping clusters with a size that scales according to the vehicles' mobility. A D-hop clustering scheme is leveraged with each node choosing their cluster leader at a distance of at most D hops. DCEV forms clusters through a metric that allows vehicles to select the more stable path to the required cluster leader in their D-hop neighborhood. Consequently, each node calculates its relative mobility's average for all discovered routes. DCEV selects routes having least relative mobility.

In [26] a vehicular cloud model is taken, in which vehicles provide data as a service. The work shaped schemes to efficiently deliver data through scheduling transmission manner when the vehicles collect data of their environment from their sensors. To achieve this, initially, it is required to arranged vehicles into clusters, in a way where each cluster operates as a vehicle cluster. Consequently, the work resented a distributed D-hop clustering algorithm to shape clouds of vehicles in a dynamic manner. The approach clusters the vehicles into non-overlapping groups, which are sized accordingly to their mobility. vehicle clusters are formed in a way making a vehicle in no more than D hops from a the broker at the cloud side. Each vehicle selects a broker according to the relative mobility estimation of their neighbors at D hops. After constructing the cloud, a scheduling optimization that both maximize the throughput and minimize the delay is proposed to deliver the vehicles' data to the associated broker vehicle cluster.

The sensed data should be aggregated, to minimize the utilization of the bandwidth and improve the content value. An aggregation is qualified as efficient if the destination have the ability and capacity to collect sensed data from a huge number of vehicles. Given a huge number of vehicles are attempting to transmit the data collected from sensors, the network gets overloaded, thus, leading to high number of collisions and loss

of packets. Therefore, the aggregation should be conducted regardless of important considerations (e.g., a significant number of vehicles and the dynamic of the network), achieving an efficient sensed data collection is quite challenging, especially, at the destination end. The work [41], [42] proposed a dynamic and hierarchical aggregation framework where the data of collected sensors is hierarchically grouped. Furthermore, this hierarchy is updated according to the delivery efficiency being estimated theoretically. In particular, split and merge processes are performed in a hierarchy fashion to obtain a better delivery efficiency value.

Within a heterogeneous network environment, an efficient mobility management framework is needed to achieve the best continuous connectivity. [43] has proposed a mobility management system focused on providing efficient selection of the network and the timely processing of horizontal and vertical handovers. This solution is based on the use of mobile IP, in which handover criteria are based on a combined delay and jitter metric calculation. For efficiency, the update rate of the links is monitored dynamically, based on speed and metric variations. The dynamic link update frequency ensures timely detection of busy points of access and cellular boundaries allowing for efficient handoffs minimizing packet loss as well as handoff delay.

The work in [44]–[46] has proposed a secured infrastructure in which EVs and smart grid share information for scheduling itineraries and booking recharging time slots at charging stations. This architecture ensures privacy and incorporates authentication and permission to secure critical information of EVs. The work introduced a novel framework for EV route scheduling, which considers the EV’s charging status, its destination, and the available charging sites on the itinerary. The framework minimizes the EV’s waiting time and its overall energy consumption to arrive at its destination. Within the same context, [47] has presented a model for guiding system to reduce the delay in waiting time of an EV to be plugged in for charging service at the public charging nodes. This work has proposed an algorithm to guide vehicles to the charging stations in a manner that helps minimizing their searching time to reach a charging station.

VI. NETWORK SLICING AT THE EDGE-CLOUD

The multi-agent resource provisioning problem in vehicular networks using NOMA and network slicing is still facing various challenges. The heterogeneity in quality-of-service demands, sharing of data collected from sensors in a scenario of high-speed communication, and the very low latency requirements, are all examples of such a challenges. To guarantee service heterogeneity demands, the work of [48] proposed slicing-based network architecture. Under these challenges, resource provisioning between vehicles is highly challenging, primarily due to the highly varying channels between vehicles (highly moving), and the absence of a central decision making entity. Therefore, to perform centralized resource provisioning based on instantly collected information about the state of the channel is not possible. Resource provisioning is involving traditional allocation of power and radio resources, in addition

to the selection of coverage and packet. To this end, this work provides first a mathematical formulation and an integral analysis of the problem’s NP-hardness, and model a multi-agent Markov decision process for the problem. Finally, this work employs a deep reinforcement learning approach to solve the formulated problem. The solution is practical due to its implementability as an online solution, additionally, to the distributed implementation. The solution is based on collaborative learning approach where each agent perceives a reward and enhance it in both distributed and cooperative way. The resource provisioning schemes are enhanced using offline training. In [49] as in [50], [51] proposed a deep reinforcement learning-based scheme to address the resource provisioning problem at the vehicular edge using network slicing. This solution leverages non-orthogonal multiple access to better utilize channel resources. The problem addressed channel slice selection, vehicles clustering, and power provisioning,. Specifically, the problem has been formulated as a Markov decision process. The solution was provided using deep reinforcement learning.

