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TOPICAL REVIEW

Mobility Management in Heterogeneous Network of Vehicular Communication With 5G: Current Status and Future Perspectives

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ABSTRACT The quality of service (QoS) in public transportation is not at an acceptable level in high-mobility scenarios as penetration loss severely degrades signal quality and reduces the achievable data rate. Also, high mobility requirement is included in 5G as an essential part of its design. In this paper, a background of mobility management in high-speed scenarios and a review of underlay mobility management are presented. After a discussion of the usual high mobility challenges, major techniques for dealing with mobility management are reviewed, including architectural support, handover optimization, and employing new techniques like non-orthogonal multiple access (NOMA), and energy efficiency maximization. Also, challenges and prospective research directions for each technique are provided. The primary objective of this research study is to enhance knowledge of mobility management in high-speed vehicular scenarios, specifically by employing network architectural support in an upcoming heterogeneous mobile network. The primary objective of this research study is to enhance knowledge of mobility management in high-speed vehicular scenarios, specifically by employing network architectural support in an upcoming heterogeneous mobile network.

INDEX TERMS Non-orthogonal multiple access (NOMA), energy efficiency, high-speed railway, 5G, heterogeneous network, moving relay.

I. INTRODUCTION

The study of high mobility scenarios has attracted significant attention over the past few years because of the widespread deployment of high-speed railways, low-altitude flying objects, and highway vehicular communication [1], [2], [3], [4], [5], [6]. In 5G communication, high mobility is included as an integral part of it by International Mobile Telecommunications (IMT)-2020 (5G) Promotion Group [7], [8]. The 5G system is anticipated to deliver broadband services with a data rate of equal to or more than 150 Mbps to customers in vehicles traveling at a speed of 500 km/h [9]. Most wireless systems available today are built to handle users with moderate to medium mobility, and in the scenario of high mobility, performance is severely constrained by coverage area and transmission rate. The Global System for Mobile Communication-railway (GSM-R) is the most popular high-mobility wireless communication system. GSM-R supports a data rate of up to 200 kbps. Long Term Evolution advanced (LTE-A) systems of the 4G support functional services between 120 and 350 km/h but practically support data rates of the order of 2 to 4 Mbps for high-speed trains [10]. It is expected to provide data rates of the order of 100 of Mbps or higher in a high mobility scenario.

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Existing systems, which were designed for both low and high-mobility users, are unable to offer services to users with high mobility due to significantly reduced performance in high-speed scenarios. Therefore, it is essential to develop new technology and methods that can tackle the challenges and requirements of high mobility and support environments with high mobility.

The 5G network focuses on some specific areas including dense deployment of small cells, multiple-input multiple-output (MIMO) antenna technology, and modulation techniques in order to increase wireless zone capacity, save energy, and provide secure, dependable, and low latency connections [11], [12]. The key technique of 5G is small cells, which provide high-capacity wired links and smaller coverage regions, allowing for high-frequency reuse per unit area. Due to their lower coverage area, small cells present a major difficulty for mobile nodes, resulting in frequent handovers and connectivity failures [13], [14]. Therefore, such heterogeneous networks (HetNets), which are made up of small cells like pico and femto base stations, have the ability to expand system capacity and offer reliable high-rate communication services [15]. However, as users must transfer radio links between cells in 5G HetNet, mobility management is a significant challenge. There is a growing demand for mobile services in a variety of transportation systems, especially high-speed rail (HSR) systems [16]. The growing use of vehicular communication as a result of automated vehicles and safety-critical applications worsens the problem. Since existing wireless technologies are unable to match the low latency and time-critical requirements needed for vehicular applications, network service providers expect that the 5G standard would bring about considerable improvements. Nevertheless, 5G networks face difficulties in serving a large number of customers satisfactorily at 500 km/h. To guarantee the quality of service delivery and other application needs, these challenges involve physical, link/media access control., network, and application layer design [17]. Key technologies include advanced signal processing methods, a precise estimate of fast time-varying channels, efficient fast handover systems, and cloud radio access networks and mobile relays are thought to be crucial for meeting 5G high mobility system requirements [18]. These technologies can provide reliable communication and effective transportation while also helping to meet the needs of 5G high mobility systems.

A. RELATED WORKS AND PAPER CONTRIBUTION

Several studies have been presented for low, medium, and high mobility management of cellular users to investigate the challenges in vehicular and non-vehicular scenarios, see [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36]. For example, the study in [20] mainly focuses on handover parameter optimization. Likewise, the other study in [22] focuses on mobility management with handover optimization with millimeter-wave (mmWave) for 5G non-vehicular users. The study in [19] highlights the challenges of mobility management, which is mainly focused on traditional orthogonal multiple access techniques (OMA). The study in [23] is mainly focused on handover management and location management. The study in [21] highlights technical issues with mobility management, paying particular attention to the main goals of the released 3GPP Radio Access Network (RAN), and also performs a thorough analysis of the HetNets handover procedure. The study in [28] discussed the advanced handover techniques of the 5G network for mobility management and also focused on the optimization of Handover Control Parameters (HCP) to increase mobility performance. The study in [29] discussed the effect of handover on latency for Vehicle-to-Everything (V2X) communication in 5G and also highlighted the need for handover techniques better suited to the dynamic mobility of intelligent vehicles in diverse V2X scenarios. The study in [30] discussed the techniques for handover management in the 5G network and beyond and also highlighted the challenges. The study in [31] proposed the learning-based intelligent mobility management mechanism for mobility management in 5G and beyond with an intelligent adaptation of hysteresis and Time-to-Trigger values. The study in [32] discussed the Machine learning algorithms to optimize handover control parameters for mobility management in ultra-dense heterogeneous networks. The study in [33] discussed machine learning-based misbehavior detection systems (MDS) for 5G and beyond vehicular networks and analyzed MDSs from a security and machine learning perspective. The study in [34] discussed efficient radio resource management for 5G networks and analyzed the different radio resource management techniques based on interference management, user association-resource-power allocation, and joint approaches. The study in [35] discussed the technologies to support mmWave communications in mobile scenarios and also discussed the mobility impact on system performance. The study in [36] discussed the intelligent load balancing models in heterogeneous networks, which are based on machine learning techniques.

Therefore, the previously studied survey papers mainly focused on handover optimization techniques and radio resource management for mobility management. Existing studies have not categorized mobility management on the basis of architectural support, handover optimization techniques, energy efficiency maximization, and using new techniques such as Non-orthogonal multiple access techniques (NOMA). Also, mobility management with architectural supports and NOMA in heterogeneous networks is not discussed in detail. The comparison of this paper with other previous relevant papers is shown in Table 1.

B. CONTRIBUTION AND STRUCTURE OF PAPER

The following are the main contributions to this paper:

- This paper categorizes mobility management on the basis of energy efficiency, handover techniques, architectural support, and new techniques.

TABLE 1. Previous relevant papers based on techniques used for mobility management.

Ref.	Handover Technique	NOMA	Energy maximization	Moving Relay diversity
[19]	✓	✗	✗	✗
[20]	✓	✗	✓	✗
[22]	✓	✗	✗	✗
[23]	✓	✗	✗	✗
[28]	✓	✗	✗	✗
[29]	✓	✗	✗	✗
[30]	✓	✗	✗	✗
[31]	✓	✗	✗	✗
[32]	✓	✗	✗	✗
[33]	✓	✗	✗	✗
[34]	✓	✗	✗	✗
[35]	✓	✗	✗	✗
[36]	✓	✗	✗	✗
This paper	✓	✓	✓	✓

- Each of these types is discussed in detail to show the challenges, and the present research emphasizes these areas.
- Further, we also simulate and compare the existing mobility management techniques in heterogeneous networks to determine the challenges for the next generation of networks under high-speed scenarios.
- We also provide future research directions to cope with these challenges.

