IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 29 September 2023, accepted 9 October 2023, date of publication 12 October 2023, date of current version 23 October 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3324297

RESEARCH ARTICLE

Future Prospects and Challenges of On-Demand Mobility Management Solutions

MUHAMMAD MUKHTAR QURESHI[1,2,3], FARIZAH BINTI YUNUS[2], JIANQIANG LI[1,4], (Senior Member, IEEE), ATTA-UR-RAHMAN[5], TARIQ MAHMOOD[6,7], AND YAHYA ALI ABDELRAHMAN ALI[8]

[1]Faculty of Information Technology, Beijing University of Technology, Beijing 100124, China
[2]Faculty of Ocean Engineering Technology and Informatics, Universiti Malaysia Terengganu, Kaula Nerus, Terengganu 21030, Malaysia
[3]Department of Computing and Technology, Iqra University, Chak Shahzad Campus, Islamabad 45550, Pakistan
[4]Beijing Engineering Research Center for IoT Software and Systems, Beijing 100124, China
[5]Department of Computer Science, College of Computer Science and Information Technology, Imam Abdulrahman Bin Faisal University, Dammam 31441, Saudi Arabia
[6]Artificial Intelligence and Data Analytics (AIDA) Laboratory, CCIS Prince Sultan University, Riyadh 11586, Saudi Arabia
[7]Faculty of Information Science, University of Education, Vehari Campus, Vehari 61100, Pakistan
[8]Department of Information System, Faculty of Computer Science and Information System, Najran University, Najran 61441, Saudi Arabia

Corresponding author: Tariq Mahmood (tmsherazi@ue.edu.pk)

This study was supported by the National Key Research and Development Program of China Under Project no. 2020YFB2104402.

ABSTRACT Generally, mobility management (MM) solutions are centralized, which means only one entity controls the mobility-related tasks of mobile nodes connected to the network. However, the massive number of users, rapid growth in the network traffic, and the recent developments regarding the architecture and capability of 5G networks forced multiple entities to perform the task of MM. Similarly, to fulfill the demand for the applications at the time of handoff, we have on-demand MM solutions. These solutions are designed to be adoptable to various service delivery use cases supported by future networks. In addition, they also have power-saving features that turn them off automatically, when all your devices are fully charged. Owing to stated features, we need to explore on-demand MM solutions and these solutions can provide divergent types of services according to the user's demand. Therefore, in this paper, the importance and comparison of on-demand MM solutions with legacy mechanisms are presented, by keeping in view the merits and constraints of their contributions. Furthermore, the significance of the MM as a service (MMaaS) model is discussed in detail, which is used for the on-demand MM mechanism. In this model, the substantial characteristics of the granularity of services are also elaborated, which are intricately tangled with the adoptability, extensibility, and power-saving requirements of future wireless networks. Finally, we discuss the challenges, future prospects, and application areas of on-demand MM solutions for researchers and application developers.

INDEX TERMS 5G, beyond 5G, MM, MMaaS, MN.

I. INTRODUCTION

The mobility management (MM) mechanism is a set of techniques and protocols used in telecommunications and wireless networks to regulate the movement of user devices such as smartphones and laptops. The primary goal of MM mechanism is to ensure that mobile users can stay connected and able to communicate with each other during handoffs. In wireless networks, it is necessary to prevent service disruptions among communicating devices and should effortlessly transfer its connection to the new base station. MM is also responsible for enrolling mobile devices, tracking their location, and sending them messages. Similarly, softwarization, also known as software-defined everything, is the process of transforming hardware-based systems and functions into software-based alternatives. This technique virtualizes

The associate editor coordinating the review of this manuscript and approving it for publication was Bilal Khawaja.

and abstracts the hardware components to make services more flexible, scalable, and manageable. Softwarization is widely used in various fields, including networking, telecommunications, cloud computing, and data centers. Further, softwarization and virtualization facilitate organizations to install, configure and manage the services [1], [3]. There are three important parts of softwareization; **I. Network Function Virtualization** (**NFV**) that involves virtualizing network functions (like firewalls, routers, and load balancers) and running them on standard servers instead of special hardware appliances. **II. Software-Defined Networking (SDN)** separates the control plane from the data plane, giving centralized control and programmability to the network infrastructure. This makes it easier to manage and optimize network resources and **III. Virtualized Network Functions (VNFs)** which are software-based implementations of specific network functions that can be deployed and controlled separately [3]. These software based mechanisms can be implemented by using the architecture of 5G, which stands for "fifth generation," of wireless communication technology. The aim of 5G network is to provide faster data speeds, less latency, more capacity, and better connectivity to support a wide range of applications and services, such as augmented reality, virtual reality, the Internet of Things (IoT), and many more [4]. The presence of consistent and well-organized wireless communication in 5G and future-generation networks is vital for the content transportation of different applications and services. Especially with the considerable development of delay-sensitive services and the massive increase in cellular devices and applications. Hence, dependable extreme-low latency standards are required to fulfill the present market demand with respect to energy utilization, transmission delay, and bandwidth usage [1]. Along this, MM is what has created a major concern in recent wireless networks. In the absence of MM mechanism, all users would have to acquire a new SIM card and lose their required level of services at the time of roaming. However, the MM mechanism will guarantee the continuity of services and improve the quality of service (QoS) and quality of experience (QoE) for attached users. The pertaining MM solutions are centralized, for example in LTE (long-term evolution) [2], where the MM entity (MME) is liable for managing the mobility of connected users. The Long-Term Evolution (LTE) system, shown in Figure 1, relies on a Mobility Management Entity (MME) to perform important tasks and make decisions. There are different entities in this system, each one having its own responsibilities. The MME is in charge of authenticating and authorizing User Equipment (UE) in Network Access Control. The Home Subscriber Server (HSS) provides the MME with provisioning and permission to help with routing. The Serving Gateway (S-GW) is the user-plane node that connects LTE RAN and Evolved Packet Core (EPC). SGW entities are grouped together to balance the load, with each eNB entity in a group having access to every SGW entity in the same group. The Policy and Charging Rules

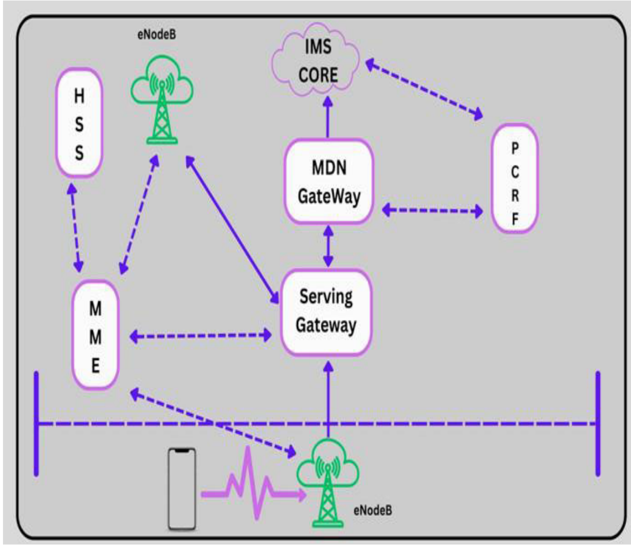


FIGURE 1. **Centralized Architecture along with its implications within a Long-Term Evolution (LTE) network context.**

Function (PCRF) is a software node that makes real-time policy decisions for multimedia networks and is a critical tool for policy in next-generation networks. QoS can interact with the access network using the IP Multimedia Subsystem (IMS) architecture to achieve the required carrier quality, allowing peer-to-peer IP connections between a variety of IMS-enabled clients and devices. Network operators and standardization organizations are working to improve MM procedures and enhance handover mechanisms in centralized LTE systems. The ongoing transition to 5G and other future technologies aim to address these issues and develop MM by introducing distributed MM as a service paradigm.

These centralized solutions, as one of them depicted above, are unable to fulfill the demand of the present applications due to large number of users and dense traffic. Similarly, such solutions are also not appropriate for 5G and future network scenarios due to the limitation of adoptability, extensibility, and more energy usage, which are also complicatedly attached to the granularity of the service aspects. Usually, the MM mechanism is established with the supposition of energy efficiency (it is about making sure that network elements, like base stations, routers, and user devices, use the least amount of energy possible while still providing exceptional network speed and quality of service.), extensibility, and adoptability of the 5G and future networks [3], [4]. Additionally, the granularity of service and handoff management solutions provide the extensibility, adoptability, and power-saving needed to fulfill the demand for 5G and future wireless network users [13]. Before exploring the details of on-demand MM solution, it is important to consider the literature [14], [15] as a basis for considering the drawbacks, compatibility and challenges, for pertaining or legacy MM solutions, especially in the context of 5G and future wireless network environment. The authors in [14] and [15] present a detailed description and critical evaluation of various efforts that have been carried on to provide smooth MM solutions. Likewise, the study in [15] also offers granularity of service based on the required cell size (which ultimately joins the obligatory quality of service and the mobility of the user). Similarly, authors in [16] cover the on-demand HO management for various sessions and slices. Further, a policy-based MM technique on a per-flow basis has been presented [17]. Furthermore, the SDN and NFV approaches have been applied to the network, CN (correspondence node), and MN (mobile node) [14], [16].

This research study provides the basis for the functional requirements of MM mechanisms in modern wireless networks. Current processes are extensively analyzed to examine whether these processes perceived by standard bodies strive to meet the specified requirements. Further, these processes are qualitatively assessed as well. Each of the discussed mechanisms is assessed in terms of its capacity to meet the reliability, flexibility, extensibility, and power consumption requirements for emerging MM schemes [5], as mentioned in Table-1. The paper also presents the outcome as well as gaps/challenges for planning and deployment of 5G and beyond MM frameworks. Such MM solutions are used with the support of Network Function Virtualization (NFV) and Software-Defined Networking (SDN) [7], [8]. NFV and SDN have been considered essential supporters of the next-generation network [7], [8].