The work in [52] tackled the problem of offloading compute-heavy UAV tasks whilst achieving the best possible trade-off between energy consumption, delay and computational cost. The focus was on the scenario of a UAV fleet carrying out an exploration mission. In the course of the mission, these constrained UAVs need to carry out very compute-intensive tasks such as pattern recognition and video pre-processing. Specifically, this problem was formulated by using a theoretical non-cooperative game with N participants and three pure strategies. The work also proposed a complete Nash equilibrium proof and implementation of a distributed algorithm that converges to such an equilibrium. Work in [53] provided an energy efficient model for users in ultra-dense LTE HetNets. In such an environment, the degradation of uplink performance at SBSs is a real challenge. To overcome the heavy interference between tiers, each SBS is attempting to open access to macro users who will eventually accept only an SBS with a SINR offer that is maximal. Consequently, arising a congestion problems of the network on the SBSs level. Such a problem was formulated as a matching game, solved through computing the stable and optimal many-to-many assignment, which consists of assigning each macro user with multihoming capabilities to the best suited SBSs and so on. In addition, this solution can provide a well balanced loads within the environment of HetNets.

VII. SECURITY OF EDGE NETWORKS

Vehicular communication raises many challenges for the next generation roadside services. Some of the critical issues that need to be addressed are those of reliability, security, and billing, along with ensuring scalability of service distribution. The work of [54], [55] addressed the provision of secure service session metrics for the receipt of service requests on-demand through an existing service domain, and discussed the performance of the underlying mechanism. This work introduced three classes of service request protocols, which are defined as multi-hop, single-hop, and extended connectivity

service requests. A comprehensive analytical model and cost study for the access protocols are discussed. The analytical study focused on estimating the overall latency cost of each access protocol with different mobility and vehicle density models in the service coverage area and in different service district domains. The work of [56] studied location-based service provisioning for access control in the mobile cloud based on attributes. This work proposed a multi-authority attribute-based access control framework and safeguards users' privacy from malicious entities. The composed framework exploits the dynamic location of the mobile user as background knowledge about the user, employed the coarse location as an attribute in attribute-based encryption to achieve K-anonymity, and filtered the returned results for increased precision. The attribute-based encryption is incorporated into re-encryption by proxy to externalize the computation to a cloud server with "limitless" computing power. The proposed framework is cost-effective as it reduces the computational cost for mobile users with limited resources.

The growth of IoT is still challenged by a range of privacy and security issues which must be addressed. In such a ubiquitous and diverse setting, dynamically and routinely changing contextual requirements, there is a need for effective and contextually adaptive systems to meet the changing needs of users. Hence, designing an adhesive access control systems to remote control smart objects while considering dynamically changing contextual conditions looks crucial. In [57] and its extension in [58], they presented a attribute-based, context-aware access control scheme that incorporates contextual information with attribute-based encryption of ciphertext policy to achieve data privacy and adaptive contextual security. The suggested design satisfies the requirements of security such as context-aware confidentiality, privacy, and tolerance against the key escrow problem.

Although blockchain has been used primarily for cryptocurrencies, it has become a trusted tool for the Internet of Things. Nevertheless, naively using blockchain for IoT results in experiencing high latency and high calculation time. The work of [9] proposed a blockchain design to be employed in a blockchain that includes different distributed IoT entities, as well as a lightweight consensus for this design.

Work of [59] addressed a certain number of weaknesses concerning fine-grained access control, user-authority collusion attack, user authorization and user privacy protection. Subsequently, proposing a novel scheme surmounting these weaknesses. A demonstration of the robustness of this scheme has been performed on authority collusion attacks, user collusion attacks and chosen plaintext attacks. Finally, it is shown that the effectiveness of our scheme is comparable to existing schemes. The work of [8] proposed a hierarchical architectural framework for securing edge IoT networks, as well as a comprehensive security framework for predicting and detecting false data injection and distributed denial-of-service attacks. The compound security framework is built on a Markov decision process, which is used to monitor the performance of each individual device in the network, and use a range-based behavior filtering scheme.

IoT blockchain embedding is still facing various issues

such as scalability and flexibility. Resources provisioning to handle a large number of interconnected IoT devices involves the need for a scalable and more a flexible blockchain. To surmount these problems, the work [60] proposed a scalable and trustworthy blockchain-based architecture suitable for IoT, that leans on sharding and blockchain oracles to establish trust between the untrusted IoT devices in a distributed and trusted manner. This work designed a network of Peer-To-Peer oracles that ensures data reliability, scalability, flexibility, and trustworthiness. In addition, this work introduced a new lightweight consensus driven algorithm that scales the blockchain beyond recognition while ensuring interoperability among blockchain contributors.

Cyber mobile physical systems involve huge amounts of data gathered by various sensors and cameras integrated into vehicles. Collaborative sensing is a model widely promoted by cyber-physical based systems to provide an intelligent knowledge base to consumers using various sensed data provided by willing contributors. Aggregation is a sustainable approach to transform sensed data into a usable format. An efficient way to perform aggregation is to partition the network into a number of geographic areas, called aggregation areas. In [61], a new scheme has been proposed to identify aggregation zones based on the location of access points. In addition, this paper proposes a method to identify the ideal aggregation location that minimizes the delivery delay of the detected data.

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