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Review

Mobility Management Issues and Solutions in 5G-and-Beyond Networks: A Comprehensive Review

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Abstract: The fully accomplished standardization of the new mobile generation has led to the deployment of fifth-generation (5G) wireless networks to gratify enormous traffic volume for Internet services. The current centralized mobility system could not be sufficient to manage an explosive increase in data volume and is considered a steadily rising issue in modern wireless communication. A new technique that can affluently handle traffic problems and completely avoid network breakdown chances is indispensable. Recently, distributed mobility management (DMM) was introduced to overcome the inevitable obstacles that destructively impact the existing networks. Specifically, a novel design based on the deployment of distributed mobility anchors, closer to the terminal points, was introduced. Several works have been proposed to build DMM solutions with different focuses for 5G-and-beyond networks (B5G), which are also referred to as sixth-generation solutions (6G). In this paper, we present the potential and benefits of flat network design for efficient and fast routing of traffic and furnish the effectiveness of the scheme toward mobility management in B5G by delineating recent research works. We also present the current limitations, challenges, and future research directions for seamless mobility to achieve the desired objectives in the current 5G and upcoming 6G cellular communications.

Keywords: mobility management; network flattening; distributed mobility management (DMM); 5G and beyond (B5G); 6G

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1. Introduction

With the globalization of mobile services, the current fifth-generation (5G)-and-beyond mobile networks are predicted to exploit radio resources via several access technologies for diversified services [1]. In parallel, mobile users and intelligent machines accessing data services are increasing in leaps and bounds. The types of applications and services accessed by devices are included but not limited to heavy-bandwidth multimedia sources, immersive media—such as augmented reality (AR) [2,3] and virtual reality (VR) [4]—and traffic handling from a large cluster of sensors, i.e., Internet of Things (IoT) [5,6], interference management [7,8], routing [9], and so on. The 5G-and-beyond (B5G) network and the upcoming 6G network is thus considered to be an extremely heterogeneous ecosystem of various technologies, including the following: ultra-dense networks (UDN) [10], device-to-device (D2D) communication [11,12], mmWave approach [13,14], low-power nodes

(LPNs) [15], IoT-based smart cities [16], multitier network architecture [17,18], vehicular networks [19], ad hoc network [20], Internet of Everything (IoE) [21], network routing [22], network slicing [23], multiple-input and multiple-output (MIMO) platforms [24], and aerial platforms [25]. The wide variety of many use cases in the 5G heterogeneous network (HetNet) greatly increases the load on mobility management functions as compared with third-generation (3G) and fourth-generation (4G) long-term evolution (LTE) [26]. Principally, mobility management is the procedure that maintains data information at the location of smart devices and controls their link connections when commuting between coverage areas [27]. The mobility protocols ensure the delivery of useful data and control signals via a radio interface link to the desired user [28]. However, to provide seamless mobility in a multitier HetNet system for all radio-connected smart devices, a uniform network deployment is impractical [29]. Hence, the 5G and forthcoming cellular networks require flexibility in network topology, ultra-reliability in handover mechanism, and modification in management protocols, to guarantee efficient provisioning of anticipated services [30,31].

Under worldwide Internet connectivity requests from the users and their convergence with cellular carriers, cellular access networks have been experiencing abundant new challenges and demanding various extensions in mobility protocols [20]. Thus, the modification of current networks for better handover performance, overhead cost, routing process, and other mobility-related processes is mandatory to meet the requirements of IoT-based smart wireless devices [32]. In mobile Internet, the mounting concern is the deployment of mobility support in the content delivery network (CDN) environment [33]. In the CDN, the content servers are placed closer to the access network to provide a suboptimal path to the mobile nodes (MNs) in close range. The CDN needs an efficient framework for robust mobility management protocols [34].

Witnessing the explosive growth in mobile Internet traffic in NR 5G and mobility support limitations, the current centralized network design raises a major challenge in handover management and performance enhancement [35]. Particularly, mobility management for end-users with frequent roaming and location changes, applications necessities, and preferences are crucial [36]. The centralized architecture is deficient in transparent data path management to the Internet protocol (IP) stack of the MN [37]. In this centralized architecture, all the IP traffic flows of the MN must pass through the same mobility process irrespective of importance. In Figure 1, the end-to-end data path between the communication peers (i.e., Mobile-1 and Mobile-2), is compelled to traverse the packet data network gateway (PGW) of the MNs core network instead of taking the most optimal path provided by local IP routing or direct link. Consequently, it threatens single points of failure, suboptimal routing, unnecessary access to mobility resources, and scalability problems. This design favors simplicity but increases the performance cost and overall latency, completely undesirable for 5G and beyond radio access carriers.

Therefore, it is fundamental to contemplate the momentous technological advancement and accessing products, novel mission-critical cases, and predecessor's limitations [38]. The future 5G networks demand a new and stringent mobility management mechanism [39]. The rising trend for the mobility process in cellular architecture is to become flattered and include minimum hierarchy levels [40]. The unconventional changes to current mobility protocols ensure reliability, low latency, and ease in network operability [41]. The new distributed mobility management (DMM) technique is essential, and can affluently handle traffic problems, avoid network breakdown chances, and overcome the inevitable obstacles that destructively impact the existing networks [42]. It may integrate the needed extension with local content servers and the flat network architecture to simplify deployment decisions and enhance the overall performance [43].

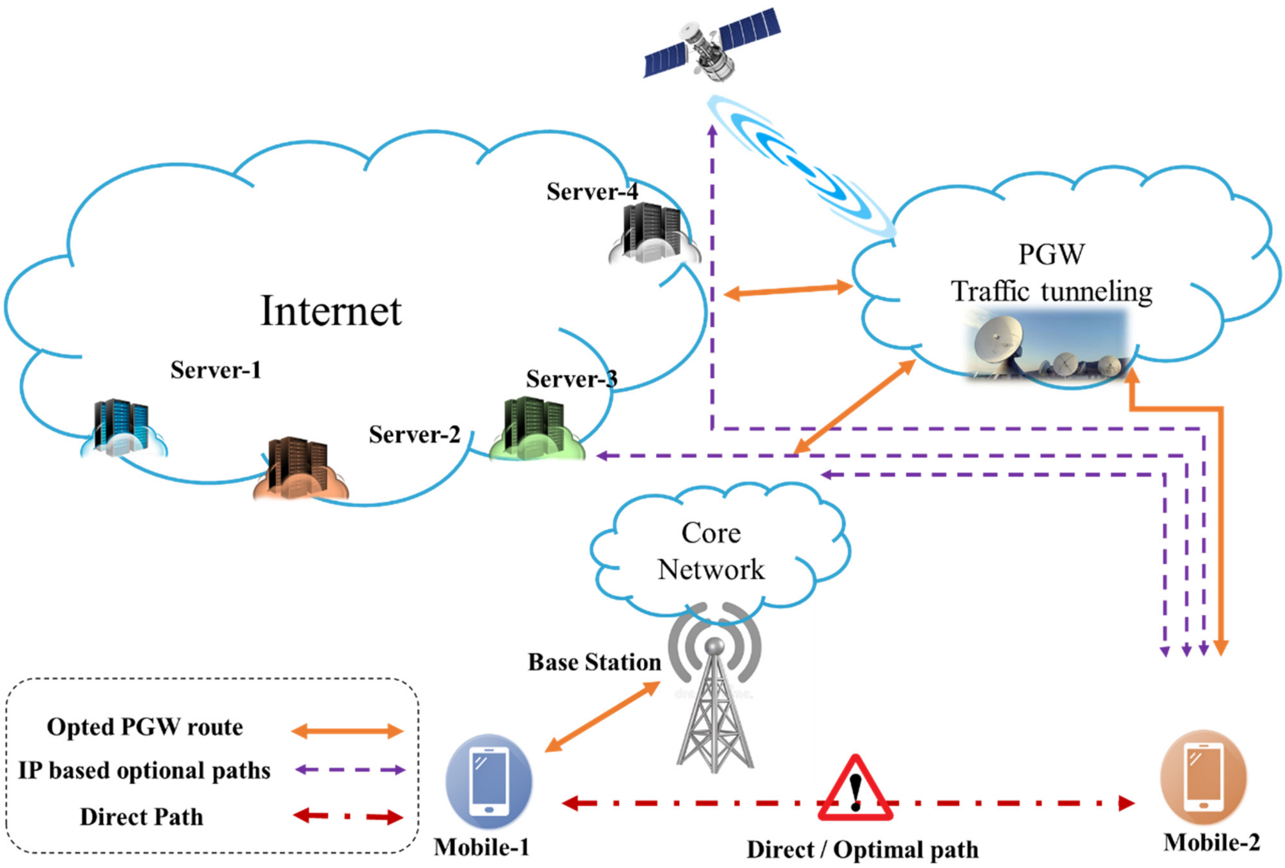

Figure 1. Centralized mobility IP data flow management.