The rest of this paper is laid out as follows. Section II shows the 5G based heterogeneous mobile network. Section III describes the challenges and requirements of a highly mobile network. Section IV describes the promising techniques used for network architecture support. Section V describes the comparative studies on mobility management. Section VI represents the open research challenges and future directions. Section VII concludes the paper.

II. 5G BASED HETEROGENEOUS MOBILE NETWORK ARCHITECTURE

Conventional wireless network architecture supports low and medium mobility. High mobility imposes challenges that necessitate the development of new wireless network architectures, and these architectures should be developed to satisfy the requirements of high mobility scenarios. 5G network support new architectures like cloud radio access network (C-RAN) [37], Control/User (C/U) plane decoupling [38], mobile relays (MRs) [39], etc. These new architectures can be utilized to give coverage and QoS to high-mobility users.

A. GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS-RAILWAY ARCHITECTURE FOR HSR

GGSM-R is the most commonly used architecture for HSR [40], [41]. Its architecture is based on Global System for Mobile Communications (GSM) technologies. It is mainly designed for the control of railway operations, which includes voice and narrow-band data traffic. It performs reliably and effectively at speeds up to 500 km/h. GSM-R was broadly deployed in Asia, South Africa, and Europe for HSR. To get linear coverage, GSM-R base transceiver stations (BTSs) were deployed. Link management and mobility management were done by the base station controller (BSC) and the mobile switching centre (MSC), respectively. GSM-R is a reliable architecture for narrowband control applications only. The demand for broadband services on onboard trains is increasing continuously. Therefore, new architectural designs are required to offer the broadband services to vehicular users. LTE is the evolution of GSM-R architecture [42], [43], [44]. It was developed for the railway system to provide broadband communication based on all-IP to both train users and railway operators [45]. The performance of HSR communication can be enhanced by the deployment of base stations (BSs) along railway tracks [46], by optimization of services in aspects of fairness of the utilization and efficiency of BSs, and also by optimizing the transmission power of BS.

B. TWO HOP ARCHITECTURE USING MOVING RELAYS

In Release 11 of the Long Term Evolution (LTE) standard, MRs were first introduced by 3GPP technical report (TR) 36.836 [47]. One of the enhancement techniques introduced in LTE-A is multihop relay, which increases the performance of LTE by the enhancement of capacity and expansion of coverage [48]. Two hop architecture of HSR is shown in Fig. 2. In HSR, it was discovered that when an MR is put on top of a train, the vehicle penetration loss (VPL) effect is eliminated due to the presence of two antennas, one on the inside of the train and the other on the outside, that are connected by a fiber cable with no loss and are powered either internally or externally [49], [50], [51]. This arrangement creates two types of links, named access link and backhaul link. Backhaul links are those that connect BS and the relay, and access links are those that connect the relay and the user. Recent studies have shown that MR can help with the handover issue because, in this situation, the handover takes place between the BS and the MR instead of between the users and the BS, which enhances the performance of the handover as a whole. An access link has a small transmission distance and it is referred to as a stationary link. Therefore, it supports high data rates without encountering any difficulties with high mobility. The bottleneck of the two-hop relaying system is the backhaul link [52]. VPL was removed because the MRs were deployed on the roof of the train. Additionally, since the BSs and MRs typically have line-of-sight, the system's spectrum efficiency may be increased as a result. Deploying MRs on the top of the train can also resolve the problem of group handover due to the fact that the MRs and BS perform the handover. This could enhance the performance of the overall handover. In order to achieve the demands of high data rates and reliable transmission while maintaining the acceptable QoS, a multi-hop scenario has been studied in the past [53]. Multihop relay is an inexpensive low-cost technique. It reduces the transmission range and increases the number of users to achieve a higher throughput and better QoS [54].

C. DECOUPLING OF CONTROL PLANE/USER PLANE

The future trend of logical network architecture is to decouple the control plane (C-plane) and user plane (U-plane). The C-plane is used to provide the control information, whereas the U-plane provides the user information. The C-plane contains control data for both train operations and communications in HSR. In a standard network architecture, data is frequently sent over the same physical channel in both the C-plane and the U-plane. The user data required to provide broadband communications are often transmitted using higher frequencies with wider bandwidth. But at higher frequencies, high propagation loss occurs. In addition, VPL and frequent handovers in HetNet due to different network elements affect the information of C-Plane. In 5G communication, to address these issues, a new architecture based on C/U-plane decoupling has been proposed in the past [55], [56], [57], [58], [59]. The lower frequency band of this new architecture is allotted to the C-plane in macrocells and the higher frequency band is allotted to small cells to achieve broader bandwidth.

D. CLOUD RADIO ACCESS NETWORK ARCHITECTURE FOR HSR

By joining multiple Radio Remote Units (RRUs) to a single baseband unit (BBU), the coverage of a cell can be increased. This arrangement is shown in Fig. 3, where multiple RRUs are deployed and connected by a single BBU along the railway track [60]. This architecture reduces the handover time and handover failure of end-users, i.e., train users. Since the multiple RRUs belong to a single BBU, handover within the RRU is not required and results in a reduction in call drops. An overlapped area between two adjacent cells is typically planned for obtaining a reliable handover. In overlapped regions, MR assesses the signal strength of nearby cells and send it to the serving cell after processing. So, it is important to set a suitable overlapping coverage area for fast-moving vehicles with MR to have sufficient time for measuring and reporting. Additionally, frequency reuse and spatial diversity among RRUs are enabled by the distributed antenna systems (DAS) structure proposed in [61] and distributed RRU, which can further increase system capacity per area. The area spectral efficiency of the overall system can be considerably increased by spatially distributed RRUs reusing the same spectrum while maintaining low co-channel interference among themselves. RRU selection and activation, in which only a specific subset of RRUs remain in active mode at a particular moment while all other RRUs stay in a sleeping mode to conserve power, can provide the spatial diversity of DAS systems or C-RAN [62]. A combined RRU activation and beamforming approach for C-RAN is suggested in [63] and [64], and the findings demonstrate that systems with sparse RRU activation provide considerable performance improvements over systems with all active RRUs.

E. MULTI-ANTENNA FOR RAILWAY AND HIGHWAY NETWORK

MIMO technology can improve the performance of system by boosting the energy efficiency and spectrum efficiency in high mobility scenarios [65]. Two types of antennas are deployed in HSR. (i) Ground BS antenna: Massive MIMO using centralized antenna systems (CAS) is used to increase cell coverage and offer considerable beamforming gain [66], [67]. While DAS and radio over fiber (RoF) technologies are particularly useful for high-speed communication [68], [69] because they can improve service coverage and reduce handover failure. (ii) Antenna Deployment on Train: In order to improve capacity and transmission reliability for HSR communications, spatial diversity using multiple antennas can be used [70], [71]. A train is about 200 meters long, so if the rail company permits it, there is enough space to deploy many antennas in a linear array. Massive MIMO is used in high-speed scenarios, which might alter its multiplexing gain and diversity gain. For instance, the signal to noise ratio (SNR) of mobile users will increase when they move closer to a BS equipped with multiple antennas. In this situation, multiplexing gains get increased while diversity gains get decreased, which increases throughput. In contrast, when mobile users travel away from a BS equipped with massive antennas, the multiplexing gains can be reduced. This may result in an increase in diversity gains, which results in better QoS and reliable transmission.