The NFV and SDN approaches used in the MM mechanism not only assist in decreasing the capital and operating dissipation for the network operator but also empower the network to facilitate the important network tasks, such as handoff controlling provision at the top of the distributed or consolidated controller [9], [10]. Therefore, locally as well globally, the employed handoff controlling schemes will be able to provide on-demand services for the users. It is necessary to state that a local perspective is required for a particular domain at the time of deploying the SDN controller, whereas a global perspective is required for the scenario at the time of implementing the MM application for a network as a whole [11], [12]. According to the literature review performed for the research study, there is a need to make further exploration on on-demand MM solutions under the umbrella of MMaaS Model. So that we can justify and use the capability of such a model for implementing in various fields of life. Therefore, this article explores the granularity of service for on-demand MM solutions by considering network burden, preplanned strategies/policies (user and network), mobility profile, and flow categories. It also provides a comprehensive analysis of the characteristics and challenges of an adoptable MM approach for 5G and future wireless networks.

Our article is divided into the following sections. Section II highlights the importance of the on-demand MM mechanism within the MM as a service paradigm and critically analyzes legacy MM techniques. Section III discusses various existing methods for providing on-demand MM mechanism along with granularity of the service. Section IV focuses on research challenges, current solutions, and application areas in the field of on-demand MM solutions. Section V outlines potential areas for future research and innovation in the context of the MM as a service model. Finally, Section VI concludes the discussion on on-demand MM under MM as a service and granularity of service, along with their worth and challenges for the future wireless network.

II. ON-DEMAND MM MECHANISMS

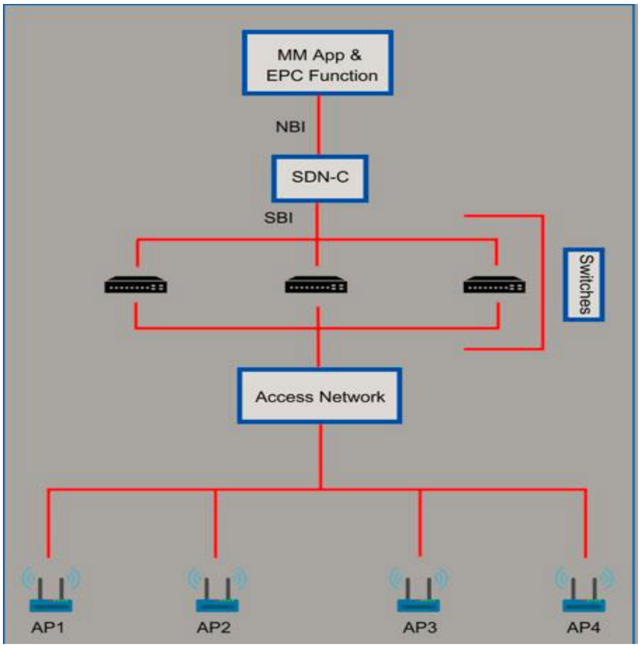
In this section, we analyze the importance of on-demand MM mechanisms within the context of the MMaaS model. This significance is discussed in light of certain parameters. On the basis of these parameters, this model is compared with prevailing MM standards.

A. SIGNIFICANCE OF ON-DEMAND MM MECHANISM

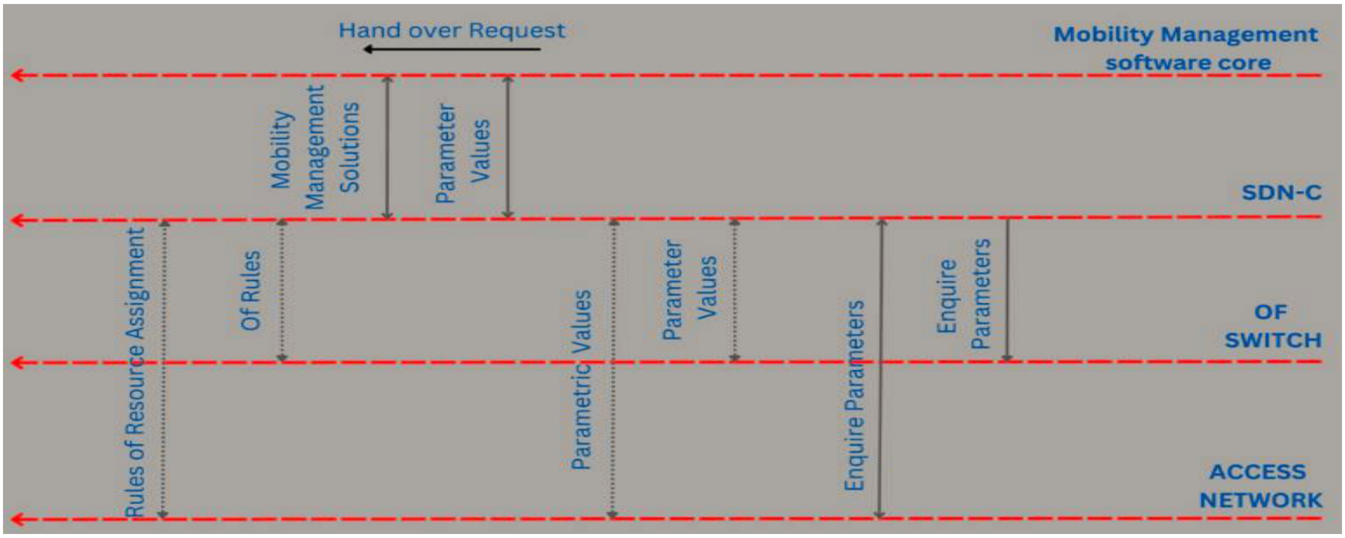
The MM mechanism can be deployed as services on top of the controller by utilizing the characteristics of SDN and NFV [14]. Then the deployed MM mechanism authorizes the operators to provide wide range of services including the option of on-demand for its MM point of view. By using MM techniques, the instances of mobility can be generated on-demand, and therefore, computation, power, and other required resources can be assigned accordingly as depicted in Figure 2. According to Figure 2(a), the access network includes a baseband group and several access points connected to it. The baseband user (BBU) group is responsible for managing the mobility of the access network, including regulating the mobility of MNs when they switch access points within the same BBU group. The term "BBU group" refers to a group of access points that are connected to the same pool.

The SDN controller, also known as the SDN switch, has to cooperate with user plane function (UPF), Data network (DN), access and mobility management function (AMF), authentication server function (AUSF), session management function (SMF), network slice selection function (NSSF) and etc., over the southbound interface (SBI) in order to fetch the values and then handover the fetched values to the MM application over the northbound interface (NBI) [20]. These values are then passed on to the MM application over the northbound interface (NBI). The framework for this process is depicted in Figure 2. In Figure 2(a), the SDN-C is connected to OpenFlow (OF) switches, which consist on the network data plane. The access network connected to these switches provides values for various considerations like mobile node strategies, flow types, signal strength of connected access points, signal-noise ratios, etc. The OF switches can also access network data like link latency, network load, connection failure, congestion details, etc. The SDN control plan regulates all these information before sending it to the MM application through NBI. The MM applications then process this data and provide a solution to SDN-C.

Figure 2(b) shows how the SDN-C provides resource distribution guidelines to the access network in response to a request, such as the need to transfer traffic [22].



(a)



(b)

FIGURE 2. a) SDN architecture providing centralized control and management of network devices. b) Network controlling through a software activity flow involves the use of software-defined networking (SDN) principles to manage and control network functions.

The SDN-C manages network-level mobility, while the BBU group controls access-level network mobility. The logical flow of the diagram (Figure. 2(b)) can be represented as follows; 1. Fetching of information then, 2. Handling (take necessary computation) of information and at last 3. Application of MM rules and regulations are conserved. Based on discussion above, it is clear that the MM as a service model is essential for control distribution. Therefore, this model provides improved and efficient results owing to the capability for the distribution of on-demand computational and other required resources.

In short, information is fetched first, then MM norms and regulations are applied, and eventually, the necessary computations are done to handle this information [18], [26]. Further, the taxonomic view for on-demand MM solutions is presented in Figure 3. It depicts, a comprehensive knowledge of mobility management in several research areas, which enables dynamic network configuration, improves network performance, and enhances user experience. Now, initially, we compare the existing standard with MMaaS in the following subsection.

B. MMaaS MODEL VS PREVAILING STANDARDS

In this section, we compare on-demand MM solutions in the context of the MMaaS model with the rest of the currently implemented standards based on certain parameters.

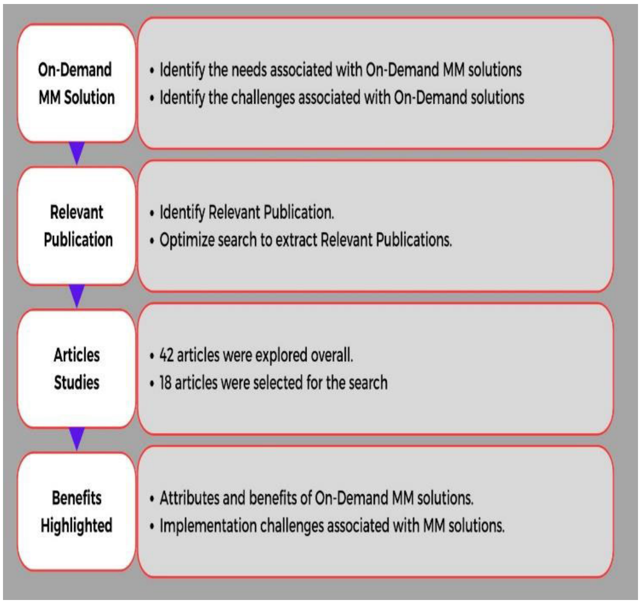


FIGURE 3. **Taxonomic view of on-demand mobility management mechanism in the form of a structured framework for understanding and comparing various methods based on their characteristics and functionalities.**

We choose the following parameters: (i) Power utilization, (ii) Self-organizing feature, (iii) Network slicing compatibility and (iv) Granularity of service. The detail of values for each parameter is depicted in Table-1 as follows. (i) **Power Utilization**: Handoff-related activities, such as finding new networks, measuring signal strength, negotiating parameters, and connecting to the new networks are consuming more energy on mobile devices. Therefore, in addition to power-saving technology, electronic gadgets also use an efficient scanning algorithm. Fortunately, the MMaaS model uses smart scanning tools and effective network selection strategies. As a result, less energy is consumed as compared to the rest of standards. (ii) **Self Organizing Feature**: The self-organization feature of MMaaS model provides very high capabilities in this domain because it allows the network to change with the environment, improve performance, and the user experience without requiring manual configuration or intervention. These capabilities make use of automated systems and clever algorithms to dynamically modify network settings and guarantee effective MM as compared to the rest of standard mentioned in Table-1. (iii) **Level of Central Control**: The level of control in the MMaaS model isdistributed because it provides significant benefits over the current or legacy standard (mentioned in Table 1). This decentralisation is achieved through the flexibility that results from the softwarization of control accomplished by the use of SDN and NFV architectures. (iv) **Network Slicing compatibility**: The current mechanisms can't support network slicing compatibility except 3GPP and Telecommunication industries association (TIA) but they too have the partial support as shown in Table 1. On the other hand, the MMaaS model will be able to support multiple network slices owing to its characteristics of softwarized control and global view.