Most of the currently developed IP mobility solutions are derived from the mobile Internet protocol (MIP) principles. In MIP, a mobility anchor, i.e., a home agent (HA), maintains the MNs' bindings, and data traffic is then encapsulated between an MN or its respective access point (AP) [44,45]. The MIP-based solutions have been implemented in a centralized design and supported the mobility contexts as well as traffic encapsulation. Such centralized deployment of mobility management gives an opportunity to optimally route data packets to an MN without the consideration of the MN's location. Additionally, it maintains credible IP session connectivity during the handovers mechanism, i.e., when the MN changes its point of attachment. However, in comparison with the DMM mechanisms, the existing centralized approach possesses several challenges, especially in scalability, cost, and transmission delay [46].

The summary of paper structure and organization is depicted in Figure 2.

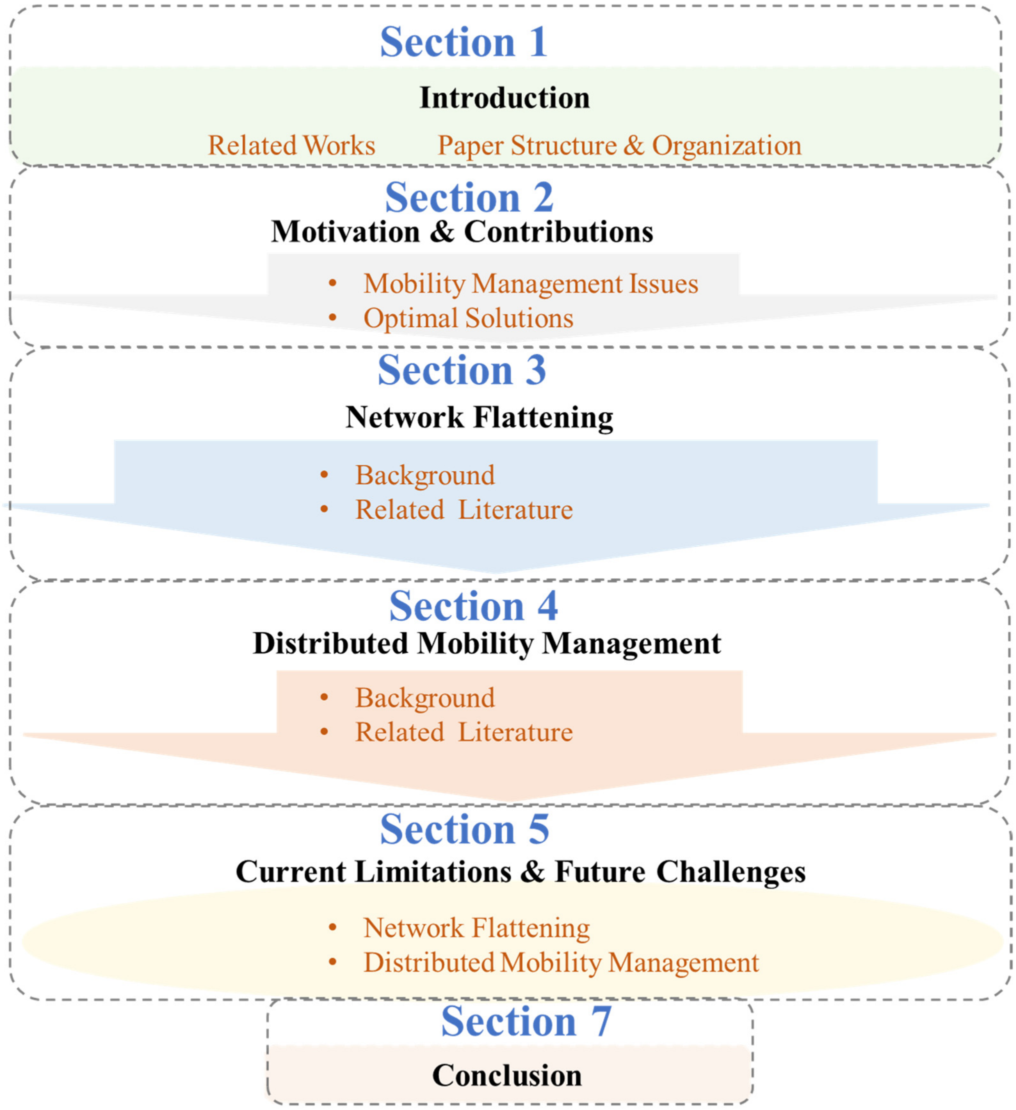

Figure 2. Paper structure and organization.

2. Motivation and Contribution

In recent years, DMM has emerged as a potential mechanism to minimize the everlasting centralized issues prosperously. It was first presented by the Internet Engineering Task Force (IETF) as a new concept of a flatter system [47]. The DMM-based approaches preserve the current IPv6 mobility management protocols along with control-plane/data-plane split to meet the 5G requirements [48]. For example, mobility management functions and roles can be distributed in the data plane, while the control plane could be either distributed or centralized [49]. It is considered the best alternative to centralized mobility management (CMM) by enabling the anchoring of data traffic closer to the MNs' point of attachment, conducing flattening mobile network design. The unique DMM approach allows the MN to perform multi-connectivity with distributed mobility anchors, optimizing data packet routing as the MN moves and changes its connected base point [50]. Lately, there are many studies have been performed to realize various aspects of the flat IP architectural concept. For instance, some authors have presented a DMM solution for efficient handling of mobile video traffic [51,52] and other researchers have provided an overview of standards and proceeding on DMM [53–55]. Similarly, researchers in [56] extensively discussed the DMM designs, user impacts, and network performance. However, no one from the researcher community has critically presented the flatter network concept from the perspective of DMM consciences and issues for transparent data routing.

Given that mobility management is a challenging task in the multi-scenario radio environment, this paper demonstrates the mobility management issues by considering flat network architecture with DMM arrangements, operations, and recent literature works, as shown in Figure 3. This article presents mobility management problems and proposes optimum solutions from network flattening and the DMM framework.

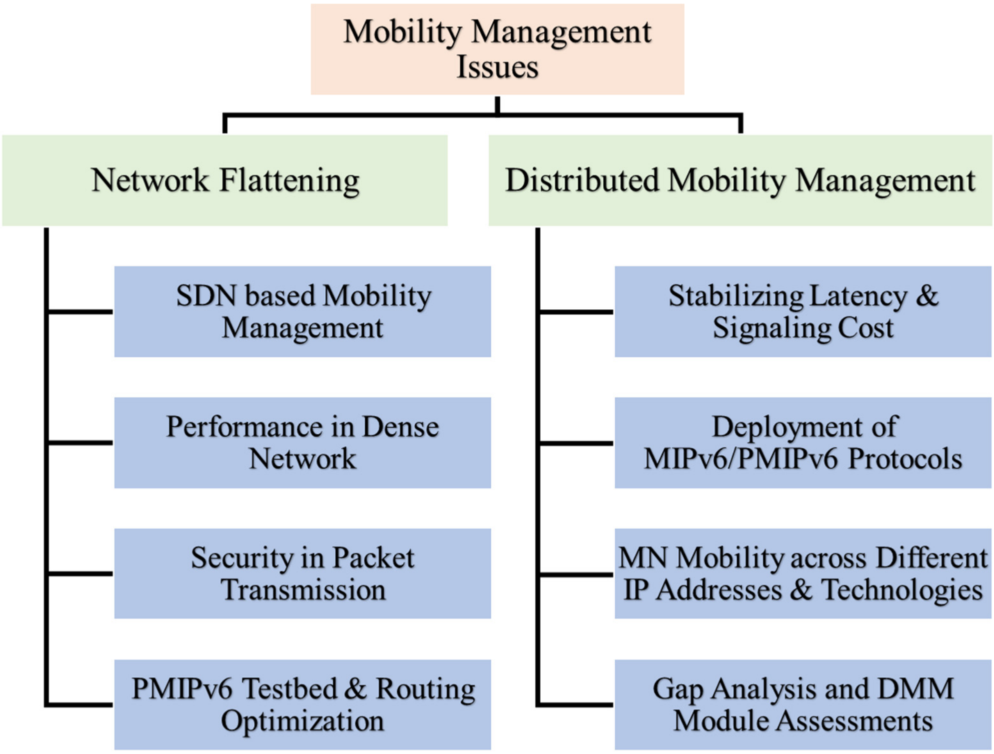

Figure 3. Mobility management issues.

The details of all the acronyms and their meanings have been explained in Abbreviations.

3. Network Flattening

Network flattening designs enable direct IP connectivity for the users from the closest gateway to co-located base stations (BSs) [57]. In practice, a classic example of such a flat architecture is the wireless fidelity (Wi-Fi) APs with its co-located access gateway, i.e., directly connected to the Internet (without tunneling to the core network) [58]. One of the critical enhancement cases in NR 5G and the forthcoming 6G network remains largely on deploying a complete, flat, IP-based system. In a flatter access design, thousands of multiple, high-definition (HD) application data traffic can be easily offloaded within the local AP area [59]. The new design would be helpful in the massive reduction in signaling cost, data routing end-to-end latencies, operational complexities, and localization [60]. Among all other advantages, the most impactful is effectiveness in mobility and active routing of 1000-fold rise data traffic management [61]. Simultaneously, it helps minimize the probability of packet data loss and traffic congestion at the core network besides enhancing the quality of experience (QoE).