III. CHALLENGES AND REQUIREMENTS OF HIGHLY MOBILE NETWORK

Modeling, designing, analyzing, and evaluating the future generation wireless network is made difficult by the high mobility of wireless devices. However, high mobility offers various opportunities that can be taken advantage of to improve system designs and enhance system efficiency. The key challenges in designing communication systems with high mobility as depicted in Fig.1 are listed below, along with several opportunities which can improve system designs.

A. HIGH VEHICLE PENETRATION LOSS

In vehicular communication, a well-shielded vehicle's body produces a severe loss in signal strength due to VPL. The body of the vehicle is made of some special alloys and the base station's signal is unable to penetrate it [72], [73], [74]. In the case of a train carriage, this VPL may range from 20 dB to 35 dB [6], [18]. This large VPL degrades the SNR at both the mobile station and the base station [75]. So, reliable broadband communication is difficult to achieve in HSR. So, the effect of VPL needs to be eliminated for vehicular communication to avoid the outage of vehicular users.

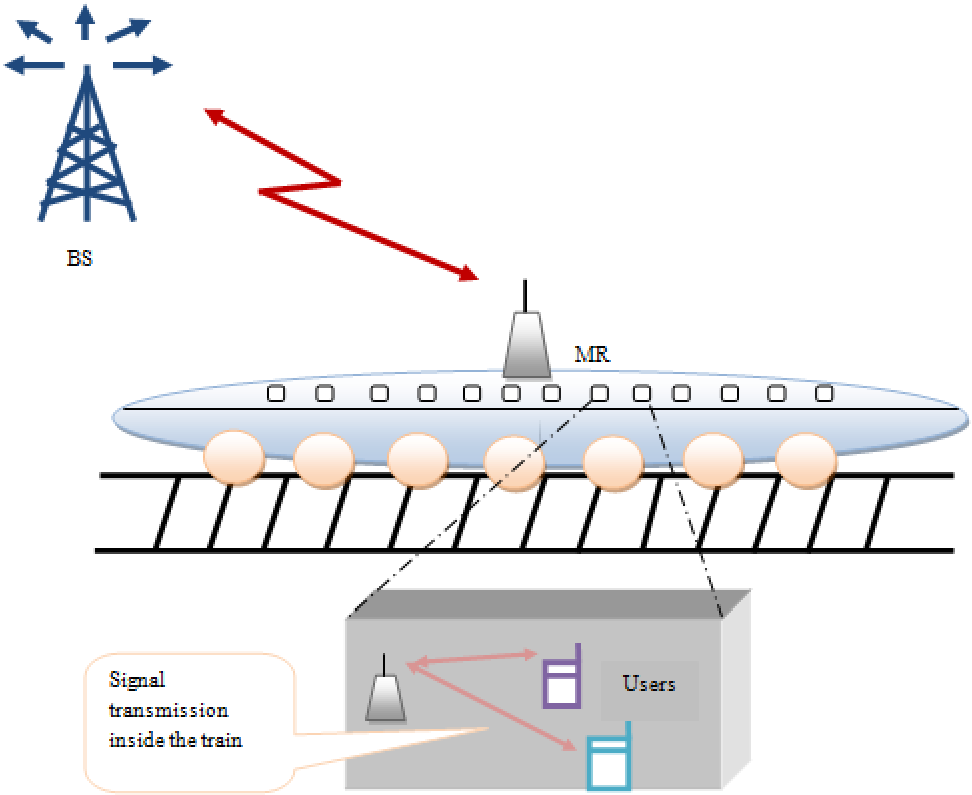

FIGURE 1. Two hop Architecture for HSR.

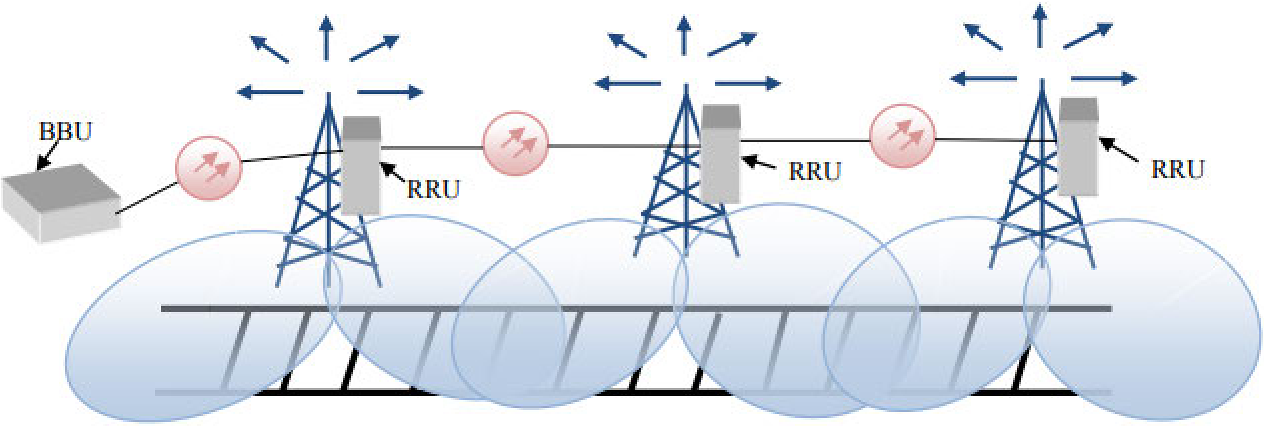

FIGURE 2. C-RAN Architecture for HSR.

B. OCCURRENCE OF FREQUENT AND QUICK HANDOVER

In a high mobility scenario, a mobile station (MS) travels across the coverage region of different BSs in a short period of time and signals fluctuate very fast at both the MS and BS end. So, during this movement, MS maintains the connection with BS through a handover process. This handover occurs very frequently [47], [76], [77], [78]. If handover is not performed within this small duration of time, handover failure occurs, which degrades the performance of the system and may lead to an outage. So, an effective algorithm or technique that performs handover in this short duration of time is required. Also, group handover is another big challenge in the case of vehicular communication, in which a number of vehicular users perform handover at the same time and generate the signaling problem.

C. DEPLOYMENT OF DIFFERENT NETWORK ARCHITECTURE

In a fast-moving scenario, MS goes through various topological variations due to the deployment of different architectures.

A new architecture may be adopted or developed that fulfills the need for high-speed communication. 5G networks support heterogeneous networks, control-plane and user-plane (C/U-plane) decoupling, MR, etc., [19], [79], [80] which may be used to offer better services to high-speed users.

D. CARRIER FREQUENCY OFFSET

Carrier frequency offset (CFO) is defined as a mismatch between the oscillator frequencies of the Tx and Rx and it occurs due to the Doppler shift. CFO may also occur in systems without Doppler shifts due to the unstable oscillators at transceivers. Inter-carrier interference (ICI) is caused by CFO, which eliminates the subcarriers' orthogonality in orthogonal frequency division multiple access (OFDM) based systems and it also significantly reduces the performance of system [81], [82]. In a high mobility scenario, CFO varies with time as changes in Doppler shift with time. Therefore, it challenging to monitor and correct the CFO [83].

E. INTERCARRIER INTERFERENCE

In a high mobility OFDM system, ICI is caused by doubly selective fading and CFO [84], [85], [86] which includes both frequency selective fading and frequency time selective fading. When channels change within a single OFDM signal due to doubly selective fading, the subcarrier's orthogonality is destroyed, and ICI results. Doppler spread has a direct impact on the ICI in systems that observe doubly-selective fading and it is used to obtain the Doppler diversity [84]. Therefore, the high mobility system should be designed such that it can achieve the advantages of both Doppler diversity and remove the harmful effects of ICI.