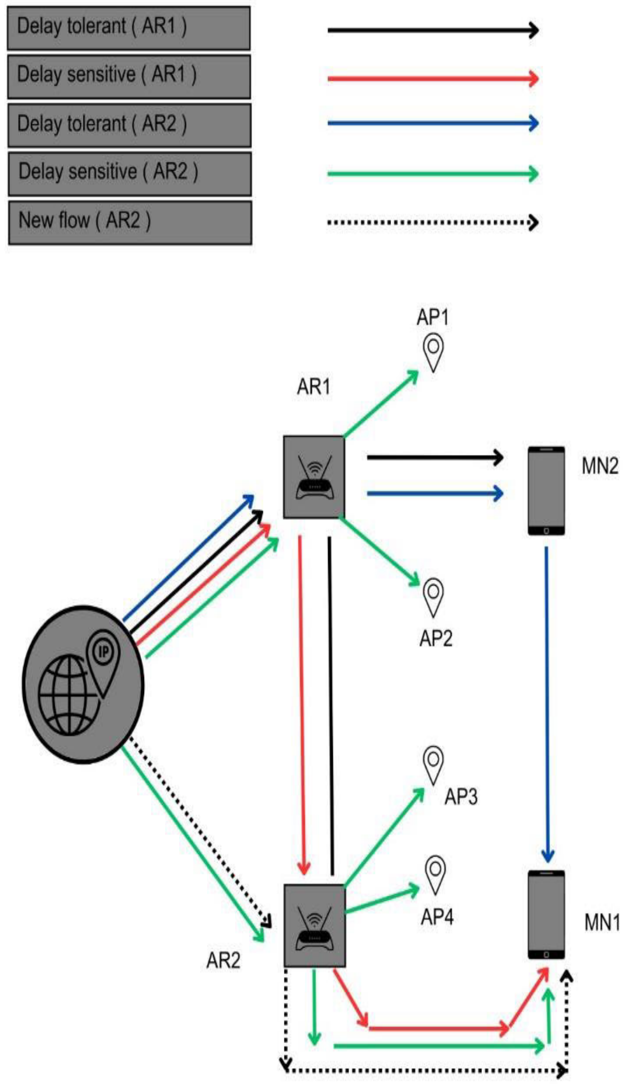


FIGURE 4. **The scenario of flow description of granularity of service provision for MMAAS.**

And, **(v) Granularity of service:** It is clear that the current MM mechanisms, designed and developed by the Institute of Electrical and Electronic Engineering (IEEE), the Internet Engineering Task Force (IETF), the International Telecommunication Union (ITU), the Global System for Mobile Communication Association (GSMA), the European Telecommunications Standards Institute (ETSI), the Telecommunications Industry Association (TIA), the Wireless Broadband Alliance (WBA), and the 3rd Generation Partnership Project (3GPP), are inadequate with respect to service granularity (a single aspect of flow), as mentioned in Table-1. whereas MMaaS is able to provide multiple granularity options, such as those based on mobility profiles, flows, policies, MN, etc.

TABLE 1. Comparison of mobility management as service model and legacy standards.

S NO	Standards	Power Utilization	Self Organizing Feature	Level of central control	Network Slicing compatibility	Granularity of Service
1	International Telecommunication Union (ITU)	High	Low	Centralized	No	MN Level
2	IETF	High	Low	Centralized	No	MN Level
3	Institute of Electrical and Electronic Engineering (IEEE)	High	Low	Centralized	No	MN Level
4	3rd Generation Partnership Project (3GPP)	High	Low	Partially Centralized	Yes to some extent	MN Level
5	Global System for Mobile Communication Association (GSMA)	High	High Enough	Centralized	No	MN Level
6	European Telecommunications Standards Institute (ETSI)	High	Low	Centralized	No	MN Level
7	Telecommunications Industry Association (TIA)	High	Low	Centralized	Yes to some extent	MN Level
8	Wireless Broadband Alliance (WBA)	High	Low	Centralized	No	MN Level
9	Mobility as service	Low	Extremely High	Distributed	Yes	Multiple ways

Similarly, in the light of Table-1 the MMaaS model offers granularity and extensibility features as mentioned earlier, that provide a high level of potential for self-organization. Therefore, it is concluded from Table-1 that prevailing MM standards are not appropriate to tackle the dynamic and heterogeneous situations for future wireless network scenarios. Next, using MMaaS model an acceptable level of adoptability and extensibility can be provided to future networks, as it would be required to assist the complicated circumstances

TABLE 2. Constrained on pertaining work and conceivable solution.

References	[30]	[32]	[33]	[34]	[35]
Existing work	The analysis of the specification of mobility signaling steps of the 5G Cellular network, with respect to the fulfilment of QoS demand for various service types in terms of throughput, adoptability, extensibility, and delay.	Graph theory is used for inter-slice organization and puts the slice in a queue based on priority, and which is achieved by a probability event. Therefore, the authors evaluate the network on the basis of a predictive solution for improving QoS for future networks.	A slice management algorithm is proposed by considering the service price; this service price represents the priority of service that is categorized into lower and higher levels.	The article presents an algorithm, where the resources are fixed for a given slice. However, the owner has no hold on a slice to satisfy the needs of the customer with respect to the provision of resources.	The research article highlights the need for significant effort for the provision of on-demand services in the future wireless network.
Recommended Changes for future Network	A SDN controller is required to have a unified handover decision mechanism for entertaining IoT-based applications. So that QOS needs may be fulfilled.	A better solution for this problem can be obtained by formulating an algorithm. This algorithm should work in a real-time environment for managing and controlling the inter and intra-slice management.	One of the techniques is to make the controller intelligent, so that requests may be sent from where the least resources (with respect to delay) are utilized.	An appropriate way is to optimize the resource allocation in such a way that QoE may be attained with the minimum utilization of the overall resources.	In the future, more analysis and investigation are required for effective handoff management, especially, for fast-moving objects.

(dynamic network conditions and various types of demand of the users) but a higher level of mobility that will occur frequently, such consideration of multiple avenues provision in granularity for MM services is a challenging aspect.

Likewise, we face numerous other challenges in saving power consumption because network load changes with time, especially at peak hours more energy is required, hence, resources are wasted and are used un-intelligently [23]. Therefore, it is required to bring the concept of zero bits with zero watts. But, in reality, the characteristics of various scenarios along with heterogeneous types of mobility profiles, differ significantly and this is a real challenge in the provision of a suitable energy-saving strategy [24]. Further, in order to tackle the challenges of energy saving in 5G and future networks, machine learning and artificial intelligence strategies can be used with controllers to take intelligence decision by turning elements on and off pre-emptively instead of waiting for the traffic burden to change before responding [25], [26].

Furthermore, the prevailing work prominence the importance of AI/ML applications for the utilization of minimum energy [27], [28], [29]. Hence, the usage of AI/ML strategies should be further enhanced, in order to cope with the complex network because it is difficult to obtain the optimum solution when we have to cooperate with heterogeneous profiles and heterogeneous networks. It has been observed that MM as a service provides the benefit in terms of using the decentralization approach of MM solutions, as compared to the rest of the standards that provide no or partial decentralization. The overall view and softwarized control solutions also allow in assisting various network slices, while pertaining methods cannot be deployed in network slicing situations. Finally, after the literature review, and from the analysis in Table-1, it is obvious that the granularity of service provides numerous advantages to the network, such as the facility of optimal MM solutions, provision of extensibility, adoptability, and energy-saving that is required in their context. Similarly, the granularity in MMaaS model can be offered in various ways. Therefore, in the following section, a thorough discussion is made on the granularity of service and the various ways (like types of flow, network policies, load, etc).

III. ON-DEMAND MM SERVICES WITH IMPROVED GRANULARITY

The granularity of service refers to the level of detail or accuracy with which a wireless network is capable of distinguishing between various users or devices in order to provide them with the appropriate level of service for their needs. It is possible that various applications and services running on a wireless network will have varying requirements for the amount of bandwidth, latency, reliability and other performance metrics. The granularity of the service strives to cater to these various requirements by customizing its approach to the management of data flows and users in order to ensure that each receives the optimal level of service quality.

According to the literature [30], we can get the advantage from the granularity of service for users, as well as for the network. In the context of users, the granularity of service provides the best possible MM solutions with the help of smart usage of batteries (reduced power consumption), enhanced QoS, and QoE. Similarly, in the context of a network, the granularity of service is feasible by providing adoptability and extensibility to the network. The abstraction for on-demand MM and granularity of service is represented in the Figure. 4. This diagram represents MM mechanism flow as follows.

1. Mobile node travel from one access point (AP) to another.
2. Meanwhile during step no.1 the access router (AR) is also changed from AR1 to AR2.
3. Next, in this step the new flow is created for AR2 after detaching from AR1, at the same time the connection with AR1 remains active until it is fully connected (All required parameter settings) to AR2

It is essential to mention that AR1 and AR2 are purely data plane entities and therefore, these entities are similar to OF-switches mentioned in the architecture of Figure. 2(a). Afterward, at the time of switching ARs or APs, the MM mechanism will examine the procedures, guidelines, and various factors related to user and network. Furthermore, in the meanwhile, the MM mechanism examines the perspective of the whole network and users in the respect of the nature of the flow, profile of mobility, etc., and will execute handoff decisions. As, of the said procedure of handoff decision, it is revealed that the MM solution employed for MN can offer granularity with respect to network burden, types of flows, the profile of mobility, policy, or combination of them according to the particular environment or scenario.