3.1. Background

Mobile operators have been searching for smart and efficient ways to reduce revenue costs and extend their network capacities with data offloading techniques in flatter design [62]. Several engineering firms, Internet service providers, standardization authorities, and research pundits presented many ideas focusing on different aspects of mobility support. In this context, the Third-Generation Partnership Project (3GPP) has also presented two IP schemes, i.e., local IP access (LIPA) and selected IP traffic offload (SIPTO) [63]. The basic idea is to enable users to access data from locally accessible peering locations via LPNs, thus freeing up cellular system capacity [64]. The 3GPP suggested solutions are productive to alleviate heavy data volume pressure and simplify mobility management over the conventional mobile architecture. It is mainly because, in the 3GPP 3G/4G hierarchically centralized design, total data traffic volume is routed via a centrally placed mobility anchor, i.e., an IP mobility anchor in an IP-based system [65]. Then, the packet data network gateway (PGW) in a 3GPP evolved packet core (EPC) aggregates traffic from several edge nodes and acts as a link between the operators and external IP networks. Principally, PGW is responsible for assigning IP addresses and trailing the movements of MNs within the IP topology. It also ensures that MNs must always be reachable at their current point of attachment (PoA) by using traffic tunneling.

3.1.1. GPP LTE LIPA/SIPTO Mechanism

The 3GPP-proposed LIPA and SIPTO approaches were introduced in 4G to alleviate the traffic load of the cellular core network [66]. Both mechanisms are briefly discussed below.

(a) SIPTO: The SIPTO technique enables an operator to offload certain types of data traffic at a network node that is optimally closer to the MN point of connection. The operation is conducted by selecting the reliable serving gateway (S-GW) and PGW that are also geographically near the MN's access point, as shown in Figure 4a [67].

(b) LIPA: The LIPA technique enables an MN connected to the LPN to connect to other local IP networks in proximity avoiding the operator's core network being crossed by the user plane system, as shown in Figure 4b. In this method, a local gateway (L-GW) is included, directly connected with the femtocell that acts as a PGW (LTE). When the LIPA default bearer (LTE) is configured, the MN data traffic flows are directly rerouted to the L-GW and then move into the local network without channeling through the wireless access or core network. Thereby, the LIPA approach is compatible with any smart device without executing modifications in software design [68].

In the 3GPP standardization Release-10, both LIPA and SIPTO have been implemented, but are provided with minimal support in mobility and offloading issues [69]. The reason for the persistence of the issues is largely due to the bearer's disappearance whenever the mobile disconnects from the femtocell. In the subsequent Release-11, a working theme on LIPA mobility and SIPTO at the local network (LIMONET) was presented to assist partial mobility support to the proposed approaches. Here, SIPTO mobility has remained unproductive in the case where S-GW and PGW are in the radio access network (RAN) site; additionally, it was not taken into the account within the local network level. Nonetheless, the LIPA mobility technique is applied for handovers between LPN femtocells by using the same L-GW [70].

In view of the proliferation of smart, intelligent equipment, many APs in close range create a dense network environment. It is forecasted that hundreds of different sizes of APs would be in the range of 1 km^2 terrestrial area in the next few years and coined the term UDN [71]. The current 5G cellular services sharply respond to the ongoing useful data demand with higher throughput and low latency. Yet, in the near future, especially for 6G cellular systems where every intelligent device or machine will be in contact with each other—such as D2D, aerial platforms, MNs, and vehicle-to-vehicle (V2V) communication [72,73], etc.—trouble will occur in data traffic management. The extreme densification of various smart peripherals in a multitier HetNet design and massive data load could have been the reason for complete chaos in the core network and heavy intrusions [74]. In consideration of traditional CMM design in the HetNet scenario, the probabilities of frequent data corruption, network breakdown, latency, and congestion are extremely high and devastative. For the management of data resources for various applications and new wireless services, plus to avoid the various core network hurdles, a flat architectural system is of the utmost importance.

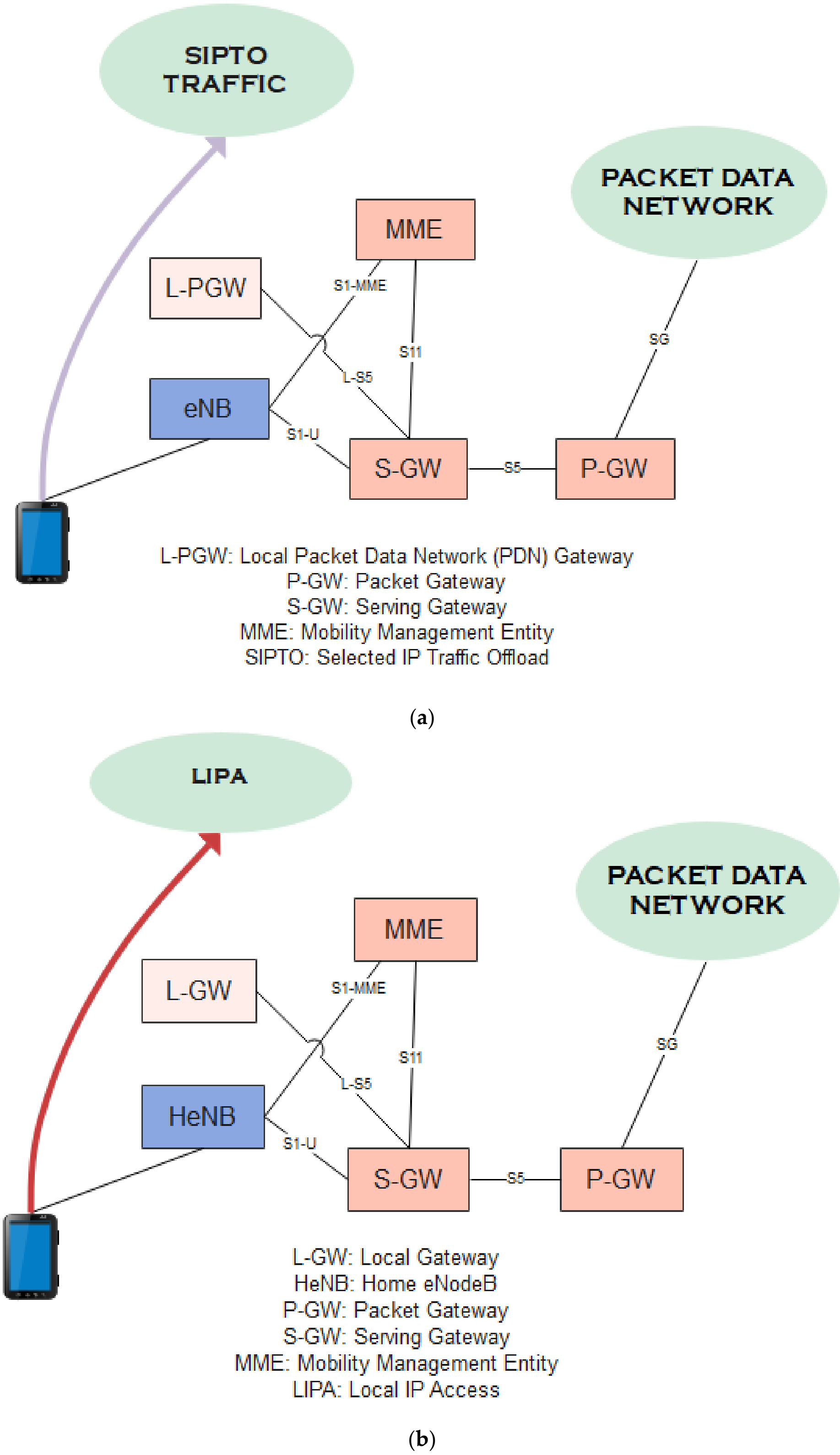

Figure 4. (**a**) SIPTO approach. (**b**) LIPA scheme.

3.1.2. PMIPv6 Mobility in the 3GPP EPC Design

Proxy Mobile Internet Protocol version 6 (PMIPv6) was deemed by 3GPP to utilize in LTE system architecture to support IP mobility management [75]. In this work, S-GW is used as the mobile access gateway (MAG) and PGW is complemented as the local mobility anchor (LMA) of PMIPv6, whereas the backhaul interfaces S1 and X2 handovers perform the same as the conventional LTE [76]. Another important aspect of PMIPv6 in LTE architecture is that it uses generic routing encapsulation (GRE) tunneling instead of general packet radio service (GPRS) tunneling between S-GW and PGW. It also exchanged proxy-binding update (PBU) and proxy-binding acknowledgment (PBA) messages between S-GW and PGW rather than "modify bearer request" and response messages. The format of PMIPv6 in the 3GPP EPC model is shown in Figure 5.