F. FAST TIME-VARYING FADING CHANNEL

Fast time-varying channel is one of the most identifying characteristics of high mobility conditions [87], [88], [89]. It occurs due to a large Doppler spread. Non-stationary fading coefficients and time-varying Doppler spread occur due to changes in the speed of the wireless terminal with time. Accurate channel modeling and channel analysis are challenging tasks in high mobility because of the non-stationary features of fading channels and dynamically varying scattering surroundings.

G. CHANNEL ESTIMATION ERRORS

Fast time-varying fading channel is one of the most significant factors of high mobility systems. It occurs due to a large Doppler spread. So, channel estimation, tracking, and prediction are difficult tasks [90]. These impact the performance of the system and system design with knowledge of perfect channel estimation information (CSI) is not valid in high-speed scenario [91]. So, it is required to develop the system for high mobility which does not need perfect CSI knowledge.

H. DOPPLER DIVERSITY

Fast time-varying fading, however, can make the system's performance worse. Doppler diversity occurs due to the short coherence time and rapid fluctuation of the fading channels. This could be utilized to raise the system's performance. Most studies of Doppler diversity with perfect CSI have been done yet but channel estimation error cannot be neglected in high-speed scenarios [92], [93]. Channel estimation error may affect the orders of Doppler diversity. The order of Doppler diversity depends upon Doppler spread and it increases with a higher value of Doppler spread but it leads to an increase in channel estimation mean squared error [94], [95], [96]. So, it is required to design the system with optimum Doppler diversity in the channel condition with imperfect CSI.

I. HETEROGENEOUS NETWORK

The 5G networks is going to be deployed because of increasing demands of high data rate and high QoS. 5G networks will have to integrate with other coexisting wireless networks like Wi-Fi, Wi-Max, GSM, Code-Division Multiple Access (CDMA), Wideband Code-Division Multiple Access (WCDMA), LTE, Universal mobile telecommunication system (UMTS), etc. 5G network will also support the ultra-cell-densification or deployment of low-power nodes (LPNs) e.g., picocells, microcells, and femtocells. These LPNs will be used to (i) improve the service quality, (ii) provide high capacity (iii) fill the coverage gaps of macrocell, and (iv) offload the user from large macrocell [20]. So such a type of heterogeneous wireless radio network (HetNet) consists of several types of radio cells and several radio access technologies, e.g., 3G, LTE. In this HetNet overlapping of coverage area will occur as LPNs having small coverage area will be deployed inside the global coverage area (macrocells). This overlapping will increase the interference and movement of users in such HetNet will result in increase in handover rate and signaling overhead [21], [72]. Due to this reduction in throughput of user and the quality of experience will occur. As per requirement, LPNs can also be made ON and OFF to save energy in a coordinated way which can result in (i) a Change in channel condition (ii) An Increase in interference (iii) a Handover rate increase due to small coverage (iv) Unnecessary Ping Pong (v) Increase in handover failures (vi) Decrease in quality of experience of the user (vii) High-energy consumption.

IV. PROMISING TECHNIQUES USED FOR NETWORK ARCHITECTURE SUPPORT

This is explained in the following two sub-sections:

A. RELAY

Relay is usually used to connect the BS to mobile equipment wirelessly. After processing the received signal relay forwards it to the destination to low coverage region within a cell for both downlink and uplink communication. The

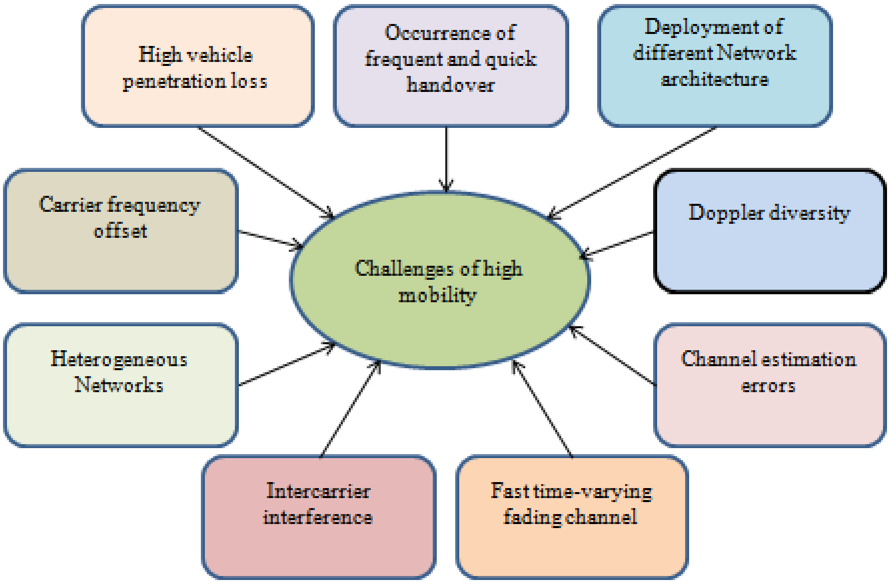

FIGURE 3. **Challenges and Requirements of High mobility.**

relay node (RN) can be placed at the cell edge or in another region with little covering. In multihop relay, the signal travels from BS to RN and then to MS for downlink communication, while the signal travels from MS to RN and then to BS for uplink communication. An increasing number of users are serviced via the link between the RN and the BS [97]. By splitting the path loss between the sender and the receiver into two parts, the RN aids in resisting propagation loss as a result, the path loss in the sum of the two parts is lower than the entire path. This aspect of the relay technique, also known as path loss gain, decreases the effect of path loss. Theoretically, propagation distance and signal-to-interference plus noise ratio (SINR) are inversely related i.e. d^{-n}. Where d represents the propagation distance n represents the path loss exponent, and the value of 'n' lies between 2 to 6 as per propagation environment [98].

The installation of relay nodes within an LTE network has several benefits that have encouraged researchers to adopt the relaying approach. Table 2 lists the key advantages and disadvantages of using a relay in a cellular network

TABLE 2. **Advantages and disadvantages of relay.**

Advantages
Coverage Extension: • Signal propagation loss impacts coverage especially, for a user at the cell edge [101]. • A relay can successfully increase the coverage by amplifying the signal.
Quality of Service: • Through cooperative diversity, the relay can successfully improve transmission robustness by ensuring transmission between the base station and users and eliminating the effects of channel fading [103].
Capacity Enhancements: • By separating the path loss into two or more hops using a relay, it is possible to achieve significant performance benefits for cellular networks with large coverage areas. • These improvements provide an increase in transmission rate and capacity [104], [105].
Disadvantages
Increased Interference: • The usage of relays results in more intercell and intracell interference, which could result in a reduction in the performance of the system [102].
Network Complexity: • In comparison to single hop, relays complicate the network in terms of resource allocation, handover, and overlapping for peer-to-peer communication.

Vehicles might be equipped with a different type of relay known as a moving relay [82]. In both metropolitan regions with heavy building shadowing effects and rural areas with weak BS signals, particularly near the cell edges, MR increases throughput for users [99], [100]. The drawback of MR is that amplification keeps going even when users are receiving strong signals from BS.