The granularity of service with respect to flow is demonstrated in Figure 4, in which flows are segregated on the bases of delay accepted and delay critical under the different guidelines/policies of MM rules and regulations. Later on in this section, a comprehensive discussion in the context of flows is elaborated. The aforementioned, general and distributed decision procedure provides the network to balance itself according to the offered services (on-demand and not centralized) and also achieve adoptability in the network. Next, at the time of a making HO decision, it is necessary to notice the context as well as to judge the required parameters because with such consideration the decision will be optimized for all attached nodes. In precise the current discussion in the draft shows an in-depth analysis of the granularity concerns and exposes that there are various ways to deliver such discretization in MM services. Hence, in the following text, we discuss the granularity of service in the context of network burden, preplanned strategies/policies (user and network), mobility profiles, and categories of flow (context of flow).

A. CONTEXT OF NETWORK BURDEN

During the times of HO, making smart decisions in the network is crucial to identify and consider network and user level concerns such as signal strength, signal quality, cell load, distance, speed and direction of the movement, QoS and neighbor cell list [22]. One effective way is the use of MMaaS model for attaining smart decision. This model allows the network to provide the appropriate MM rules and regulations for each situation. For instance, if a user is in an area that overlaps with more than one Access Point (AP), these APs could belong to one or more Radio Access Technologies (RATs), which creates a highly populated and diverse environment. In such cases, the number of users are growing rapidly, and some APs or ARs may struggle to keep up with the traffic, leading to poor QoS regarding propagation delays for the attached user. To address this issue, network MM solutions start to reduce the load on the network components as mentioned earlier. Therefore, through flow and mobility profile-based method, MMaaS models is trained to ensure QoS and QoE at the targeted point of attachment.

B. PREPLANNED STRATEGIES/POLICIES FOR USER AND NETWORK

The MM mechanism implements a particular solution by not just assessing the context and parameters but also taking into consideration the predefined policies of the user and network. The predefined strategies and policies may include characteristics such as roaming procedures, network preference, provision of service, etc. Next, according to the context of the user, the MMaaS model can choose to give more weight to certain aspects or components as compared to others. This characteristic allows the MM solutions to offer certain services to specific users depending on the context with respect to defined policy vectors [31]. The authors [7] and [15] suggest a mechanism on the basis of user context and policy vectors. To elaborate more, the study [7] found an SDN-based technique that can be employed on core and multi-mode mobile terminals (MMT). The multi-mode mobile terminal collects information like RSRP (reference signal receive power) value, RSSI (received signal strength indicator) value, accessible AP (access point) and their IDs, etc. It allows the MMT to collate these listed parameter values with its already-described policy vectors. Further, it permits the MMT to make network selections, which are then passed on to the core network. The core network then, by means of its SDN-C and in support of the C-RAN, organizes the desired operations in order to offer resources inside the core network as well as to the MMT. Additionally, the MN is permitted to formulate its rules and policies at the time of choosing the AP to whom they will be attached [15]. Furthermore, MN will update the core network about its elected APs, and the network will formulate rules and policies in order to choose the most appropriate AP for connection from the list of APs. Eventually, the core network will update the MN about the elected AP for the connection. Hence, as a result of the utilization of MMaaS framework, the policy-based granularity of service is attained.

C. CONTEXT OF MOBILITY PROFILE

The network user may have two broad categories of profiles: (i) users in vehicles: The speed of the user ranges from 15 KM to 600 KM/hour, and (ii) users as pedestrians: The speed ‘of the user ranges from 0.5 KM to 10 KM/hour. Additionally, the future network is also supposed to support the mobility of IoT devices, where sensors are attached to each device. The said and such other profiles are key concerns to incorporate into the MM solutions. The MMaaS model permits the operator to implement software and intelligent techniques and solutions on top of the controller. Hence, such a technique or mechanism can be coupled with an explicitly defined mobility profile of the user, such as in the scenario where you may have numerous slow-speed (pedestrian) users and some of them are high-speed (vehicle) users. These users are also accompanied by static sensors. So, in such a situation, the network assigns the mobility profile as well as the physical and computational resources required for the purpose of MM to all the devices, whether they use it or not.

Though the mentioned method is simple for the device but not so efficient, therefore, MMaaS model offers an option of granularity on the basis of mobility profiles and the required resources that will be allocated according to the profile of the user in the network. In the above example, the most appropriate solution for slow-speed (pedestrian) users can be attained by putting the data plan in a small cell and allocating resources using a control plan at the macro-cell, while the macro-cell resources are assigned to the high-speed user in order to avoid needless handoff. The approach used in MMaaS paradigm resembles with phantom cell approach [11], [32], in which the data plan is at the small cell and the control plan (CP) is attached to the macro cell. Similarly, the mobility profile is not required for the static sensor as it is not involved at the time of mobility. Hence, MMaaS evades the allocation of mobility profiles and subsequently offers a resource-efficient and flexible avenue to offer MM services depending on the profile of mobility.

D. CONTEXT OF FLOW

The world of cellular phones has expanded exponentially with the latest technologies and a wide selection of phone models and applications. Experts predict that by 2030, the use of cellular devices and applications will continue to rise. However, current techniques may not be able to keep up with the growing demand for diverse applications. Fortunately, MMaaS offers a solution by providing a global view of the domain and allowing for the differentiation of delay-sensitive and delay-tolerant application flows. This approach enables MM solutions to implement IP-based transfer for delay-tolerant applications and path optimization and data forwarding for delay-sensitive applications. By managing each flow independently, we can ensure quality, predictability, extensibility and power conservation. The MM as a service paradigm can also help to manage massive machine-to-machine communication by dividing it into two categories based on its latency requirements. Figure 4 provides a visual representation of this capability. According to the figure, AR-1 has two flows: (i) delay sensitive and (ii) delay tolerant. At the time of HO to the next access router (AR-2), under the mobility as a service model, IP-based switching is done by the network for delay-tolerant flow, whereas data forwarding capability is done for delay-sensitive flow. Furthermore, with the help of MM as a service model, the novel flow is initiated at AR-2 to offer access to the IP core network over AR-2 instead of AR-1; therefore, the elimination of data plan anchoring resembles the functionality of legacy MM solutions. Similarly, some other applications like massive-type machine communication [13], Xtreme mobile broadband, ultra-reliable machine-type communication, and so on and so forth can also be segregated into two broad categories with respect to latency requirements, and these are delay-tolerant and delay-sensitive applications. And, with the help of MM as a service paradigm, each flow can be managed individually, and the services can also be offered to the above-mentioned application types with respect to guaranteeing predictable QoS, extensibility, and attaining the required level of power (battery-operated devices) saving.

In this section, we have explored the objectives of the MMaaS model, which provide a seamless and integrated transportation experience to users. This model offers a high level of service granularity, which grants users access to a diverse range of transportation options, each tailored to specific needs and preferences. In summary, the MMaaS model offers users a broad spectrum of transportation choices that cater to varying travel requirements and preferences. However, this approach also presents challenges related to integration, technology, and regulatory matters. Therefore, in the next section, an overview of research challenges and suggest potential solutions to address them. We also provided most critical future research areas and application domains for on-demand MM mechanisms, which are particularly relevant within the context of the MMaaS model.

IV. RESEARCH CHALLENGES AND APPLICATIONS AREAS

In this section, research challenges that are faced for implementing the complete solution for on-demand MM mechanisms, along with their objectives are presented. Next, we discuss the most prominent and latest research areas in this domain. Followed by some well-known application areas that provide paths for researchers and application developers. The existing research and challenges [28], [34], [36], [37], [61], reveal that some aspects of MM solutions are still facing major issues. These issues are encountered at the time of slice management, prioritisation of a slice, distribution of resources (bandwidth and energy) per slice, computation offloading, and monitoring the network slice dynamically by using a set of guidelines or procedures, especially when we have a heterogeneous network environment. Similarly, although the features of security associated with network slicing are not within the scope of this article, future networks will still demand network policies to protect the network from threat or risk [38]. In addition to the above, some of the research efforts, their boundaries, and recommended changes have been identified in Table 2 for future perspective [30] and [39].

MM solution requires in-depth exploration in order to resolve the issue of on-demand satisfaction of users for actual (professionally used) applications like GrubHub, Instacart, Postmates, etc. [36]. Though MM as a service offers numerous benefits in terms of the granularity of services but on the other side, we are also facing some obstacles and challenges in implementing complete MM solutions as a service model for future networks. Following is a list of these challenges and a brief explanation for each of them:

A. PROVISION OF NETWORK SLICE

The provision of proper services to different slices is a significant aspect of 5G and future networks, especially at the time of handoff. So, MMaaS model is required to support various types of services, which will further be enhanced to include joint MM solutions used to accommodate each slice separately [8]. This variability in offering MM as a service is a real obstacle to develop and deploy such a diversified type of effective MM mechanism for each user.

B. MANAGEMENT OF COMPUTATIONAL RESOURCES

In order to meet the specified purpose of 5G and future networks, the number of computational resources should be allocated in such a way that the profile and context of the user are considered on top priorities. In such a situation (dense environment and variety of users with various profiles and contexts), it is a difficult and challenging task to properly assign and manage the computational resources among the users.

C. DELAY AT THE CONTROL PLANE

In the case of MMaaS paradigm and also in some other MM solutions, the network entities are controlled and managed through the implementation of OF rules, and most of the time the query is executed through certain parametric values. The real challenge of the control plane is the occurrence of delays, that happens due to the complete dynamic nature of the network at the time of using on-demand applications.

D. INEFFICIENT ALGORITHM

In MMaaS model, we need to process, analyse, and optimize the various parameters of the data at several levels. The aim of this analysis or optimization is to improve the extensibility, adoptability, QoS of flow or user, QoE of user, and so on and so forth of the network. We also need an efficient algorithm (with respect to time and space) for performing the said tasks, but getting or formulating such an algorithm is a real challenge due to the high level of heterogeneity in the network.

E. REQUIREMENT OF MULTIPLE CONTROLLERS

Multiple controllers are required to be implemented in the control plan so that flexibility and extensibility for the provision of services in 5G and future networks can be improved.

F. USAGE OF REPRESENTATION STATE TRANSFER (REST) API

NBI (northbound interface) makes a connection between the SDN controller and the 5G entities at the time of implementation in the application plane. Therefore, the REST API in the NBI and West/Eastbound Interface needs further consideration to improve the scalability of the controller.

G. REAL-TIME LEARNING

Real-time learning algorithms are required in order to enhance on-demand services for MM as a service model.