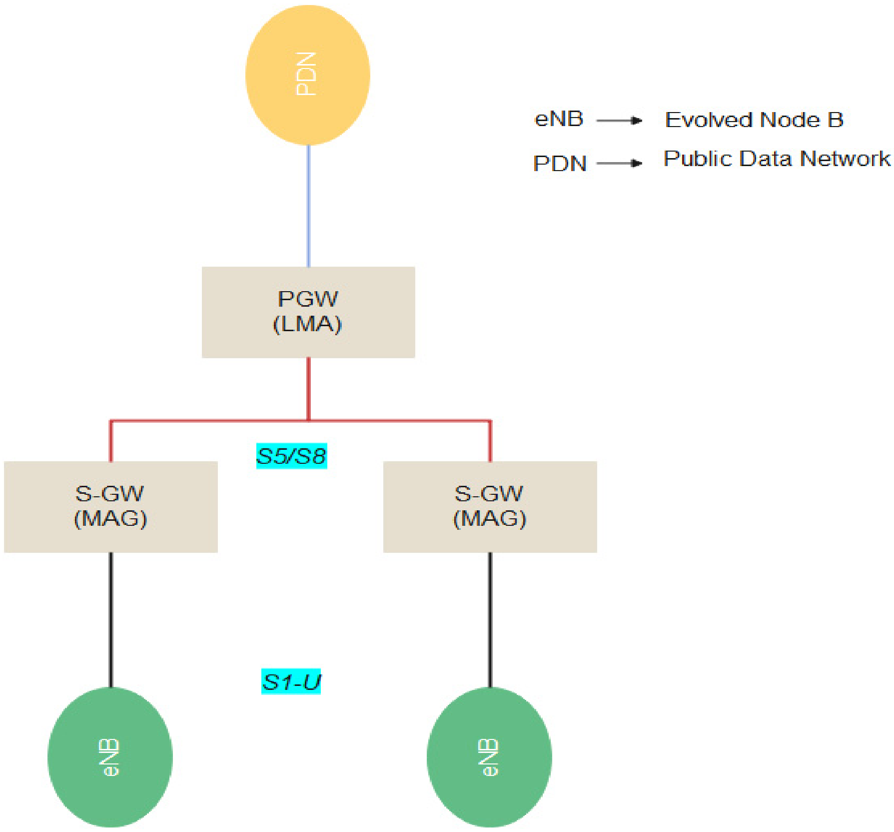

Figure 5. PMIPv6 in the 3GPP EPC system.

3.1.3. Advantages of PMIPv6 over MIPv6

The mobility MIPv6 protocols have been implemented in a centralization-based mobility mechanism in mobile access networks. It showed the plausibility of maintaining MN applications and displayed sufficient support for moving terminals. However, with the dramatic changes in traffic dynamics of wireless communication, the abilities of MIPv6 are considered unreliable and PMIPv6 was introduced to overcome the shortcomings of the existing mobility design [77,78]. PMIPv6 exhibited three major advantages over the conventional mechanism that are discussed below.

1. It significantly minimized HO-related signaling overheads by evading tunneling overheads over the air along with remote binding updates either to the correspondent node (CN) or HA.
2. By keeping the MN's home address unchanged, it reduced the possibility of malicious attacks that could expose the precise position of the MN.

3. Latency in IP HOs limits the performance by keeping the mobility management functions within the PMIPv6 domain. It largely avoided remote service, which is critical in initiating long services.

Table 1 depicts the baseline comparison between two IPv6 schemes, i.e., MIPv6 and PMIPv6, based on numerous protocol criteria.

Table 1. Differences between MIPv6 and PMIPv6.

Protocol Criteria	MIPv6	PMIPv6
Latency during HO	Not Good	Good
MN enhancement	Possible	Not Possible
Mobility scope	Universal	Local
Location management	Possible	Possible
Mobility anchor	HA	LMA
Signaling agent	FA	MAG

3.2. Literature Related to Mobility Management in Network Flattering

The recent research work on mobility management in flatter access networks with different categorizations is summarized below.

3.2.1. SDN-Based Mobility Management

Software-defined network (SDN)-based approaches are designed for flexible and dynamic controlling and monitoring of network assignments via software. In cellular networks, an SDN is responsible for maximizing the general routing protocols in networking, helping to update the hardware components used for observation and generating critical analysis reports for managing all networking components. We have discussed some of the SDN-based mobility management methods from the recent literature focused on managing and controlling the networking components.

For example, the authors in [79] focused on handling heavy data traffic in SDN-EPC cellular systems by using cloud computing and functions virtualization approaches. The results achieved reliable routing with low handover (HO) latency, but the technique could be tested for a higher density of the users, whereas a call control flow for the HO case in the current mobile architecture was evaluated [80]. The proposed SDN plus mobile network (S+ MN) solution has managed to significantly reduce signaling and delay problems to the tunnel and routing-based IP mobility management approaches. The authors in [81] have implemented a network based partially on the DMM-SDN solution, considering the growth in maintaining session continuity, performance, and scalability. The results confirmed that the suggested scheme provides fundamental advantages in the HetNet access network. Similarly, a new protocol type, on-demand mobility, was used, focusing on HO and signaling cost issues in [82]. The analytical results validated the sharp reduction in HO latency and up to 50% signaling cost, whereas in [83] an SDN-based fast HO optimum routing in DMM (SDN-FHOR-DMM) scheme was proposed for vehicle communication. It improved current SDN-based mobility management protocols in terms of signaling cost, HO delay, and loss of packets.

3.2.2. Performance in Dense Network

To increase the network reliability and maintain the latency requirement in an ultra-dense user environment in wireless networks, the flat IP design showed high expectations of efficiently managing the available resources, mobility scenarios, and network quality. Because of the need in the current densely deployed radio communication setting to manage arbitrary heavy data applications, the authors in [84] introduced a distributed dynamic mobility management framework for the flat IP system. The outcome of the analysis proved that the proposed solution is effective for flat architectures and significantly avoids specific mobility functions in access gateway or core network nodes. Similarly, imitation issues due to the high density of users and traffic demand in the MIPv6 protocol have been discussed in [85]. Flat access and mobility architecture (FAMA) was presented under the MIPv6 protocol and accomplished better network performance because of the short HO duration and mobility patterns for MNs. Likewise, researchers in [86] presented IP mobility performance issues in a centralized network. It proposed a terminal-centric distribution and orchestration approach by placing the smart intelligence on the MN and achieving higher 5G networks efficiency. Few authors decided to increase mobility suppleness and performance by using a distributed dynamic MIPv6 (DDM) framework [87]. The empirical studies showed that the proposed DDM outperforms MIPv6 in terms of network resources.

3.2.3. Security in Packet Transmission

Security is an essential element in any data transmission network to avoid malicious attacks, loss of confidentiality and privacy, and other harmful attacks. It is a serious concern in wireless access networks, especially when sensor nodes are deployed in the hostile surrounding area. A study was conducted by the researchers in [88] on the false data injection in the flat wireless sensor network (WSN) [89]. An integrated routing and authentication protocol was attempted to achieve multiple goals. The designed technique enabled better routing guidance, the discovery of shared keys between two nodes, and routing paths plus key graphs, updated in an integrated step. A DMM-based, HO-secure and efficient protocol (DMM-SEP) was used, and it commendably minimized the privacy issues and defended against redirection attacks [90].

Since centralized mobility support is undesirable for data contents in 5G-and-beyond cellular wireless systems, it is essential to handle the locations of MNs in a distributed way, but in a highly secure and fault-tolerant environment. An analytical model applying secure and fault-tolerant distributed location management was presented [91]. The evaluated results of the proposed security scheme analyzed the authentication latency time and the number of authentication messages needed for a secure HO. Consequently, the simulation values were excellent and outperformed the popular conventional authentication schemes in a DMM environment. In contrast, the researchers in [92] utilized a blockchain-based DMM approach and tried to remove hierarchical security issues without changing the mobile wireless layout. The contemplated approach created a shield against different sorts of malicious attacks and supported deregistration policies. Moreover, the authors in [93] contributed to secure transmission in fronthaul/backhaul (Xhaul) communication in case of the fast movement of an object. A novel key exchange and authentication protocol was presented, and the achieved results showed prominence over the other subsisting solutions.

3.2.4. PMIPv6 Testbed and Routing Optimization

Initially, MIPv6 was introduced by IETF to handle the IPv6 mobility of wireless data packets in a centralized architecture. This MIPv6 effectively provided multimedia and augmented services for MNs to continue Internet activities without any disturbance. It also allows MN to move and change the attachment point without changing the address, but MIPv6's abilities have not sufficiently answered the true mobility effects and the triggered HO issues. In response, IETF presented PMIPv6 to balance the shortcomings of the MIPv6 protocol and enhance flexibility in routing traffic in a network. The major difference between the MIPv6 and PMIPv6 is that the latter is a 'network-based' approach, while MIPv6 is a 'host-based' scheme.