Relays Classification Relays can be categorized based on their functionality and the signal processing methods used which are defined as:

1) AMPLIFY-AND-FORWARD RELAY

Amplify-and-Forward Relay: Amplify-and-Forward (AF) relay amplifies the signal that has been received from the source and re-transmit to destination [106], [107]. In addition to amplifying the desired signal, the AF relay also amplifies noise and interference [108], which lowers the value of SINR and reduces system throughput. The following model is applicable to AF relay channel. The signal received at relay (Y_s^r) is defined as [109]

$$Y_s^r = \sqrt{P_s} h_s^r x + n_s^r \tag{1}$$

where h_s^r is the fading channel coefficient between the source. P_s denotes the power transmitted by the source and x denotes the signal transmitted by the source. n_s^r represents the Additive white Gaussian noise (AWGN) between source and relay with zero mean and N_0 variance. The signal received at destination (Y_s^d) is defined as

$$Y_s^d = \sqrt{P_s} h_s^d x + n_s^d \tag{2}$$

where h_s^d represents the fading channel coefficient between the source and the destination. n_s^d represents the AWGN between source and destination with zero mean and N_0 variance. The relay amplifies the received signal and forwards it to the destination by minimizing the impact of fading produced between the source and relay channel. The relay performs the scaling of the signal received from the source by a factor β_r known as relay gain, which depends on the received power, denoted by [119]

$$\beta_r = \sqrt{\frac{P_r}{|h_s^r|^2 P_s + N_0}} \tag{3}$$

where P_r denotes the power transmitted by the relay. So, the transmitted signal by relay (Y_r^r) can be given as

$$Y_r^r = \beta_r Y_r^r \tag{4}$$

Now, the signal received at the destination (Y_r^d) is provided by

$$Y_r^d = Y_r^r h_r^d + n_r^d \tag{5}$$

where, h_r^d represents the fading channel coefficient between the relay and the destination. n_r^d represents the AWGN between the relay and destination with zero mean and N_0 variance After replacing Y_r^r from Eq. (5), we get

$$Y_r^d = \beta_r Y_s^r h_r^d + n_r^d \tag{6}$$

After substituting Y_s^r from Eq.(2), we get

$$Y_r^d = \beta_r (\sqrt{P_s} h_s^r x + n_s^r) h_r^d + n_r^d \tag{7}$$

2) DECODE-AND-FORWARD RELAY

A decode-and-forward (DF) relay decodes the signal it has received from the source in the first stage and forwards the received signal to the destination after encoding or without encoding in the second stage [110]. So, the signal received at the destination is given as,

$$Y_r^d = Y_s^r h_r^d + n_r^d \tag{8}$$

B. NON-ORTHOGONAL MULTIPLE ACCESS (NOMA)

NOMA, a unique and promising multiple-access technique for LTE upgrades and 5G systems has gained a lot of interest recently [111], [112]. In order to increase spectrum efficiency, NOMA incorporates power-domain user multiplexing. In the NOMA technique, many users are paired and share the same radio resources, whether in terms of time, frequency, or coding. NOMA applies non-orthogonal user multiplexing, which uses superposition coding at the transmitter (Tx) and successive interference cancellation (SIC) at the receiver (Rx), and it performs better than orthogonal multiplexing from an information-theoretic perspective. In general, NOMA techniques can be divided into two types: code-domain NOMA and power-domain NOMA [113]. Code-domain NOMA is identical to CDMA. It uses complete time and frequency slots. It is also capable of providing significant shaping gain and spreading gain with enhanced signal bandwidth. In code-domain NOMA, multiplexing is achieved in the code domain. In power-domain NOMA, to achieve maximum gain, a separate power level is assigned to different users according to their channel status information, and SIC is used to minimize multi-user interference [114]. In power-domain NOMA, multiplexing is achieved in the power-domain.

1) DOWNLINK NOMA

Fig. 5 depicts the NOMA system for the downlink scenario with the single macrocell BS and two users. In this case, BS transmits signal mi with power P_i (i = 1, 2) to i^{th} user with condition $E[|m_i|^2] = 1$ and $\sum P_i = P$, where P represents the total power transmitted by BS and mi is the massage transmitted to i^{th} user. The superimposed signal for downlink transmission is defined as,

$$m = \sqrt{P_1} m_1 + \sqrt{P_2} m_2 \tag{9}$$

The received signal by i_{th} user is defined as,

$$Y_b^i = m h_b^i + n_b^i \tag{10}$$

h_b^i is the fading channel coefficient between the BS and the i^th user. n_b^i $(0, N_0)$ represents the AWGN. In downlink NOMA, both users received the superimposed signal transmitted by BS. The user equipment (UE) side must therefore perform multiuser signal detection, i.e. SIC, in order for each user to be able to get its data and decode its own data [115], [116], [117]. Decoding is performed in the highest to the lowest order of channel conditions normalized by intercell interference power and noise $(|h_b^i|^2/N_0)$ for SIC. Therefore, if $(|h_b^i|^2/N_0) > (|h_b^j|^2/N_0)$, SIC is performed on i^{th} user to reject the inter-user interference of j^{th} user. In two user scenario, and supposing that $(|h_b^1|^2/N_0) > ((|h_b^2|^2)/N_0)$, user-2 does not conduct SIC because user-2 occurs first in the decoding sequence. User-1 decodes m_2 first and removes its component from the incoming signal Y_b^1 before decoding m_1 independently of m_2. After successful decoding, the SNR of user-1 (γ_1) can be defined as

$$\gamma_1 = \frac{P_1 |h_b^1|^2}{N_0} \tag{11}$$

Also, the SINR of user-2 (γ_2) can be defined as

$$\gamma_2 = \frac{P_2 |h_b^2|^2}{P_1 |h_b^1|^2 + N_0} \tag{12}$$

So, BS can control each UE's SNR so that the signal assigned to each UE can be decoded at its associated receiver by modifying the power allocation ratio, P_1/P_2. Additionally, since the channel gain of cell-centre user (near-user) is higher