H. MANAGEMENT OF NETWORK SLICE

According to the demand of the users, policies and services should be offered to the slice, and it must be ensured that network slice management is done dynamically in this operation.

I. NEED FOR MACHINE LEARNING PROCEDURES

The organization of the services and flow of data in a slice need to be evaluated and considered through machine learning approaches.

J. EXTENSIBILITY AND RESOURCE ALLOCATION (INTER-SLICE)

Consideration is required for resource allocation among the slices.

K. SECURITY OF THE NETWORK

The network security part is desired to be considered by the provision of isolation among the slices at the start of communication.

Concretely, in light of the unresolved problems (research challenges) mentioned above, we have provided further details of these challenges, suggested solutions and objectives as depicted in Table 3.

Utilizing on-demand MM solutions allows us to effectively address the challenges arising from user mobility and the constantly changing nature of communication networks. Consequently, Table 4 provides a useful reference to explore the different areas of applications, including digital platforms, real-time tracking, transportation systems, marketing and advertising, business development, real-time analytics, environmental condition assessment, e-banking, development of smart cities and many more. These solutions are versatile and can be tailored to specific domains to achieve desired outcomes.

Similarly, the domain of on-demand MM solutions requires research in key areas like Software-Defined Networking (SDN), Network Function Virtualization (NFV), and Artificial Intelligence (AI). As we delve deeper into this complex area, it's evident that SDN/NFV and AI features will play a significant role in shaping future networks. The multifaceted approach used in this research direction ensures top-notch network performance in the 5G and beyond networks. This synergy between SDN and NFV emphasizes the importance of having an adaptable network system. Furthermore, the concept of a self-optimizing network can make

TABLE 3. Mobility management research challenges, solutions and objectives.

MM Challenges	MM solutions	Objectives
SDN based HO optimization [58]	This review offers a few potential research paths for SDN-based handover optimization.	The objective is to evaluate offloading methods, strategies for implementation, and advanced SDN-enabled radio access network topologies.
Scalability [59]	This review highlights the obstacles, drivers, and proposed solutions for resolving the drawbacks of present MM approaches.	The objective of the review paper is to show significant cost savings in terms of delivery paths and end-to-end packet delay, especially at the time of mobility.
Data traffic and Interference [61]	The proposed architectures can support various configurations of space-distributed mobility management functions (MMFs) for obtaining optimal mobility management	The objective of the study is to provide mobility management designs for a higher orbit with an improved reconfigurable management plane.
Computation offloading [40]	A service work flow is proposed for MM in mobile cloud computing.	Computation offloading strategy for interdependent services with respect to user mobility and fault tolerance in order to minimize execution time and energy consumption
Energy consumption[41]	A quick-response framework for multi-user computation offloading in mobile cloud computing	Framework that uses agents between mobile devices and the cloud to retrieve the offloading decision and results quickly, minimize energy consumption, and reduce communication burden
Heterogeneity [42]	Access schemes for mobile cloud computing	The objective of architecture is to provide an intelligent network access strategy for mobile users to satisfy application requirements.
Bandwidth [43]	Cloud-assisted P2P media streaming for bandwidth-constrained mobile subscribers	The proposed architecture allows mobile users located in the same location to share the limited bandwidth between them.
Security [44]	Towards cloud-based compositions of security functions for mobile devices	The proposed module installed an OpenFlow controller (cloud side) and an OpenFlow switch (mobile side) for redirection.

TABLE 3. ***(Continued.)*** **Mobility management research challenges, solutions and objectives.**

Privacy [44]	A Privacy-Aware authentication scheme for Distributed mobile cloud computing services.	The objective of the approach is to use a single private key to strengthen its security by utilizing a bilinear cryptosystem and dynamic nonce generation. It results in reduced authentication processing time and usage of memory spaces.
Seamless connecti vity[45]	Use sophisticated handover algorithms to make proactive handover decisions.	Minimize handover latency, lessen packet loss, and make sure that conn ectivity isn't interrupted while handovers are occ urring.
Network congesti on[46]	Utilise congestion-aware mobility management strategies to dynamically allocate network resources, carry out load balancing, and improve traffic routing.	Reduce network traffic, uphold the level of servi ce, and make sure that r esources are used effecti vely.
Vertical HO mobility[47]	Develop intelligent vertical handover mechanisms that a llow for seamless transitions between network types.	Enhance the user experi ence by facilitating unin terrupted connectivity a nd service continuity du ring vertical handoffs.
Ultra-Low Latency Require ments [48]	Utilise edge computation, lo cal decision-making, and distributed mob ility management to decreas e handover latency.	Achieve low-latency handoffs to supp ort real-time responsiveness and satisfy the stringent de mands of latency-sensitive applications.
Assuranc e quality of Service (QoS)[16]	Implement QoS-aware algorithms for mobility management that priorities user requirements and dynamically alter handover decisions based on QoS metrics.	Provide a high-quality user experience for various applications by ensuring consistent QoS provisioning during mobility.
HetNet Integrati on [50]	Utilize intelligent handover algorithms, load balancing mechanisms, and interferenc e management strategies to optimize the performance of HetNets.	Enable seamless mobilit y transitions between va rious types of base statio ns, increase network cap acity, and maintain peak performance.
Massive Support of IoT D evices[3]	developed an efficient MM mechanism that can handle the size and variety of IoT devices, including signaling and resource allocation optimization.	Enable seamless mobility for IoT devices, thereby ensuring effective communication and network connectivity.

changes for optimal performance in order to make real-time decisions. This ability to adapt holds the key to manage networks and delivering on-demand MM solutions. As we

TABLE 3. ***(Continued.)*** **Mobility management research challenges, solutions and objectives.**

Transfer of context[5 2]	Implement efficient context transfer mechanisms that minimize delays and facilitate the rapid reestablishment of user sessions.	Reduce context transmis sion latency during hand overs in order to preserv e session continuity and a seamless user experien ce.
Manage ment of interfere nces [53]	To reduce interference, employ interference coordination techniques such as interference avoidance, power control, and advanced beamforming.	Minimize interference effects during mobility events, thereby enhancing handover success rates and network performance.
Scalabilit y [14]	Develop scalable architectures for mobility management capable of handling a large number of connected devices and network growth.	To ensure that mobility management mechanisms are scalable to accommodate the growing number of devices and network expansion.
Mobility resilienc e [55]	Implementation of algorithms for adaptive mobility management that can handle unforeseeable occurrences and ensure rapid mobility failure recovery.	Enhance network resilience, recoverability, and robustness during mobility-related events, thereby minimizing service interruptions.

prepare ourselves for the 5G networks and beyond, the combination of SDN, NFV, and AI will also enable on-demand multimedia solutions. This will not only enhance network performance but also provide seamless, high-quality multimedia experiences for companies, people, and industries. Therefore, investing in these research areas is essential to guide network evolution toward a future where performance has no limit.

V. THE FUTURE OF THE MMaaS MODEL

The MMaas model is still a subject of discussion and is being looked into by both telecommunication firms and academia, particularly at a service level for real-time applications in the core and radio access layers. The research in this article was done in the domain of on-demand MM, where it was found that the MMaas model is still a subject of discussion. Within the framework of the MMaas model, we are able to propose the following probable areas for future direction and technological development:

A. INCORPORATION WITH EDGE COMPUTING

MM services may integrate with edge nodes in order to optimize data processing and reduce latency. This could result in improved device management and enhanced user experiences, particularly for real-time applications.

TABLE 4. Application areas of On-Demand mobility management solutions.

Sno	Application Domains
1	Digital platforms for booking, dispatching, and payment [66]
2	Real-time tracking of vehicles and passengers [25]
3	Customer rating systems to rate drivers and vehicles [27]
4	Driver screening and background checks [25]
5	Multiple payment options, including credit cards and mobile payments [84]
6	Integration with other mobility services, such as public transit [85]
7	Personalized customer experiences, including preferred routes and vehicle types [66]
8	Multi-modal transportation options, including ride-sharing and carpooling [67]
9	Integration with smart city infrastructure, including traffic signals and parking systems [68]
10	Environmental sustainability, including electric or hybrid vehicles [69]
11	Real-time analytics and data collection for performance measurement and optimization [70]
12	Vehicle safety and maintenance standards [71]
13	Driver training and certification programs [71]
14	Integration with airline and hotel booking systems [73]
15	Dynamic routing to avoid traffic congestion and optimize travel time [74]
16	High-quality in-vehicle amenities, including Wi-Fi and entertainment systems [69]
17	Gamification to incentivize safe driving and eco-friendly behavior [75]
18	Integration with parking systems to provide seamless travel experiences [67]
19	Multi-language support for global mobility services [76]
20	Integration with car rental and leasing services [67]
21	Real-time demand and supply matching algorithms [77]
22	Driver incentives to ensure high-quality service [78]
23	Integration with public transit systems to provide first- and last mile connectivity [79]
24	On-demand bike and scooter-sharing services [80]
25	Integration with autonomous vehicle technology for a seamless travel experience [86]
26	Integration with airport shuttle and ground transportation services [81]
27	Multiple vehicle types to cater to diverse customer needs [82]
28	In-application navigation and real-time traffic updates [87]
29	Integration with smart parking solutions to optimize vehicle parking and reduce congestion [24]
30	Multi-destination support for efficient route planning and ride-sharing [83]
31	Personalized marketing and advertising opportunities for businesses [83]

B. AI-BASED AUTOMATION

AI and machine learning (ML) algorithms can be used to automate routine tasks, predict device behavior, and optimize network resources for MM services. AI-powered solutions could improve security measures, predict user behavior, and resolve mobility-related issues proactively.

C. 5G AND BEYOND

As 5G and future generations of mobile networks evolve, MM services must adapt themselves to the unique challenges and opportunities of these networks. This may require more dynamic and context-aware device and service management.

D. ZERO-TRUST SECURITY MODEL

As MM services evolve, they may adopt a zero-trust security approach that prioritizes ongoing authentication and monitoring of both devices and users. This is a departure from the traditional approach of relying solely on perimeter-based security measures.

E. IMPROVED USABILITY

In the future, MM services may focus on improving the user experience by offering personalized and context-aware services. This could mean customizing device settings, application access, and content delivery based on a user's preferences and behaviors.

F. COMPATIBILITY WITH CROSS-PLATFORM

To cater to the diverse range of devices and platforms used by organizations, upcoming MM services may provide management across multiple operating systems like iOS, Android, Windows, and mac OS. This cross-platform support will ensure seamless management of mobility services across all devices.