Therefore, the authors of [94] developed a PMIPv6 testbed for real-scenario analysis and used the Kernel version. The Kernel setup enables several features to support the PMIPv6 environment, and the testbed based on PMIPv6 performed successfully without errors. Similarly, another bench test was performed [95] by presenting a flow-based and operator-centric mobility management framework in the EPC architecture. The proposed framework was evaluated in a virtual testbed scenario and the results displayed improved functional flexibility for operators, enhanced user experience, and promptly decreased signaling overheads. In the ongoing 5G-and-beyond wireless system, the multimedia and augmented realities are the main reason for cellular data traffic load. In this context, IP multicast plays a vital role in the delivery of robust multimedia content, yet very limited work on multicast mobility protocols in a DMM situation was established. In [96], the authors have tried to tackle multicast-listener-related issues by presenting different techniques based on the system dynamics in a DMM environment. A partially and fully distributed DMM scheme to deal with the multicast problems was evaluated and the outcome showed the superiority of the method over other available frameworks. Moreover, a flat routing process routes data packets according to a globally unique flat identity, and in [97], a scalable, centralized flat routing technique based on the open-flow network paradigm called centralized flat routing (CFR) was presented. Preliminary prototype results on a small scale proved the feasibility of CFR in the real environment.

Table 2 summarizes all the above-discussed related literature for network flatting.

Table 2. Summary of related work for network flatting.

Issues	Methodologies	Advantages	Limitations/Future Work	Refs.
		SDN-based Mobility Management		
Handling large data traffic management of mobile users in software-defined networks (SDNs)	Evolved packet core (EPC)-based SDN network functions virtualization and cloud-computing-based network	Better routing optimization with lower handover latency	Requires higher user mobility factors	[79]
Call control flow for handover scenario in an SDN network	Efficient mobility management that isolates the chains of IP preservation and the data path	Improves the chains of IP preservation without breaking and reestablishing the connection	Architecture validation is required for multipath transmission control protocol (MPTCP)	[80]
Distributed mode of mobility management in an ultra-dense heterogeneous network	SDN-DMM-based technique to handle the distributed functionalities of mobility management	Reduce handoff latency and signaling cost, while improving scalability and QoS	A hybrid model with SDN extension is needed for autonomous systems	[81]
Frequent handover failure and signaling cost	On-demand mobility for registration and handover process	Minimize delay and signaling cost by up to 50%	Required session connectivity; limited by delay intolerance	[82]
High signaling cost, handover delay, and packet loss during data offloading in an SDN-based system	Enhanced handover control for DMM and optimum routing scheme	1. It connects to the new MAAR before the MN disconnects 2. Resolves the triangle routing issue in DMM with low packet loss	The proposed technique can be fostered in vehicular communication	[83]
		Performance in High User Density		
A new mobility management scheme is designed to reduce the traffic encapsulation	The control functions are deployed at the edge of the network utilizing the flat architecture	Lower handover delays with better QoS performance	Multi-attachments and multi-interface terminals cause a delay	[84]
Limitation occurs due to the higher number of users and traffic demand for the mobile IPv6 protocol	A new DMM solution is proposed, which is based on cryptographically generated addresses	Better performance in terms of handover delay	Experimental comparison can be carried out of mobile IPv6 with the FAMA	[85]
IP mobility management efficiency issues occur in a centralized approach	Proposed a distributed approach that provides optimal mobile data path and distribution	Achieve scalability and higher efficiency	Optimum channel state information needed with no delay	[86]

Table 2. *Cont.*

Issues	Methodologies	Advantages	Limitations/Future Work	Refs.
Performance in High User Density				
Investigate local and global mobility support in a distributed manner	Proposed a DDM scheme for network resource	DMM outperformed MIPv6 significantly	DDM scheme for various critical cases	[87]
Security in Packet Transmission				
Prevent the false data injection in the flat wireless sensor network (WSN)	A reauthentication routing protocol is proposed, which eliminates the unnecessary node from the pool	Update the latest routing path and key graph with the node's mobility	Uses TinyOS operating system software to implement routing protocols	[88, 89]
Malicious and harmful attacks besides the secrecy	Secure and efficient protocol based on DMM design	Defense against multidirectional attacks	Limited to SA 5G networks	[90]
Distributed location management and secure authentication mechanism for MNs	Unique fault-tolerant scheme based on a distributed hash table of access nodes and ticket-reuse approach for secure and robust authentication of the MNs	1. Avoids traffic congestion, single point of failure issues 2. Reduce malicious attacks 3. Less delay in location queries	Traffic congestion increase with higher mobility	[91]
Hierarchical security issues	Distributed block-chain strategy based on DMM	Counterfeit distributed DoS, impersonation, session hijacking, and backward broadcasting	The proposed technique can be applied to different types of broadcasting mechanism	[92]
Integration of fronthaul and backhaul networks for smooth operation	New key exchange and authentication protocol for moving objects	Efficiently manage security parameters along with privacy during handover	A line-of-sight link is required for smart handover	[93]
PMIPv6 Testbed and Routing Optimization				
Develop a PMIPv6 testbed for experimental use	A proxy mobile IPv6 protocol using a flat domain model testbed	PMIPv6 testbed was successfully run without error	Can compare with the other testbed and simulation on NS3	[94]
Architectural limitations of EPC for effective and strong offloading	Flow-based and operator-centric dynamic mobility management with proxy mobile IPv6 (PMIPv6)	Enhancing operation's flexibility and flow-level functioning; with low overhead signaling	It requires a strong offloading algorithm	[95]
The multicast listener related issues for the DMM environment	A DMM scheme based on flat IP architecture can help to tackle multicast-listener-related issues	Resolve the tunnel convergence problem	Experimental testing can be carried out on the existing PMIPv6 testbed	[96]
The scalable centralized flat routing architecture	The CFR routing scheme is based on the open-flow network to improve network scalability	CFR works efficiently in a realistic environment	More advanced schemes are needed for optical communication	[97]

4. Distributed Mobility Management

The new DMM approaches enable an absolute flat network structure for easy access to IP services and densely fast mobility scenarios. It offers inbuilt support for mobility in multitier HetNet design wireless networks. The DMM paradigm is the prime example of the aforementioned concepts and cases concerning network flattening [98]. In the DMM framework, all IP-based user data packets are transported through the suboptimal paths, taking advantage of multiple anchor points and IP services in the local network closer to the users [99]. Figure 6 portrays the core idea of DMM in multitier HetNet and promises great mobility support across different use cases.

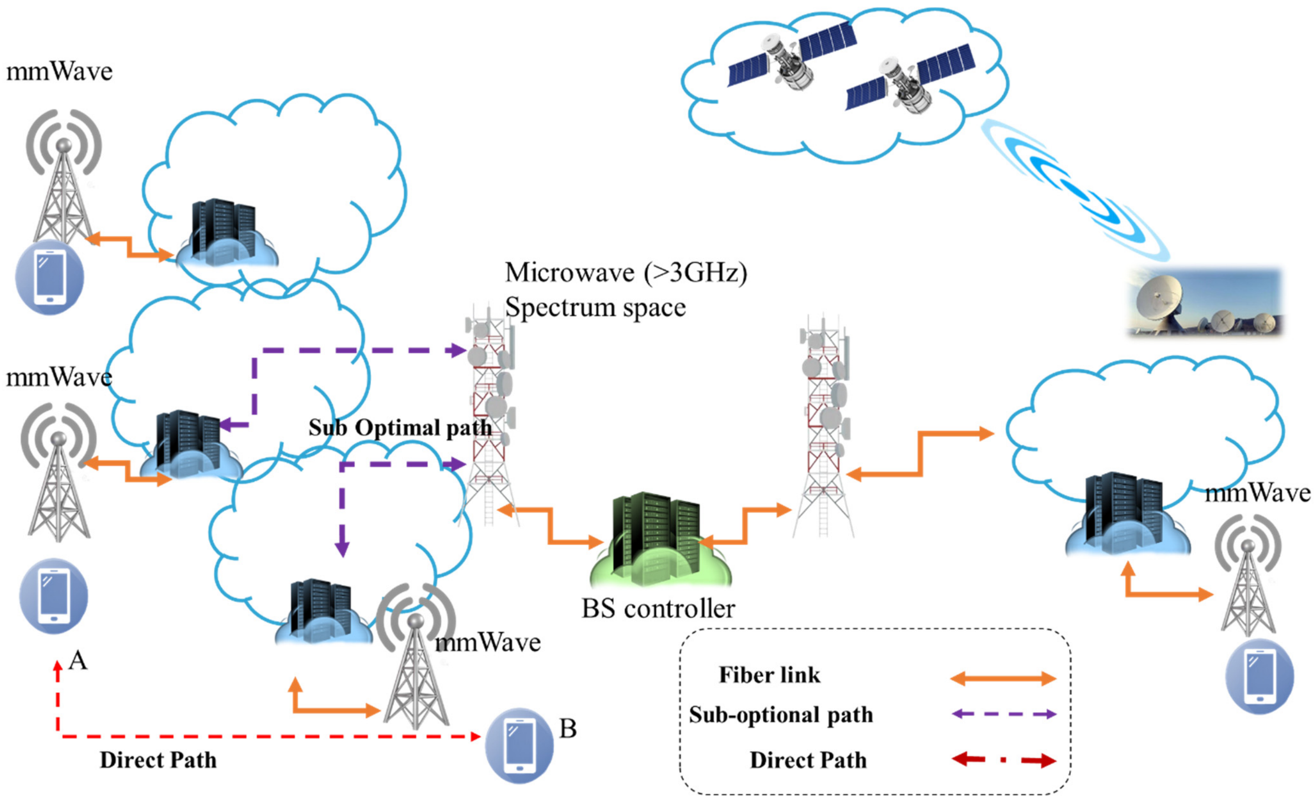

Figure 6. A distributed network that places content servers in the access network.