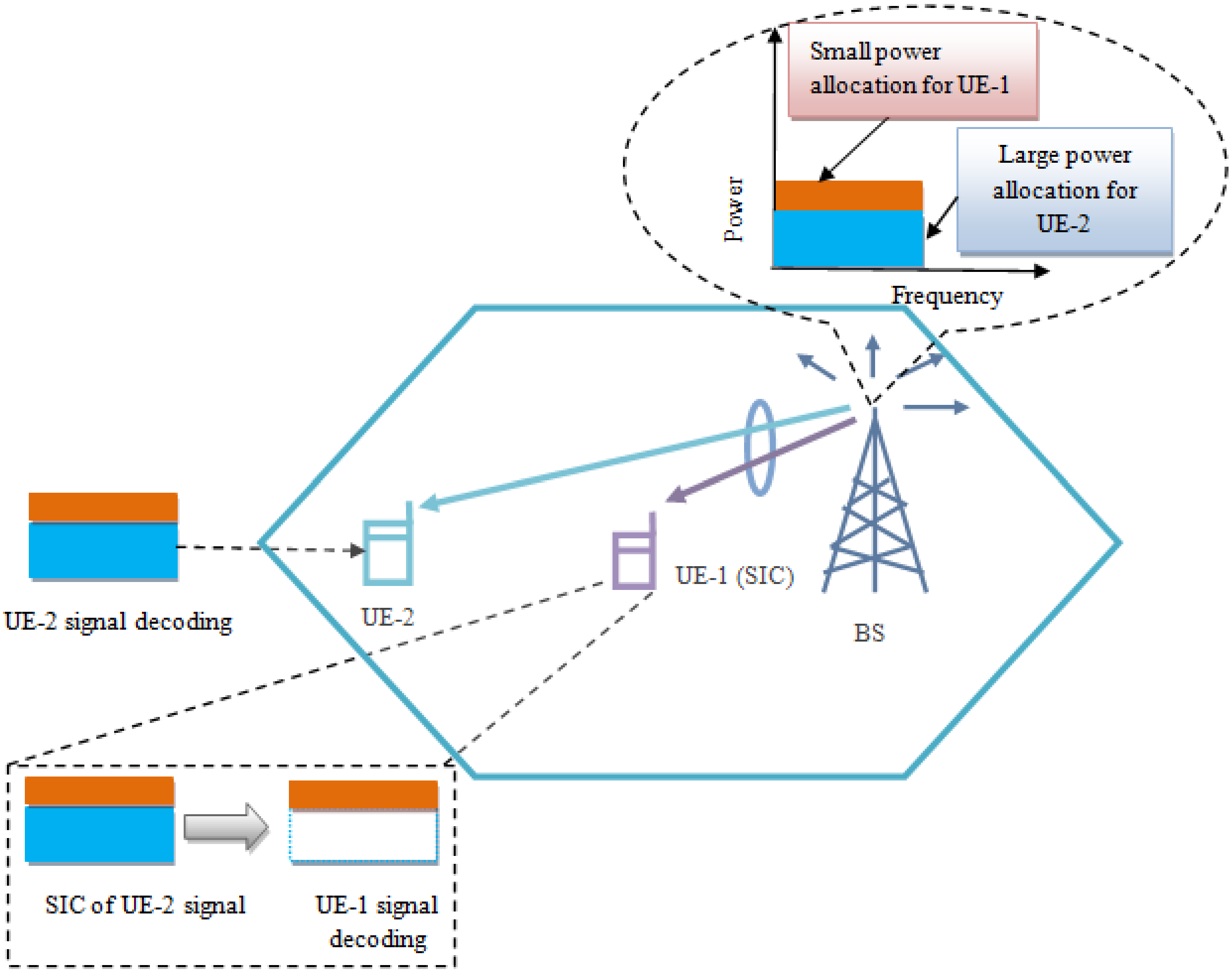

FIGURE 4. Downlink communication of NOMA system.

than that of a Cell edge user (CEU) (far-user), decoding of the CEU at the receiver of a cell-center user has a high chance of success as long as it is feasible at the Rx of CEU.

2) UPLINK NOMA

Fig. 5 depicts the uplink communication of NOMA system. Similar to downlink NOMA scenario, consider a single BS and two users. In this case, i_{th} user transmits signal m_i (i = 1,2) with power P_i to BS with condition $E[|m_i|^2] = 1$. The signal received by BS is the superimposed signal of m_1 and m_2 and it can be defined as,

$$Y = h_b^1\sqrt{P_1}m_1 + \sqrt{P_2}|h_b^2 m_2 + n_b \tag{13}$$

h_b^i is the fading channel coefficient between the BS and the, ith user. n_b represents the AWGN having zero mean and N0 variance. Now, assume user-1 and and user-2 are the cell-center user and CEU respectively, i.e., $(|h_b^1|^2)/N_0) > (|h_b^2|^2)/N_0)$, BS performs SIC in the descending sequence of channel gain. The SNR of user-1 (γ_1) can be defined as

$$\gamma_2 = \frac{P_1|h_b^1|^2}{P_2|h_b^2|^2 + N_0} \tag{14}$$

Also, the SINR of user-2 ($\gamma 2$) can be defined as

$$\gamma_2 = \frac{P_2|h_b^2|^2}{N_0} \tag{15}$$

BS performs SIC in the ascending sequence of channel gain. The SNR of user-1 (γ_1) can be defined as

$$\gamma_1 = \frac{P_1|h_b^1|^2}{N_0} \tag{16}$$

Also, the SINR of user-2 (γ_2) can be defined as

$$\gamma_2 = \frac{P_2|h_b^2|^2}{P_1|h_b^1|^2 + N_0} \tag{17}$$

It's worth noting that irrespective of whether the SIC order is descending or ascending order of channel gain, the overall

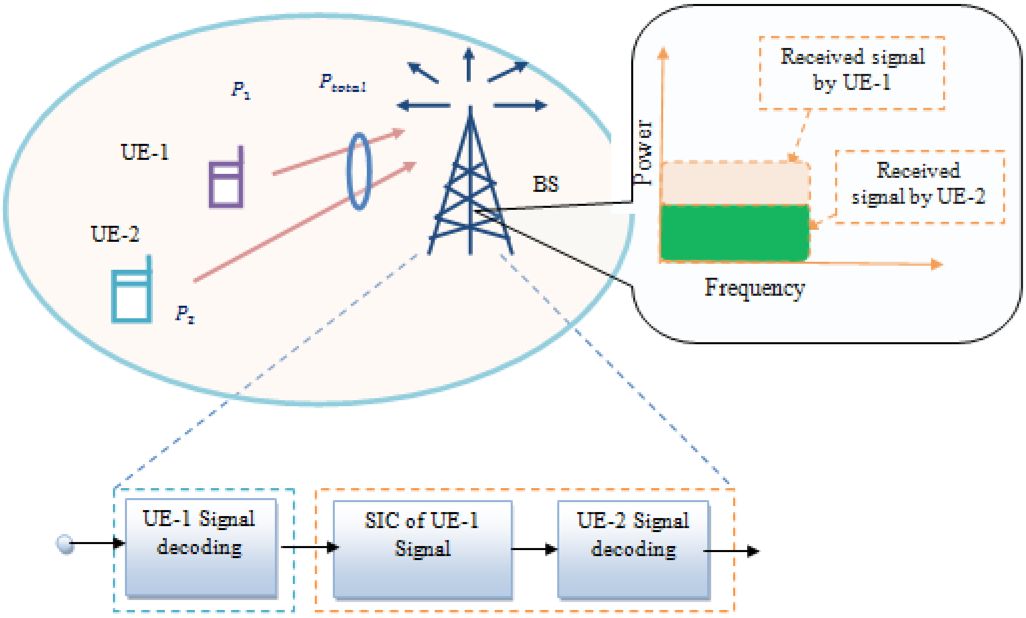

FIGURE 5. Uplink communication of NOMA system.

UE throughput is the same

$$R_1 + R_2 = \log_2\left(1 + \frac{P_1|h_b^1|^2 + P_2|h_b^2|^2}{N_0}\right) \tag{18}$$

where R_i represents the throughput of i_{th} user. The total UE throughput of various SIC orders is the same. This only applies under the assumption of error-free propagation. The ideal SIC order is the decreasing order of channel gains.

V. COMPARATIVE STUDIES ON MOBILITY MANAGEMENT

Mobility management in HetNet has attracted a great deal of attention from researchers in recent years due to the high demand for data and QoS for vehicular users. VPL, frequent handover, and higher battery consumption are the major problems in high-speed vehicular communication and need to be minimized it. A study of various research articles on each key technique has been performed and a list of some important articles is tabulated in the following subsections.

A. MOBILITY MANAGEMENT USING ARCHITECTURAL SUPPORT

In the 3GPP technical report, a number of solutions for vehicular users have been provided to achieve high QoS in high-speed scenarios which include deployment of dedicated BSs, Layer 1 repeaters, and LTE backhaul plus on-board Wi-Fi access. Initially, dedicated BSs with directive antennas were deployed along the well-known route of vehicle especially on the route of HSR to provide coverage along the track. These dedicated BSs directly served the vehicular users. But these deployments cannot eliminate the effect of VPL which is the major challenge of vehicular communication. Additionally, it is difficult to apply this solution in urban environments [118]. Deployment of layer-1 repeaters on vehicles can eliminate the effect of VPL, reduce the transmission power requirements of user's, and increase the battery life. But, in addition to amplifying the desired signal, it also amplifies the unwanted interference. Also, it is difficult to achieve seamless connectivity with Wi-Fi due to the requirement of the same central unit to control all the access points and security Wi-Fi network. To overcome the above limitations, 3GPP has proposed the moving relay which was mainly focused on the high-speed train. Moving relay is a promising technique for HSR and it can also improve the QoS of onboard users in other vehicles such as buses, and cars. Relays can be divided into two categories according to the mobility behavior of the relay node, which are fixed and moving relays. Before moving the relay, a fixed relay was proposed and investigated to improve the coverage and capacity of wireless networks. Several studies have been performed on fixed relays, but they cannot be deployed directly into the moving relay scenario as fixed relays do not eliminate the effect of VPL and support group mobility. The performance of half duplex (HD) MR in HetNet using selection combining relay diversity was analyzed for downlink communication [95] and shown to have a better coverage probability than a single HD- MR model-based HetNet system in a high-speed vehicular scenario [109]. Fig. 6 shows the comparison of the outage probability of the without HD-MR, one HD-MR, and two HD-MR models with selection combining relay diversity in HetNet with respect to SIR threshold for cell-edge-user. It is observed that two HD-MR model has 33% less outage probability than one HD-MR model at the 5 dB threshold.