G. SMARTER MONITORING AND COMMUNICATION

Organizations can gain deeper insights into device utilization, performance, and user behavior with MM as a service, which may offer more smarter monitoring and communication capabilities.

H. CONFORMITY AND SAFETY

As regulations around data privacy is continued to develop. Therefore, MM services must prioritize strengthening their conformity and safety measures in order to protect user data and adhere to both regional and international regulations.

I. INTERNET OF THING (IOT) AND MMaaS MODEL

It is necessary for MM services to expand their scope so that the administration and security of mobiles and IoT devices can be carried out efficiently.

To sum up the article, the major concern was on MMaaS model and is expected to develop and adjust according to changes in communication networks and user needs. With the progress of technology, on demand MM mechanism will remain an important factor in providing smooth, effective and tailored mobile experiences.

VI. CONCLUSION

The MMaaS model presents a new and exciting approach to wireless network management. The model provides on-demand service, software control, and overarching perspective, it has the potential to revolutionize the way we manage the mobility of the nodes in the networks. Through its granularity of service provisioning, as explored in detail in this paper, it provides networks with the flexibility and scalability characteristics necessary to accommodate the dense, heterogeneous, and dynamic environments that 5G networks will encounter. This paper delved into the characteristics and challenges of on demand MM mechanism and highlighted its significance within MMaaS paradigm. Next, by comparing legacy MM techniques with the MMaaS model for various operational metrics, we also provided a qualitative analysis of the MM mechanism. Similarly, recent developments in MM solutions demonstrated the potential benefits of the MMaaS model, which are adoptable and flexible, making it suitable for various network environments, as described in Section III. Furthermore, the research challenges, possible solutions, future prospects of the domain, and application areas have been identified in Sections IV and V, respectively. The discussion on these research challenges also provides the researchers with an understanding of the opportunity for future work on MM solutions. Finally, in light of the discussion and identified future prospects in the article, it is concluded that model will also play a pivotal role in future wireless networks by enabling network slicing, accommodating a large network volume, improving accessibility, and enhancing the user experience for added users. Therefore, it has also been suggested that this model must be validated and evaluated for further experimental setup in the future.

AVAILABILITY OF DATA AND MATERIALS

Not applicable

COMPETING INTERESTS

All the authors declare that they have no conflict of interest.

ACKNOWLEDGMENT

The authors would like to thank China's National Key Research and Development Program for providing the experimental facilities used to perform these experiments, and also would like to thank Artificial Intelligence and Data Analytics Laboratory (AIDA), CCIS Prince Sultan University, for their support.

REFERENCES

[1] X. Ge, H. Cheng, G. Mao, Y. Yang, and S. Tu, "Vehicular communications for 5G cooperative small-cell networks," *IEEE Trans. Veh. Technol.*, vol. 65, no. 10, pp. 7882–7894, Oct. 2016, doi: 10.1109/TVT.2016.2539285.

[2] R. Nossenson, "Long-term evolution network architecture," in *Proc. IEEE Int. Conf. Microw., Commun., Antennas Electron. Syst.*, Nov. 2009, pp. 1–4, doi: 10.1109/COMCAS.2009.5385947.

[3] I. Rabet, S. P. Selvaraju, H. Fotouhi, M. Alves, M. Vahabi, A. Balador, and M. Björkman, "SDMob: SDN-based mobility management for IoT networks," *J. Sens. Actuator Netw.*, vol. 11, no. 1, p. 8, Jan. 2022, doi: 10.3390/jsan11010008.

[4] B. Alhayani, A. S. Kwekha-Rashid, H. B. Mahajan, H. Ilhan, N. Uke, A. Alkhayyat, and H. J. Mohammed, "5G standards for the industry 4.0 enabled communication systems using artificial intelligence: Perspective of smart healthcare system," *Appl. Nanosci.*, vol. 13, no. 3, pp. 1807–1817, Mar. 2023, doi: 10.1007/s13204-021-02152-4.

[5] T. Baker, J. M. García-Campos, D. G. Reina, S. Toral, H. Tawfik, D. Al-Jumeily, and A. Hussain, "GreeAODV: An energy efficient routing protocol for vehicular ad hoc networks," in *Proc. Int. Conf. Intell. Comput.*, in Lecture Notes in Computer Science: Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics, vol. 10956, 2018, pp. 670–681, doi: 10.1007/978-3-319-95957-3_69.

[6] A. Tahir, F. Chen, B. Hayat, Q. Shaheen, Z. Ming, A. Ahmad, K.-I. Kim, and B. H. Lim, "Hybrid HP-BOA: An optimized framework for reliable storage of cloud data using hybrid meta-heuristic algorithm," *Appl. Sci.*, vol. 13, no. 9, p. 5346, Apr. 2023.

[7] A. Galal, X. Hesselbach, W. Tavernier, and D. Colle, "SDN-based gateway architecture for electromagnetic nano-networks," *Comput. Commun.*, vol. 184, pp. 160–173, Feb. 2022, doi: 10.1016/j.comcom.2021.12.017.

[8] D. Kafetzis, S. Vassilaras, G. Vardoulias, and I. Koutsopoulos, "Software-defined networking meets Software-defined radio in mobile ad hoc networks: State of the art and future directions," *IEEE Access*, vol. 10, pp. 9989–10014, 2022, doi: 10.1109/ACCESS.2022.3144072.

[9] I. H. Abdulqadder and S. Zhou, "SliceBlock: Context-aware authentication handover and secure network slicing using DAG-blockchain in edge-assisted SDN/NFV-6G environment," *IEEE Internet Things J.*, vol. 9, no. 18, pp. 18079–18097, Sep. 2022.

[10] P. Radoglou-Grammatikis, P. Sarigiannidis, P. Diamantoulakis, T. Lagkas, T. Saoulidis, E. Fountoukidis, and G. Karagiannidis, "Strategic honeypot deployment in ultra-dense beyond 5G networks: A reinforcement learning approach," *IEEE Trans. Emerg. Topics Comput.*, early access, Jun. 23, 2022, doi: 10.1109/TETC.2022.3184112.

[11] Y. Sun, S. Zhou, and J. Xu, "EMM: Energy-aware mobility management for mobile edge computing in ultra dense networks," *IEEE J. Sel. Areas Commun.*, vol. 35, no. 11, pp. 2637–2646, Nov. 2017, doi: 10.1109/JSAC.2017.2760160.

[12] J. V. Ananthi and P. S. H. Jose, "Mobility management UAV-based grouping routing protocol in flying ad hoc networks for biomedical applications," *Int. J. Commun. Syst.*, vol. 36, no. 1, Jan. 2023, Art. no. e5362.

[13] M. Amissah and S. Lahiri, "Modelling granular process flow information to reduce bottlenecks in the emergency department," *Healthcare*, vol. 10, no. 5, p. 942, May 2022.

[14] H.-B. Lee, S.-G. Min, Y.-H. Han, K.-H. Lee, H.-W. Lee, and W. Ryu, "IP flow mobility scheme in scalable network-based mobility management architecture," *Telecommun. Syst.*, vol. 60, no. 2, pp. 315–325, Oct. 2015, doi: 10.1007/s11235-015-0032-7.

[15] Y. Wang, "Energy-saving scheme of 5G base station based on LSTM neural network," *J. Phys. Conf. Ser.*, vol. 2083, no. 3, 2021, Art. no. 032026, doi: 10.1088/1742-6596/2083/3/032026.

[16] M. Gramaglia, I. Digon, V. Friderikos, D. von Hugo, C. Mannweiler, M. A. Puente, K. Samdanis, and B. Sayadi, "Flexible connectivity and QoE/QoS management for 5G networks: The 5G NORMA view," in *Proc. IEEE Int. Conf. Commun. Workshops (ICC)*, May 2016, pp. 373–379, doi: 10.1109/ICCW.2016.7503816.

[17] M. G. Khoshkholgh and H. Yanikomeroglu, "RSS-based UAV-BS 3-D mobility management via policy gradient deep reinforcement learning," in *Proc. IEEE Int. Conf. Commun.*, Jun. 2021, pp. 1–6, doi: 10.1109/ICC42927.2021.9500827.

[18] N. A. Mohammedali, T. Kanakis, M. O. Agyeman, and A. Al-Sherbaz, "A survey of mobility management as a service in real-time inter/intra slice control," *IEEE Access*, vol. 9, pp. 62533–62552, 2021, doi: 10.1109/ACCESS.2021.3074024.

[19] A. Heidari, N. J. Navimipour, M. Unal, and G. Zhang, "Machine learning applications in internet-of-drones: Systematic review, recent deployments, and open issues," *ACM Comput. Surv.*, vol. 55, no. 12, pp. 1–45, 2023.

[20] K. Pentikousis, Y. Wang, and W. Hu, "Mobileflow: Toward software-defined mobile networks," *IEEE Commun. Mag.*, vol. 51, no. 7, pp. 44–53, Jul. 2013.

[21] I. F. Akyildiz, A. Kak, E. Khorov, A. Krasilov, and A. Kureev, "ARBAT: A flexible network architecture for QoE-aware communications in 5G systems," *Comput. Netw.*, vol. 147, pp. 262–279, Dec. 2018.

[22] M. A. Habibi, M. Nasimi, B. Han, and H. D. Schotten, "A comprehensive survey of RAN architectures toward 5G mobile communication system," *IEEE Access*, vol. 7, pp. 70371–70421, 2019, doi: 10.1109/ACCESS.2019.2919657.

[23] S. D. A. Shah, M. A. Gregory, S. Li, R. d. R. Fontes, and L. Hou, "SDN-based service mobility management in MEC-enabled 5G and beyond vehicular networks," *IEEE Internet Things J.*, vol. 9, no. 15, pp. 13425–13442, Aug. 2022, doi: 10.1109/JIOT.2022.3142157.

[24] I. P. Chochliouros, M.-A. Kourtis, A. S. Spiliopoulou, P. Lazaridis, Z. Zaharis, C. Zarakovitis, and A. Kourtis, "Energy efficiency concerns and trends in future 5G network infrastructures," *Energies*, vol. 14, no. 17, p. 5392, Aug. 2021, doi: 10.3390/en14175392.