4.1. Background

A smart allocation of IP addresses based on the service demand of MNs gives an edge to the mobile network operators (MNO) in flexibly managing users' content traffic with additional protocols [100]. For instance, IP traffic flow must be anchored to a centralized node for long sessions and locally for short sessions data exchange. Herein, DMM uses prefix tagging where certain types of prefixes are assigned to the selected services of the users. The users belonging to the particular network group are allowed to access the meta-data related to the assigned prefixes based on the operator's policy [101]. Thus, researchers corroborated that the DMM framework is an absolute solution for mobility and related management services for gigabytes of data traffic in current 5G and hyper UDN 6G cellular carriers. Assuming several PHY and MAC layer advantages, the most beneficial impact on the distribution of network functionalities could be received by MNOs and service providers. The framework significantly increases the simplicity of controlling and assessing many assorted technologies in a system. Additionally, it can efficiently transfer valuable resources to the wireless backhaul network and increase the performance of network backhaul communication [102].

Classifying various positive aspects of the DMM, the essential characteristics of DMM frameworks are agility in handover management and guidance in optimum data delivery route by avoiding unnecessary routing loops [103]. Subsequently, among many other new technologies, in-band D2D communication is receiving attention in the industry for mobility support and is considered a first choice for the operators. The new addition to the wireless system, i.e., D2D communication, is beneficial for seamless ping–pong handover between large-scale smart devices and cooperative interference management in mobile networks [104]. It enhances spectral efficiency, transmission reliability, and network capacity, yet security remains a threatening issue. Several DMM-activated solutions have been developed under 3GPP and IETF authorities [105,106]. The performed empirical and simulation analysis validated the massive advantages over the conventional mobility support entities. However, the proposed DMM methods that can be applicable and effective in a real environment for static and moving platforms still need more research exploration. Nonetheless, reducing handover losses, signaling cost, and round-trip delay, besides ultra-reliability, is highly desirable in future wireless communication [107].

DMM frameworks are used to develop a flat mobility architecture by accommodating several anchors closer to the MNs. The main families of DMM-based solutions belong to network-based mobility protocols and are described below.

4.1.1. Routing-Based DMM

In a routing-based DMM solution, the border gateway protocol (BGP) is used to conduct mobility functions and transfer data packets to and from mobile devices. All the BGP routers are involved with the DMM gateways in the network domain, eliminating any anchors, and reestablishing the path for the routing mechanism. In the context of the initial attachment, the gateway uses the dynamic host configuration protocol (DHCP). It allocates the IP address while the MN updates its domain name system (DNS) by using the IP address (e.g., prefix 1). The DMM gateway transmits a DNS request to attain the IP address that the MN must acquire [108]. Then, it broadcasts to all the routers in the network that a specific address is reachable through the corresponding DMM gateway. Additionally, when a handover occurs, the new DMM gateway validates that the MN has already been allotted an IP address. Subsequently, by using the BGP protocol, the prefix 1 is advertised in the routing network (BGP routing update), and the IP address remains unchanged during the handover process. Thus, the routing-based DMM extensively relies on BGP updates to announce the new route in a network. Later, the DMM gateway will update the routers in the network so the traffic will be able to reach the new position of the MN [109].

4.1.2. PMIPv6-Based DMM

The concept behind the PMIPv6 solution is to utilize one of the elements in the network as a proxy for the MN and the care-of-address (CoA) option would not be allocated to the MN, instead of being assigned with the proxy of the MN [110]. The proxy protocol design showed the existence of new entities compared with the conventional MIPv6. Indeed, the correspondence node (CN) is responsible for transmitting the data to the MN which is connected to the access router point. The LMA is similar in function to the HA in MIPv6 and the MAG keeps track of the MN. In a network, the domain where PMIPv6 is applied is termed as PMIP domain or localized mobility domain (LMD) [111]. The positive aspect of the PMIPv6 mobility solution is that the MN can change the access router without requesting a new IP address. Additionally, the MN can attach to the new access router without changing the standard protocol stack (i.e., any modification in software/hardware). Meanwhile, the MN is on the common network that is capable of accommodating various wireless access technologies, such as LTE [112], wireless local area network (WLAN) [113], and worldwide interoperability for microwave access (WiMAX), etc.) [114].

Combined with the DMM, the centralized entity is detached and resides in the access node. So, the IP sessions have the gateway in the access network and provide ease in data packets transmission by avoiding the packet core network [115]. In this regard, the architecture showcases the mobility access router DMM gateway, the same as the MAG, which is used to forward the user useful data back and forth to the Internet. It also supports managing MN seamless mobility while hopping from one MAG to another. Additionally, in traffic redirection coordination, a node referred to as the control mobility database (CMD) is used, which stores users' mobility sessions. This CMD node is never crossed by the user data traffic link, as shown in Figure 7. The traffic follows the channel through the DMM gateway and the CMD node does not participate [116].

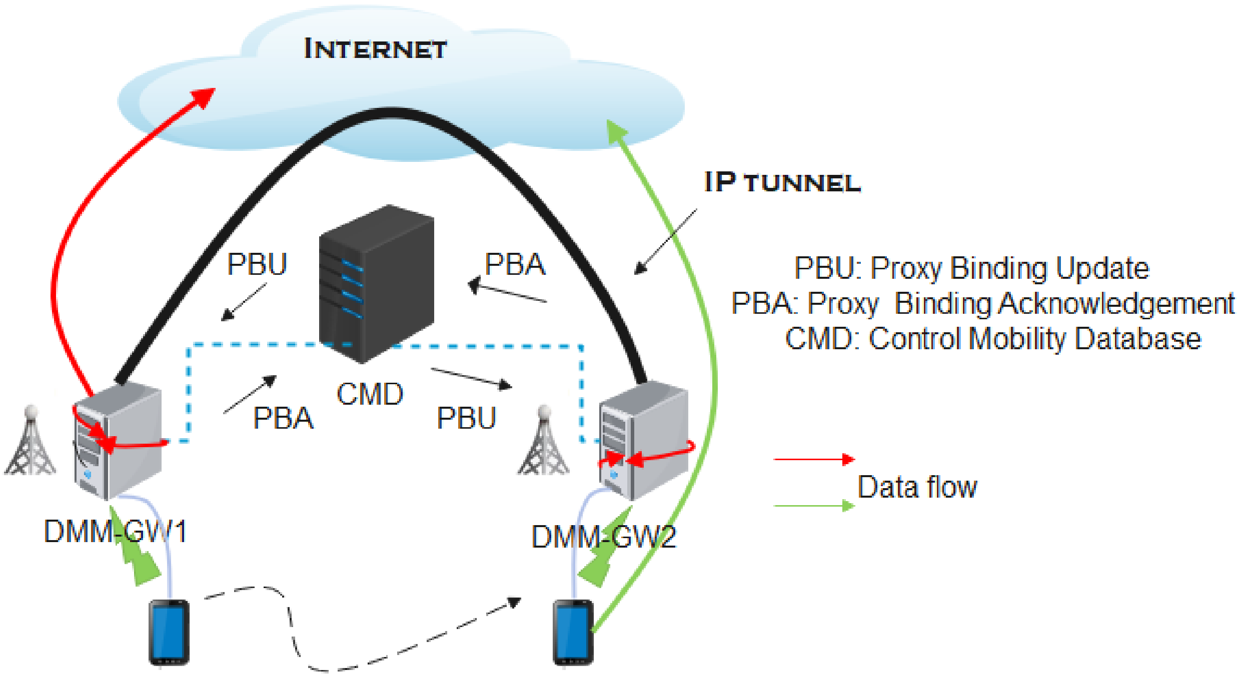

Figure 7. PMIPv6-based DMM.

The DMM gateway transmits signaling messages, proxy binding acknowledge (PBA) messages, to the control and process unit, and it returns the information with IP metrics in proxy binding updates (PBUs) that must be forwarded to the MN to connect to the network. At this stage, the MN could communicate with any other node in the network, and data packets move through the gateway, and then from the gateway to the Internet.

4.2. Literature-Related Mobility Management in DMM Networks

4.2.1. Stabilizing Latency and Signaling Cost

All IP-based mobility support and IP-based networks are the de facto solutions for the growing population of mobile Internet users since it offers seamless mobility and high reliability to the users between the HetNet access paradigms without interrupting the service. Various mobility management solutions based on DMM schemes have been proposed so far. The authors in [117] have implemented a hybrid DMM (HDMM) method, where the mobility operation is also distributed at the access routers (ARs), except in the areas of high latency and routing costs. Simulation results confirmed the worthiness of time-sensitive, over-the-top services. In article [118], the authors initiated PMIPv6 and the IEEE 802.21-media-independent HO (MIH) protocols to preserve seamless HO in the HetNet environment. The proposed solution helped stabilize signaling costs and packet loss frequency during the transmission; however, more advanced algorithms are needed for real-time mobile user communication.