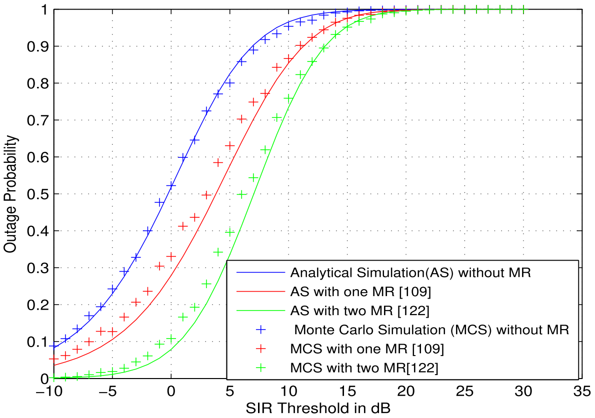

FIGURE 6. Outage probability vs SIR threshold for downlink communication.

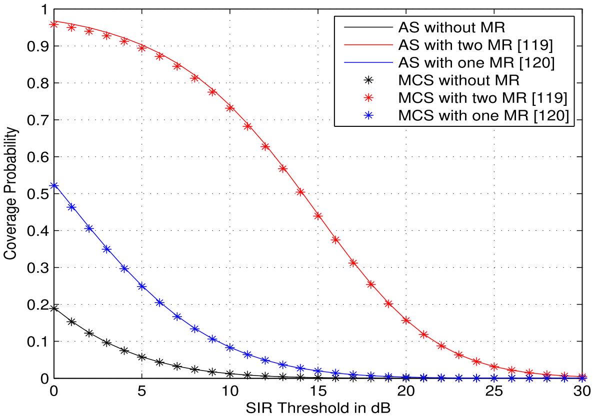

FIGURE 7. Coverage probability vs SIR threshold for uplink communication.

The performance of two HD-MR in HetNet using equal gain combining relay diversity for uplink communication was studied [119], and it was shown that it has a lower outage probability than a single HD-MR model [120]. Fig. 7 shows the comparison of the coverage probability of the without HD-MR, one HD-MR, and two HD-MR model with equal gain combining relay diversity in HetNet with respect to the SIR threshold for cell-edge-user for uplink communication. It is observed that two HD-MR model have more than three times the coverage probability of one HD-MR model at a 5 dB threshold for uplink communication.

The performance of one MR with full duplex (FD) relay in HetNet was analyzed [121] for downlink communication and shown that it has better coverage performance than one MR with HD relay model in HetNet [109] for downlink communication at given residual self-interference (RSI). Fig. 8 shows the comparison of the outage probability of the HD-MR and FD-MR model with respect to the SIR threshold for cell-edge-user for downlink communication. It is observed that one FD-MR model has 31% less outage probability than one HD-MR model at a 5 dB threshold. Some of the relevant research articles on moving relays are summarized in Table 3.

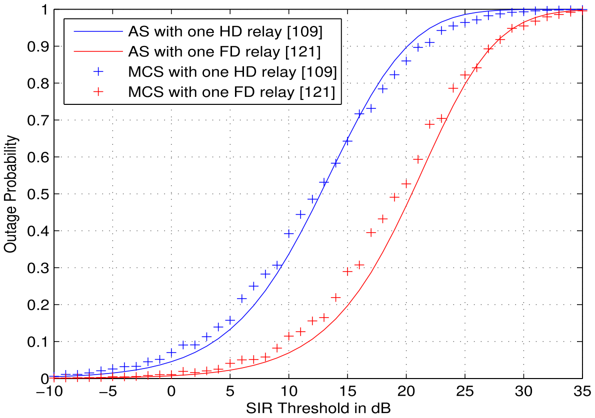

FIGURE 8. Outage probability vs SIR threshold at 3dB RSI.

B. MOBILITY MANAGEMENT USING HANDOVER OPTIMIZATION TECHNIQUE

In order to achieve seamless connectivity and quality of service in high-speed scenarios when switching between several base stations, handover optimization techniques are crucial. Handover optimization techniques are developed to reduce the HOF by minimizing latency, reducing packet loss, and ensuring a seamless user experience. To ensure successful handovers and reliable connectivity, handover strategies combine signal analysis, predictive modeling, and dynamic parameter adjustment. The various types of research done to avoid the HOF are listed in Table 4.

C. MOBILITY MANAGEMENT EMPLOYING NEW TECHNIQUE

Mobility management is undoubtedly an important aspect of wireless communication, and new techniques are always needed to enhance the effectiveness, reliability, and user experience when switching between various network cells. In literature, various techniques such as NOMA, MIMO, mm-wave, small cells, etc. are used to increase the coverage, throughput, QoS, and reduce the HOFs for vehicular users. Most of the researches are based on the performance enhancement of vehicular users. There are very less number of research are available for non-vehicular users. NOMA and cooperative communication support one another, and using them jointly enhances the performance of cooperative networks [136], [137], [138], [139]. The outage performance of the NOMA system with one HD-MR in HetNet for downlink communication is analyzed [140] and shown it is lower than the OMA based system in HetNet with one MR [109]. Fig. 9 shows the comparison of the coverage probability of the one HD-MR based NOMA system with the one HD-MR based OMA system with respect to the SIR threshold for cell-edge-user for downlink communication. It is observed that one HD-MR model with NOMA system has 110% more coverage probability than one HD-MR model with OMA system at 5 dB threshold and having a power allocation coefficient of 0.9 for the far users. Some of the

TABLE 3. Comparison of literature based on architectural support.