[25] K. Ganesh, M. Thrivikraman, J. Kuri, H. Dagale, G. Sudhakar, and S. Sanyal, "Implementation of a real time passenger information system," 2012, *arXiv:1206.0447*.

[26] H. B. Nafea, M. M. Sallam, and F. W. Zaki, "Study of DRX sleep mode performance on virtual base station energy saving in 5G networks," *Wireless Pers. Commun.*, vol. 118, no. 4, pp. 3251–3270, Jun. 2021, doi: 10.1007/s11277-021-08178-9.

[27] A. Rosenblat, K. E. Levy, S. Barocas, and T. Hwang, "Discriminating tastes: Uber's customer ratings as vehicles for workplace discrimination," *Policy Internet*, vol. 9, no. 3, pp. 256–279, 2017.

[28] E. Hossain and M. Hasan, "5G cellular: Key enabling technologies and research challenges," *IEEE Instrum. Meas. Mag.*, vol. 18, no. 3, pp. 11–21, Jun. 2015, doi: 10.1109/MIM.2015.7108393.

[29] C. Jiang and X. Zhu, "Reinforcement learning based capacity management in multi-layer satellite networks," *IEEE Trans. Wireless Commun.*, vol. 19, no. 7, pp. 4685–4699, Jul. 2020, doi: 10.1109/TWC.2020.2986114.

[30] N. Akkari and N. Dimitriou, "Mobility management solutions for 5G networks: Architecture and services," *Comput. Netw.*, vol. 169, Mar. 2020, Art. no. 107082, doi: 10.1016/j.comnet.2019.107082.

[31] M. Zekri, B. Jouaber, and D. Zeghlache, "A review on mobility management and vertical handover solutions over heterogeneous wireless networks," *Comput. Commun.*, vol. 35, no. 17, pp. 2055–2068, Oct. 2012, doi: 10.1016/j.comcom.2012.07.011.

[32] B. Bordel, R. Alcarria, D. Sánchez-de-Rivera, and Á. Sánchez, "An inter-slice management solution for future virtualization-based 5G Systems," in *Advanced Information Networking and Applications*, vol. 926. Cham, Switzerland: Springer, 2020, pp. 1059–1070, doi: 10.1007/978-3-030-15032-7_89.

[33] N. An, Y. Kim, J. Park, D.-H. Kwon, and H. Lim, "Slice management for quality of service differentiation in wireless network slicing," *Sensors*, vol. 19, no. 12, p. 2745, Jun. 2019, doi: 10.3390/s19122745.

[34] S. Katti and L. E. Li, "RadioVisor: A slicing plane for radio access networks," in *Proc. Open Netw. Summit (ONS)*, 2014, pp. 1–2.

[35] A. A. Barakabitze, A. Ahmad, R. Mijumbi, and A. Hines, "5G network slicing using SDN and NFV: A survey of taxonomy, architectures and future challenges," *Comput. Netw.*, vol. 167, Feb. 2020, Art. no. 106984, doi: 10.1016/j.comnet.2019.106984.

[36] R. A. Addad, T. Taleb, M. Bagaa, D. L. C. Dutra, and H. Flinck, "Towards modeling cross-domain network slices for 5G," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Dec. 2018, pp. 1–7, doi: 10.1109/GLOCOM.2018.8647504.

[37] G. Nencioni, R. G. Garroppo, A. J. Gonzalez, B. E. Helvik, and G. Procissi, "Orchestration and control in software-defined 5G networks: Research challenges," *Wireless Commun. Mobile Comput.*, vol. 2018, pp. 1–18, Aug. 2018, doi: 10.1155/2018/6923867.

[38] I. Afolabi, T. Taleb, K. Samdanis, A. Ksentini, and H. Flinck, "Network slicing and softwarization: A survey on principles, enabling technologies, and solutions," *IEEE Commun. Surveys Tuts.*, vol. 20, no. 3, pp. 2429–2453, 3rd Quart., 2018, doi: 10.1109/COMST.2018.2815638.

[39] G. Seok-Ju, "A comparative analysis of centralized and distributed mobility management in IP-based mobile networks," *Telecommun. Rev.*, vol. 25, no. 4, pp. 656–671, 2015.

[40] L. Li, Y. Niu, S. Mao, B. Ai, Z. Zhong, N. Wang, and Y. Chen, "Resource allocation and computation offloading in a millimeter-wave train-ground network," *IEEE Trans. Veh. Technol.*, vol. 71, no. 10, pp. 10615–10630, Oct. 2022.

[41] S. Malathy, P. Jayarajan, H. Ojukwu, F. Qamar, M. N. Hindia, K. Dimyati, K. A. Noordin, and I. S. Amiri, "A review on energy management issues for future 5G and beyond network," *Wireless Netw.*, vol. 27, no. 4, pp. 2691–2718, May 2021.

[42] S. T. Arzo, D. Scotece, R. Bassoli, F. Granelli, L. Foschini, and F. H. P. Fitzek, "A new agent-based intelligent network architecture," *IEEE Commun. Standards Mag.*, vol. 6, no. 4, pp. 74–79, Dec. 2022.

[43] N. Zhang, N. Cheng, A. T. Gamage, K. Zhang, J. W. Mark, and X. Shen, "Cloud assisted HetNets toward 5G wireless networks," *IEEE Commun. Mag.*, vol. 53, no. 6, pp. 59–65, Jun. 2015.

[44] G. Hurel, R. Badonnel, A. Lahmadi, and O. Festor, "Towards cloud-based compositions of security functions for mobile devices," in *Proc. IFIP/IEEE Int. Symp. Integr. Netw. Manage. (IM)*, May 2015, pp. 578–584.

[45] A. Priyanka, P. Gauthamarayathirumal, and C. Chandrasekar, "Machine learning algorithms in proactive decision making for handover management from 5G & beyond 5G," *Egyptian Informat. J.*, vol. 24, no. 3, Sep. 2023, Art. no. 100389, doi: 10.1016/j.eij.2023.100389.

[46] H. Farag and C. Stefanović, "Congestion-aware routing in dynamic IoT networks: A reinforcement learning approach," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Dec. 2021, pp. 1–6.

[47] K. Sagar and P. P. Kumar, "5G heterogeneous network in vertical handoff for making enhanced decision algorithm," *AIP Conf. Proc.*, vol. 2418, no. 1, 2022, Art. no. 020004.

[48] H. Zhang, R. Wang, W. Sun, and H. Zhao, "Mobility management for blockchain-based ultra-dense edge computing: A deep reinforcement learning approach," *IEEE Trans. Wireless Commun.*, vol. 20, no. 11, pp. 7346–7359, Nov. 2021.

[49] K. Zia, A. Chiumento, and P. J. M. Havinga, "AI-enabled reliable QoS in multi-RAT wireless IoT networks: Prospects, challenges, and future directions," *IEEE Open J. Commun. Soc.*, vol. 3, pp. 1906–1929, 2022.

[50] W. K. Saad, I. Shayea, A. Alhammadi, M. M. Sheikh, and A. A. El-Saleh, "Handover and load balancing self-optimization models in 5G mobile networks," *Eng. Sci. Technol., Int. J.*, vol. 42, Jun. 2023, Art. no. 101418.

[51] H. Zhang, S. Xi, H. Jiang, Q. Shen, B. Shang, and J. Wang, "Resource allocation and offloading strategy for UAV-assisted LEO satellite edge computing," *Drones*, vol. 7, no. 6, p. 383, Jun. 2023.

[52] F. A. Al Emam, M. E. Nasr, and S. E. Kishk, "Context-aware parallel handover optimization in heterogeneous wireless networks," *Ann. Telecommun.*, vol. 75, nos. 1–2, pp. 43–57, Feb. 2020.

[53] F. B. Mismar, B. L. Evans, and A. Alkhateeb, "Deep reinforcement learning for 5G networks: Joint beamforming, power control, and interference coordination," *IEEE Trans. Commun.*, vol. 68, no. 3, pp. 1581–1592, Mar. 2020.

[54] T. Campisi, A. Severino, M. A. Al-Rashid, and G. Pau, "The development of the smart cities in the connected and autonomous vehicles (CAVs) era: From mobility patterns to scaling in cities," *Infrastructures*, vol. 6, no. 7, p. 100, Jul. 2021.

[55] A. Litke, D. Skoutas, K. Tserpes, and T. Varvarigou, "Efficient task replication and management for adaptive fault tolerance in mobile grid environments," *Future Gener. Comput. Syst.*, vol. 23, no. 2, pp. 163–178, 2007.

[56] M. Z. Chowdhury, M. Shahjalal, S. Ahmed, and Y. M. Jang, "6G wireless communication systems: Applications, requirements, technologies, challenges, and research directions," *IEEE Open J. Commun. Soc.*, vol. 1, pp. 957–975, 2020.

[57] J. Tanveer, A. Haider, R. Ali, and A. Kim, "An overview of reinforcement learning algorithms for handover management in 5G ultra-dense small cell networks," *Appl. Sci.*, vol. 12, no. 1, p. 426, Jan. 2022.

[58] P. K. Mangipudi and J. McNair, "SDN enabled mobility management in multi radio access technology 5G networks," 2023.

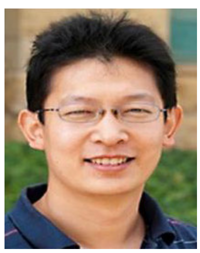
[59] M. Al-Khalidi, R. Al-Zaidi, and M. Hammoudeh, "Network mobility management challenges, directions, and solutions: An architectural perspective," *Electronics*, vol. 11, no. 17, p. 2696, Aug. 2022.

[60] A. Abrar, A. S. C. M. Arif, and K. M. Zaini, "A systematic analysis and review on producer mobility management in named data networks: Research background and challenges," *Alexandria Eng. J.*, vol. 69, pp. 785–808, Apr. 2023.