Network mobility (NEMO) is a technology deployed in public transportation and personal network to enable Internet services. Different NEMO-based DMM schemes have been presented [119,120] to mitigate issues such as central core entity, HO latency, signaling operation, and decreased packet delivery cost. Likewise, the authors in [121] designed a preemptive HO scheme (PHS) to remove the signal point failure and traffic bottleneck issues, and the simulation test outperformed the rest of the methods. In [122], a hybrid centralized–DMM in the NEMO context (called H-NEMO) provided better performance, based on packet delivery cost, HO latency (and disruption time), signaling cost, and end-to-end delay.

4.2.2. Deployment of MIPv6/PMIPv6 Protocols

In future cellular Internet, MIP/PMIP will be the elementary mobility management protocol that can support multimedia and other services. To effectively address the scalability hurdles caused by the escalating number of MNs and traffic volume generated would be critical to endorse IP-based mobile Internet. For the DMM extension, three basic categories have been created to address some of the drawbacks and shortcomings of MIPv6 and PMIPv6: (1) client-based, (2) routing-based, and (3) network-based techniques. Although the solutions based on the classification of DMM extension are still being standardized, there is a mounting interest to address some issues for the new services (e.g., distribution caching for multimedia content).

In order to address some problems of the existing Internet, caused by the underlying location-based communication design, and make it stringent for future applications, a new theme, named data networking (NDN), has emerged as one of the most robust techniques among various information-centric networking (ICN) proposals. A novel all-IP-based DMM, designed by leveraging an NDN overlay, was discussed in [123]. The unique method enables the DMM requirements to distribute the anchor point and efficiently guide the best packet transmission route in the mobile computing structure. Likewise, a tunnel-free DMM support protocol framework was analyzed and the performance in terms of packet loss, latency in HO, and HO blocking probability by IPv6 protocols was compared [124]. The derived framework successfully reduced HO latency by about 12%, HO blocking probability by 71%, and data packet loss by 82%. Correspondingly, the authors proposed an analytical expression evaluating the HO process of different centralized and distributed protocols [125]. It is used to compare PMIPv6, PFMIPv6, and DMM performances in terms of HO latency, session recovery delay, packet and signaling cost, and HO failure. The results showed that PFMIPv6 is the most well-suited protocol for low–high mobility scenarios.

Moreover, an analytical evaluation of a network-based IP DMM solution in terms of signaling cost, HO timelapse, and signaling cost was performed [126]. The authors concluded that the future network architecture would exhibit hybrid centralized–DMM behavior. In this regard, the mobility management of certain traffic will be kept centralized, while other traffic will be distributed.

4.2.3. MN Mobility across Different IP Addresses and Technologies

The thirst for Internet services and applications continues to escalate, and many wireless standardization authorities envisaged that this trend would gain more momentum in the future. As the desire for MNs connectivity via the Internet expands, it has given birth to more diverse smart wireless nodes and cases to become part of the network. Service disruption for roaming MNs across different IP addresses, domain networks, or technologies in multicell architectures is a huge challenge. Lately, for the seamless mobility of MNs, such as virtual machines or containers, multicell architectures were dispensed, but they cannot guarantee reliable service for objects in motion.

The authors in [127] introduced a live migration (LM) method for uninterrupted mobility support for mobile terminals. The experimental characteristics of LM demonstrated the great potential to provide a reliable connection for MNs hopping across different IP addresses' domain networks. Identically, a distributed, IP-based mobility management protocol (DIMMP) was evaluated for the free movement of MNs across wireless mesh networks (WMNs) [128]. It contributed by removing the limiting aspects of single-hop and centralized network architectures, as well as improving the HO procedure. Additionally, a fast HO for network-based DMM (FDMM) for PMIPv6 was evaluated to reduce HO latency and data packets corruption during the mobility of MNs [129]. The analytical experiments showed that FDMM comprehensively outclassed DMM, whereas an enhanced fast HO PMIPv6 (ePFMIPv6) was presented to support rapid IP HO in vehicular networks [130]. The simulation test confirmed the excellent performance of the proposed ePFMIPv6 in comparison with PFMIPv6 protocols.

4.2.4. Gap Analysis and DMM Module Assessments

Engineers, researchers, and radio regulatory authorities have been developing NSs of IP mobility management protocols since the advent of the first and most commonly deployed IP protocol, MIPv6. For example, the MobiWAN NS-2 extension was designed for NS-21 to simulate MIPv6, owing to the inherited limitation of NS-2 that supports only IPv4. Therefore, in [131], engineers have developed the DMM module in Network Simulator-2 (NS-2) to implement the DMM protocols' functionalities, entities, and operations. An analytical study was conducted to ensure the accuracy of the module compared with the theoretical values. Consequently, the obtained values from the simulation showed a high coherence with the assessed theoretical data. In parallel, a network-based full-DMM approach was developed to eliminate any dedicated centralized mobility anchor from the system architecture [132]. The simulation results of the proposed full-DMM approach showed the significance of the traditional CMM model.

Another analytical experiment was performed on the implementation gaps of the DMM models in 3GPP 4G/5G cellular networks [133]. The researchers audibly advised that all DMM designs could be deployed in a 4G EPC, and partial implementation would be possible in NR 5G due to unspecified entities in the core architecture. In [134], the authors characterized recent research works based on the DMM mechanism in D2D communications. After a vigilant thought process, they then identified the most impactful approaches that could be highly suitable for D2D mobility management in current NR 5G-and-beyond mobile networks.

Table 3 summarizes all the above-discussed related literature for DMM.

Table 3. Summary of the literature in distributed mobility management.

Issues	Methodologies	Advantages	Limitations/Future Work	Refs.
Stabilizing Latency and Signaling Cost				
An optimization problem for provisioning efficient centralized MA deployment	An HDMM scheme that jointly characterized both centralized and distributed mobility management	Better results in terms of handover support with no-delay QoS	The threshold needs to be set for switching between DMM and centralized mobility management	[117]
Network-based DMM scheme between the mobile node and the access networks	Modification of PMIPv6 and the IEEE 802.21 media MIH protocols to supply seamless handover	Substantial aid for signaling cost, handover latency, and packet loss in heterogeneous networks	A more advanced algorithm is needed for real-time mobile users	[118]
A DMM protocol based on NEMO that mitigates long interval	DMM is based on the PHS method to reduce scalability issues in network mobility	Decrease long intervals with low latency in network mobility	It can be extended to more detailed parameters for method validation	[121]
Network mobility architecture management	Hybrid centralized–DMM architecture based on the NEMO	Better results for packet delivery cost, handover latency, and end-to-end delay	Lack of performance metrics in terms of number of nodes and flows	[122]
Deployment of MIPv6/PMIPv6 Protocols				
DMM named data networking overlay IP	NDN approach of all-IP-based mobility management architecture where multiple anchor points are placed at the edge of the network	Subjugate centralized IP limitations and enhance mobile traffic transmissions path	Induce signaling costs due to state synchronization of location management	[123]
Addressing and tunneling management for current DMM based mobility protocols	Tunnel-free DMM support protocol	Minimize handover latency by about 12%, handover blocking probability by 71%, and packet data loss by up to 82%	DMM handover hurdles when multiple MNs perform handover simultaneously	[124]

Table 3. *Cont.*

Issues	Methodologies	Advantages	Limitations/Future Work	Refs.
		Deployment of MIPv6/PMIPv6 Protocols		
Analyzing the performance of distributed and centralized mobility protocols based on traffic characteristics in the vehicular system	Implement an analytical model for CMM protocols and DMM protocols to analyze handover performance competency	PFMIPv6 provides quality results in low to high mobility environments	DMM is limited to low–medium mobility cases only to curtail the loss of packets	[125]
Analytical and experimental assessment of a network-based DMM	Develop an analytical model	Allows resources to be saved in some situations by reducing packet delivery cost	The complexity of the model has increased with higher mobility	[126]
		Mobility of MNs across Different IP Addresses and Technologies		
Seamless mobility of MOs, such as virtual machines or containers	LM system and protocol to support mobility of MOs connected via the Internet	Seamless mobility of MOs hopping around the different network	Expand the LM testbed on LM of MOs in a large-scale scenario	[127]
During mobility of MNs connection failure issues in WMNs	Distributed IP-based mobility management protocol to manage intra- and inter- WMNs	Support seamless connectivity and multi-hopping transmission scenarios	Limited to one aspect of DMM functionality to MBGs, MARs, and end nodes	[128]
Changes in IP addresses of MNs in intelligent transportation systems	Fast HO for network-based DMM (FDMM) based on the fast HO for PMIPv6 (PFMIPv6) protocol	HO latency, session recovery, and packet loss FDMM performed better than IETF network-based DMM	Extra signaling cost	[129]
MNs mobility in vehicular networks under geographic restrictions	Enhanced PFMIPv6 h (ePFMIPv6) for fast HO and modified signaling process by accommodating NML	ePFMIPv6 performs better HO latency, packet loss, and signaling cost than PFMIPv6	Limited to a small geographical area	[130]
		GAP Analysis and DMM Module Assessment		
Conduct simulation test to verify DMM operational and functional characteristics	Design of network simulator module for DMM protocol	The DMM module shows high reliability and theoretical results are almost similar	Higher mobility causes degradation in the network output	[125]
A comprehensive performance evaluation of DMM and CMM models	Implement a network-based full-DMM process on the NS-2 simulator	Full-DMM approach supports lower end-to-end latency than CMM	Increase HO latency and packet loss at MN speed	[132]
Gap analysis to demonstrate technology that needs standard-based applicability and extension for interoperability	An IP-based DMM model is obtained from five models specified by IETF DMM WG, and the 3GPP	All DMM models and technologies are applicable, defined in the standardization documents in 4G EPC	Effective mobility distribution model in different scenarios	[133]
Survey on handover performance in DMM-based D2D mobility in 5G networks	PMIPv6-, LIPA-, SIPTO-, SDN-, and routing-based approaches performed	SDN-based DMM technique is a promising candidate to manage D2D mobility	Required sophisticated SDN architecture to manage and increase the operational abilities	[134]

5. Current Limitations and Future Challenges

Extensive studies have been performed to tackle the mobility issues and operational challenges for current 5G and future wireless networks. Many proposed research methodologies on efficient mobility management assist in simplifying the packet transmission process and increasing system reliability. Hence, a variety of the discussed frameworks largely manage to minimize the signaling costs, packet losses, ping–pong handovers, operational functionalities of the core network, round-trip latency, and the load balancing of the access network, etc. However, the challenges involved are due to the proposed mechanism's continuous network development and limitations. Apart from the discussed studies, several other works can be combined and explored with the mobility issues that can enhance the performance of the 5G-and-beyond network, for example, energy management [135], interference mitigation [136], machine learning protocols [137], and antenna designing [138]. The following sections will discuss the domains and crucial aspects that need immediate attention, and robust solutions in the effective management of mobility protocols that have been discussed before.

5.1. Network Flattening

The augmentation in the population of Internet-connected things and thousands of wirelessly coupled devices raises critical questions about the current networking protocols. The home-based Internet-connected networks, connected to wireless broadband communication, produce an excessive bulk of data and centralized data routing, and the acquisition of the current system is not capable of combatting the hurdles. Therefore, in [139], the authors presented a mobile matrix protocol that uses an IPv6 address for routing and mobility management without changing the MN IP address. The proposed technique would be helpful in the social and mobile IoT services in future wireless services. Nonetheless, mobile and social IoT communication are in the beginning stage, and a tremendous amount of work is required on the impactful and robust mobility support for the newly introduced services [140]. In [141], researchers presented a distributed core system design for 5G and upcoming 6G networks. A distributed mapping mechanism was applied for the management of fast mobile smart devices and IoT. It minimized the smaller user plane path lengths and control overheads, yet the proposed frameworks could be used for delay and mobility studies in the ORBIT radio testbed.

Contemplating the constructive enhancement in every radio communication domain, standardization authorities, researchers, and various drive tester groups are working to utilize thousands of low earth orbit (LEO) satellite networks. The multi-satellite model is expected to increase the flexibility, consistency, and stringency of reliability, as well as ensure minimum latency in cellular networks. After an in-depth analysis, the groups suggested that it has great potential to answer the forthcoming needs in extremely critical, varied scenarios happening anytime and anywhere. For example, in [142], the authors advised that it is necessary to design a location management framework for several groups of wireless, associated things with different orbital parameters. Those parameters depend on variables such as handover frequency and duration, footprints, and the density of satellites.

5.2. Distributed Mobility Management

Vehicular communication is the most promising addition to 5G and 6G radio networks. Owing to the limited resources of the spectrum, systematic and efficient use of frequency bands is necessary. The current 5G-and-beyond networks are expected to exploit cellular resources for vehicle communication, including aerial platforms. The sharing of resources between cellular-connected and vehicular products could be a serious threat to network disconnection, frequent interruption, interferences, and so on. The high chances of vulnerability would certainly be complex channel modeling for air-to-air and air-to-ground transmission [143], whereas the researchers claimed that there has not been much interest shown in the secure route characterization for DMM logic. Hence, a secure-route model for DMM-based smart home networks is proposed in [144]. The authors suggested that it is viable to extend the model for IoT, mobile IoT, and social IoT networks. After discussing the feasibility of the proposed model, the study further advised that this could apply to standalone and non-standalone 5G architectures. In the future, vehicles with every smart machine communication option can play a big part in taking the wireless digital communication system to the next level. In vehicle-to-everything (V2X) communication, sensor-based data updates would also be activated for various domains, such as medical health monitoring, airports' critical base communication, and data updates in high-mobility scenarios. Consequently, a real-time, practically applicable, DMM-based solution to maintain the system is crucial. Such a developed framework must be capable of avoiding malicious threats, various interference issues, undesired handover problems, and call drop count, while ensuring an increase in security level [145]. Likewise, users and intelligent electronic devices can identify more than one air interface in their proximity, mainly due to the concurrent wireless activities of different access technologies, such as 4G, ISM, WWAN, and WLAN. The appropriate switching and handover mechanism is essential for the continuity of the user's activities.

The agility of cloud-based computing services demonstrated its potential to answer the ever-growing demand for wireless. It is estimated that development will try to connect everything to the Internet in the next few years, with pedestrians, cars, flying machines, smart appliances, and sensor networks, etc., all connected; the desire for Internet services is increasing tremendously fast. This massive demand and the varying speeds of a large variety of users and smart electronic devices would certainly create a fuss. The available literature on cloud-based computing processes showed multiple issues and could not be any more fruitful with the same functionalities. Some of the issues described in the literature include the unbalanced coordination of small-cell APs, massive congestion, online cancellation performance issues, and frequent packet loss, which reduce the quality and defeat the purpose. However, edge and caching computing are also used to overcome the limitations of the cloud computation process. However, these schemes are not fully efficient and face difficulties in balancing computation resources [146].

6. Conclusions

Current 5G and future wireless networks are expected to simultaneously support billions of smart devices while maintaining extreme reliability and QoS for each smart product, especially those residing on cell edges or in motion. With the rapid increase in intelligent peripheral gadgets and novel intelligent machines in the last few years, the demand for data from smart devices is also rising exponentially and shaping serious challenges for the mobility process, while escalating chaos in the core network. The sudden increase in hefty data requirements is mainly due to the heavy BW applications and immersive media components, in addition to time-sensitive cases. The unprecedented data volume introduces different mobility management protocol complications and adversities in centralized network architectures. A new paradigm of a flat network architecture based on DMM design was conceptualized and considered as an evolutionary step towards a complex and dynamic HetNet radio network. In this article, mobility management techniques for future wireless networks are highlighted and discussed from the perspective of network designs where traffic will be largely offloaded locally at the RAN level, instead of routing all traffic through the core network. This study broadly discussed flat and DMM-based IP mobility management architectures and their types. The review demonstrated state-of-the-art research studies and the potential benefits of robust mobility support in dynamic DMM 5G-and-beyond radio communication environments. Furthermore, this review article comprehensively delineates numerous current and ongoing studies and challenges, while detailing potential future research dimensions regarding flat DMM-based 5G and the upcoming 6G networks. It is believed that this article is a potential source for designing 5G-and-beyond wireless networks.

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Abbreviations

access point	AP
augmented reality	AR
base station	BS
border gateway protocol	BGP
centralized mobility management	CMM
content delivery network	CDN
device-to-device	D2D
distributed mobility management	DMM
evolved packet core	EPC
fifth generation	5G
fourth generation	4G
fronthaul/backhaul	Xhaul
general packet radio service	GPRS
generic routing encapsulation	GRE
handover	HO
heterogeneous network	HetNet
Internet Engineering Task Force	IETF
Internet of Things	IoT
Internet protocol	IP
LIPA mobility and SIPTO at the local network	LIMONET
local gateway	L-GW
local Internet protocol access	LIPA
local mobility anchor	LMA
long-term evolution	LTE
low-power nodes	LPN
mobile access gateway	MAG
mobile Internet protocol	MIP
mobile network operator	MNO
mobile node	MN
new radio	NR
packet data network gateway	PGW
proxy-binding acknowledgement	PBA
proxy-binding update	PBU
proxy mobile Internet protocol version 6	PMIPv6
quality of experience	QoE
radio access network	RAN
selected Internet protocol traffic offload	SIPTO
serving gateway	S-GW
sixth generation	6G

software-defined network	SDN
Third-Generation Partnership Project	3GPP
third generation	3G
ultra-dense networks	UDN
unmanned aerial vehicle	UAV
vehicle-to-vehicle	V2V
virtual reality	VR
wireless fidelity	WiFi
wireless sensor network	WSN

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