[61] S. Ji, M. Sheng, D. Zhou, W. Bai, Q. Cao, and J. Li, "Flexible and distributed mobility management for integrated terrestrial-satellite networks: Challenges, architectures, and approaches," *IEEE Netw.*, vol. 35, no. 4, pp. 73–81, Jul. 2021.
[62] S. Zeb, M. A. Rathore, A. Mahmood, S. A. Hassan, J. Kim, and M. Gidlund, "Edge intelligence in softwarized 6G: Deep learning-enabled network traffic predictions," in *Proc. IEEE Globecom Workshops (GC Wkshps)*, Dec. 2021, pp. 1–6.
[63] R. Peng, X. Fu, and T. Ding, "Machine learning with variable sampling rate for traffic prediction in 6G MEC IoT," *Discrete Dyn. Nature Soc.*, vol. 2022, pp. 1–11, Nov. 2022.
[64] A. Amaral, L. Barreto, S. Baltazar, and T. Pereira, "Mobility as a service (MaaS): Past and present challenges and future opportunities," in *Proc. Conf. Sustain. Urban Mobility*, Volos, Greece, 2021, pp. 220–229.
[65] Y. Gao, Y. Song, X. Wei, X. Gao, and G. Chen, "SACA: An end-to-end method for dispatching, routing, and pricing of online bus-booking," in *Proc. Int. Conf. Database Syst. Adv. Appl.*, 2023, pp. 303–313.
[66] P. K. Chowdhury, N. Ghosh, and P. N. Kuriakose, "Towards seamless urban mobility through smartphone-based mobility apps: Insights from India," in *Urban Commons, Future Smart Cities and Sustainability*. Cham, Switzerland: Springer, 2023, pp. 935–955.
[67] M. Trombin, R. Pinna, M. Musso, E. Magnaghi, and M. D. Marco, "Mobility management: From traditional to people-centric approach in the smart city," in *Emerging Technologies for Connected Internet of Vehicles and Intelligent Transportation System Networks*. Cham, Switzerland: Springer, 2020, pp. 165–182.
[68] M. S. Alam and P. Georgakis, "The state of the art of cooperative and connected autonomous vehicles from the future mobility management perspective: A systematic review," *Future Transp.*, vol. 2, no. 3, pp. 589–604, Jul. 2022.
[69] K. Zheng, Z. Yang, K. Zhang, P. Chatzimisios, K. Yang, and W. Xiang, "Big data-driven optimization for mobile networks toward 5G," *IEEE Netw.*, vol. 30, no. 1, pp. 44–51, Jan. 2016.
[70] J. Jeong, Y. Shen, T. Oh, S. Céspedes, N. Benamar, M. Wetterwald, and J. Härri, "A comprehensive survey on vehicular networks for smart roads: A focus on IP-based approaches," *Veh. Commun.*, vol. 29, Jun. 2021, Art. no. 100334.
[71] L. Lonero, "Trends in driver education and training," *Amer. J. Preventive Med.*, vol. 35, no. 3, pp. S316–S323, Sep. 2008.
[72] P. D. Vascik, "Systems-level analysis of on demand mobility for aviation," Ph.D. dissertation, Massachusetts Inst. Technol., 2017.
[73] Y. Geng, E. Liu, R. Wang, Y. Liu, W. Rao, S. Feng, Z. Dong, Z. Fu, and Y. Chen, "Deep reinforcement learning based dynamic route planning for minimizing travel time," in *Proc. IEEE Int. Conf. Commun. Workshops (ICC Workshops)*, Jun. 2021, pp. 1–6.
[74] K. Degirmenci and M. H. Breitner, "Gamification and sensory stimuli in eco-driving research: A field experiment to reduce energy consumption in electric vehicles," *Transp. Res. F, Traffic Psychol. Behav.*, vol. 92, pp. 266–282, Jan. 2023.
[75] T. A. Vilela, "Global mobility chatbot: Chatbot model to improve mobile employee experience," Ph.D. dissertation, 2021. [Online]. Available: https://run.unl.pt/handle/10362/116183
[76] S. He, Z. Zhang, S. Han, L. Pepin, G. Wang, D. Zhang, J. A. Stankovic, and F. Miao, "Data-driven distributionally robust electric vehicle balancing for autonomous mobility-on-demand systems under demand and supply uncertainties," *IEEE Trans. Intell. Transp. Syst.*, vol. 24, no. 5, pp. 5199–5215, May 2023.
[77] P. M. Madhani, "Rewards strategy: A key driver of service–profit chain," *Compensation Benefits Rev.*, vol. 51, no. 4, pp. 162–172, Sep. 2019.
[78] C. Kanuri, K. Venkat, S. Maiti, and P. Mulukutla, "Leveraging innovation for last-mile connectivity to mass transit," *Transp. Res. Proc.*, vol. 41, pp. 655–669, Jan. 2019.
[79] R. Zhu, X. Zhang, D. Kondor, P. Santi, and C. Ratti, "Understanding spatio-temporal heterogeneity of bike-sharing and scooter-sharing mobility," *Comput., Environ. Urban Syst.*, vol. 81, May 2020, Art. no. 101483.
[80] S. Roy, M. T. K. Herniczek, B. J. German, and L. A. Garrow, "User base estimation methodology for a business airport shuttle air taxi service," *J. Air Transp.*, vol. 29, no. 2, pp. 69–79, Apr. 2021.
[81] M. Barth and S. A. Shaheen, "Shared-use vehicle systems: Framework for classifying carsharing, station cars, and combined approaches," *Transp. Res. Rec., J. Transp. Res. Board*, vol. 1791, no. 1, pp. 105–112, Jan. 2002.
[82] J.-K. Huang, Y. Tan, D. Lee, V. R. Desaraju, and J. W. Grizzle, "Informable multi-objective and multi-directional RRT* system for robot path planning," in *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, May 2023, pp. 5666–5673.
[83] V. Kumar and S. Mittal, "Mobile marketing campaigns: Practices, challenges and opportunities," *Int. J. Bus. Innov. Res.*, vol. 21, no. 4, pp. 523–539, 2021.
[84] M. Rysman and S. Schuh, "New innovations in payments," *Innov. Policy Economy*, vol. 17, no. 1, pp. 27–48, 2017.
[85] E. Lund, J. Kerttu, and T. Koglin, "Drivers and barriers for integrated mobility services. A review of research," 2017.
[86] Y. Guan et al., "Integrated decision and control: Towards interpretable and computationally efficient driving intelligence," 2021, *arXiv:2103.10290*.
[87] Y. Benmessaoud, L. Cherrat, and M. Ezziyyani, "Real-time self-adaptive traffic management system for optimal vehicular navigation in modern cities," *Computers*, vol. 12, no. 4, p. 80, 2023.

MUHAMMAD MUKHTAR QURESHI received the M.Sc. and M.S. degrees in computer science from Muhammad Ali Jinnah University, Islamabad, Pakistan. He is currently pursuing the Ph.D. degree with the University of Malaysia Terragenu, Malaysia. He is also a Faculty Member and the HOD of the Department of Computer Science, Iqra University Chak Shehzad Campus, Islamabad. He has more than 15 years of teaching experience at the undergraduate level in the domain of core computing courses, such as data structure, theory of computation, wireless networks, and database systems.

FARIZAH BINTI YUNUS received the B.Sc. degree in electrical engineering (telecommunication) and the Ph.D. degree in telecommunication engineering from Universiti Teknologi Malaysia (UTM). She is currently a Senior Lecturer in computer science with the Faculty of Ocean Engineering Technology and Informatics, University Malaysia Terengganu (UMT). Her research interests include wireless sensor networks, networking, cloud computing, and the Internet of Things (IoT). She is a member of MBOT and BEM. She has worked as researcher in several national funded research and development projects.



JIANQIANG LI (Senior Member, IEEE) received the B.S. degree in mechatronics from the Beijing Institute of Technology, Beijing, China, in 1996, and the M.S. and Ph.D. degrees in control science and engineering from Tsinghua University, Beijing, in 2001 and 2004, respectively. He was a Researcher with the Digital Enterprise Research Institute, National University of Ireland, Galway, from 2004 to 2005. From 2005 to 2013, he was with NEC Laboratories China as a Researcher, and he was with the Department of Computer Science, Stanford University, as a Visiting Scholar, from 2009 to 2010. He joined the Beijing University of Technology, Beijing, in 2013, as a Beijing Distinguished Professor. His research interests include Petri nets, enterprise information systems, business processes, data mining, information retrieval, semantic web, privacy protection, and big data. He has over 300 journal articles, and 58 international patent applications (27 of them have been granted in China, U.S., or Japan). He served as PC members in multiple international conferences and organized the IEEE workshop on medical computing. He served as a guest editor to organize a special issue on information technology for enhanced healthcare service in computer in industry.

ATTA-UR-RAHMAN received the B.S. degree in computer science from the University of the Punjab, Lahore, Pakistan, in 2004, the M.S. degree in EE from International Islamic University, Islamabad, Pakistan, in 2008, and the Ph.D. degree in EE from ISRA University, Islamabad Campus, Pakistan, in 2012. He is currently an Associate Professor with the College of Computer Science and Information Technology, Imam Abdulrahman Bin Faisal University (IAU), Dammam, Saudi Arabia. He has been involved in teaching and research, since 2003, and he has authored/coauthored more than 100 publications in conferences, books, and journals of good reputation. His research interests include digital communication, DSP, information and coding theory, AI, and applied soft computing.

TARIQ MAHMOOD received the master's degree in computer science from the University of Lahore, Pakistan, and the Ph.D. degree in software engineering from the Beijing University of Technology, China. He is currently an Assistant Professor/the HOD of the Faculty of Information Sciences, University of Education, Vehari Campus, Vehari, Pakistan. He is a renowned expert in image processing, healthcare informatics and social media analysis, ad-hoc network, and WSN. He is contributed with 40 research articles in well-reputed international journals and conferences. He is an Editorial Member and a Reviewer of various journals, including *PLOS One*, *Journal of Supercomputer*, *Journal of Digital Imaging*, *International Journal of Sensors*, and *Wireless Communications and Control*. His research interests include image processing, social media analysis, medical image diagnosis, machine learning, and data mining. He aims to contribute to interdisciplinary research of computer science and human-related disciplines.

YAHYA ALI ABDELRAHMAN ALI received the bachelor' degree in computer science from the University of Science and Technology, the master's degree in computer science from University Technology Malaysia (UTM), in 2007, and the Ph.D. degree (Hons.) in computer science from the Sudan University of Science and Technology. He was the Head of Programming Department, Computer Center, Sudan University of Science and Technology. He is currently an Assistant Professor with the College of Computer Science and Information System, Najran University (NU), Saudi Arabia. His research interests include natural language processing (NLP), information retrieval (IR), plagiarism detection, and data mining, natural language processing, and text mining.