References	Objective/ Identified work	Proposed work/Algorithm	Performance achieved / Re- search Outcome
Khan and Jamalipour [109]	To improve the weak signal strength and reduce the VPL in HSR for downlink communication.	Proposed the system model for downlink communication in HetNet with a relay deployed on the roof of the train	Coverage Probability of train user and CEU got enhanced
Khan et al. [122]	To improve the coverage and capacity of macrocell user.	Proposed the system model for downlink communication in HetNet with two relay deployed on the roof of the train	Coverage Probability of train user and CEU got enhanced. An increase in per-user capacity is also observed.
Khan et al. [121]	To improve the coverage probability and decrease the outage capacity of macro-cell users.	Proposed the system model for downlink communication in HetNet with one Full duplex amplify forward relay deployed on the roof of the train	Coverage Probability of train user and CEU got enhanced in comparison with half duplex relay at low value of residual self-interference.
Khan and Jamalipour [120]	To improve signal strength and reduce the VPL in HSR for uplink communication	Proposed a system model for uplink communication in Het- Net with an MR deployed on the roof of the train.	Reduction in the outage probability of train users as well as non-vehicular users
Munjal and Singh [119]	To reduce the outage probability of CEU using MRs in high-speed HetNet for uplink communication	Proposed system model for uplink communication using two MRs	Outage and handover (HO) probability got reduced
Sui et al. [99]	To increase the coverage, capacity, and reliability of vehicular users	Consider the dual-hop system where signal transmission takes place through a HD-AF protocol-based relay node	MR-supported communication performs noticeably better than fixed relay (FR) supported communication and direct communication when the MS is moving away from the BS.
Sui et al. [123]	To improve the energy efficiency for vehicular communication at the same time also maintaining the required QoS.	Proposed a system model using fixed and moving relay and analyzed the outage probability and energy efficiency	While reducing average transmission power, MR can still maintain the acceptable minimum QoS level.
Liu and Fan [124]	Frequent HOs occur in HSR, which results in handover failure (HOF) and low quality of experience (QoE)	Used DAS and MR-supported two-link architecture and proposed the optimum power allocation scheme	Rate of HO, HOFs and Probability of link outage got decreased
Roh and Paulraj [125]	Frequent HOs in HSR results in HOFs and low QoS	Proposed generalized DAS and compare with optimum combing technique.	Although DAS may be a better option for outage performance, micro-optimum combining should be used to enhance bit-error-rate performance.
Li et al. [126]	Doppler spread, HOFs, and sudden changes in radio conditions decrease the QoS of the HSR system.	MR is used to analyze these issues for LTE systems	MR provides performance gains by decreasing radio link failures and improving the QoS and QoE of the system.
Oliva and Alonso [75]	HSR suffers from large signal attenuation and Doppler spread in LTE-A situations.	A relay architecture using two-hop relaying is studied by using both MR and mmWave	With respect to a MIMO direct channel, a high throughput gain is achieved by the proposed system model.
Zhang et al. [127]	To provide reliable and high data rates to train users	Proposed the two-hop transmission model with access point on the top of the train's carriage and examined the deployment of BSs along the line, arc, and unusual curve rails	Showed that the BS spacing remains fixed irrespective of the train's speed and total service provided by the BS depends upon the speed of the train.
Ishii et al. [55]	To increase the data rates of CEU and capacity by considering the mobility requirement	Proposed the novel architecture in which C/U plan decoupling with Phantom cells were used with small cells for LTE network	Obtaining the enhancement in user data rate and showed that the conventional HO schemes are not fit for small cells
Yan and Fang [56]	To increase the security and reliability of train control information for HSR communication	A new architecture is proposed that uses the decoupling of U-plane / C-plane and wide spectrum with high frequency.	Enhancement in capacity and security of train control system is achieved with the proposed architecture.
Yan and Fang [57]	To ensure the reliable transmission in HSR wireless communication	C/U-plane decoupling architecture of 5G network in used for HSR communication and pro- posed the unreliability factor for the transmission reliability of decoupling architecture.	Unreliability factor gives optimal transmission reliability of de-coupling C/U-plane design.
Liu et al. [60]	To satisfy the future networks' capacity needs in a way that is both affordable and power-efficient.	Presented a new architecture for a small cell cloud radio over a fiber access system with several services.	The suggested new architecture offers a flexible, economical, and power-efficient solution.
Kerdoncuff et al. [128]	To improve the QoS of vehicular user	Proposed a MR based architecture which uses two imbricated levels of LTE networks	MR can be deployed in standard LTE architecture for enhancement of QoS of vehicular user
Scott et al. [129]	To improve the throughput of vehicular user	Proposed the system model of HST with 8 distinct carriages each one having an MR	Cooperative MR can improve the throughput of vehicular user

relevant research articles related to this are summarized in Table 5.

D. MOBILITY MANAGEMENT USING ENERGY MAXIMIZATION IN HIGH-SPEED SCENARIO

Mobility management is essential in high-speed scenarios when the available energy is constrained by factors like battery capacity and life, especially when focusing on energy maximization. A green radio trend has emerged as an outcome of the exponential increase of wireless devices and the resulting significant rise in energy usage [150]. The key performance indicator for next-generation wireless systems is energy efficiency, which is measured as the system throughput-to-energy ratio. Relaying can shorten

TABLE 4. Comparison of literature based on handover optimization technique.

References	Objective/ Identified work	Proposed work/Algorithm	Performance achieved / Re- search Outcome
Arshad et al. [130]	Mobility causes higher HO rates in two-tier cellular networks due to network densification	HO skipping techniques for a two-tier mobile network that take into account user velocity were suggested and validated using Monte Carlo simulations (MCS)	Minimization in the HOF and improvement in average throughput
Alhammadi et al. [131]	One of the primary challenges of the mobility is HOF	Proposed dynamic handover control parameters in HetNets	Proposed algorithm reduces ping pong, handovers, and radio link failure
Bilen et al. [132]	Handover delay and HOF in ultra-dense network (UDN)	A handover management scheme using Markov-chain was proposed for software-defined UDN in 5G communication.	HOF and handover delays are minimized by up to 52% and 21%, respectively
Semiari et al. [133]	To decrease the energy consumption, increase smooth mobility, and eliminate HOF in fast-growing dense HetNet.	A new method to control and analyze the mobility in combined mmWave-microwave wireless networks which uses the dual-mode small BSs' capabilities as well as device-level caching	Reduction in HOs, HOFs, and also reduction in energy consumption for inter-frequency scanning was achieved.
Tayyab et al. [134]	At medium to high speeds, vehicular users can still experience frequent HOs since the MR is unable to perform HO as it uses the traditional downlink measurement-based HO (DL- HO) approach.	Suggested an uplink reference signal (UL-RS) based HO process for the MR that uses the current sounding reference signal in LTE/new radio (NR) in which measurement reports are not required.	The suggested UL-HO method performs better than the existing DL-HO scheme.
Yan et al. [58]	To ensure the soft and seamless U-plane handover	Introduced the Coordinated Multi-Point (CoMP) transmission and reception-based handover technique for C/U-plane decoupled architecture in HSR communication.	According to the findings, a decoupled architecture can increase capacity while balancing the diversity of propagation between high and low-frequency bands.
Song et al. [59]	C/U Plane Split suffers in Het-Net for HSR communication due to HOFs	Re-designing and analysis of technical aspects and handover techniques based on LTE specification are done and also proposed the decision method for handover triggering using gray system theory based model.	The suggested scheme significantly increases the probability of handover success and can effectively trigger the handover in advance.
Davaasambuu and Sato [135]	To reduce the handover failure using a dominant factor of	MR Proposed the cost function based adaptive HO method which includes the velocity of MR and load of the system	The success probability of HO is increases in comparison with SINR based methods.

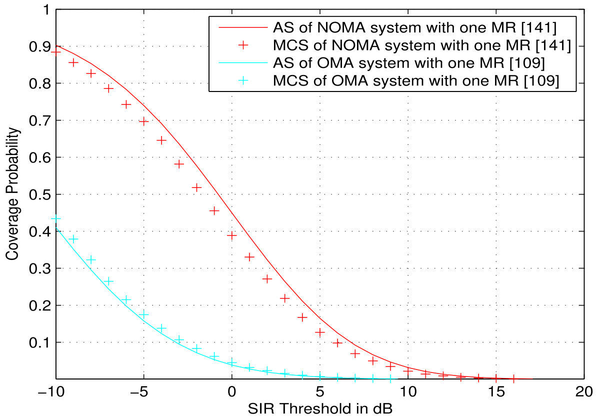

FIGURE 9. Coverage probability vs SIR threshold for downlink communication.

the transmission range, which is another way to save power. An energy-efficient algorithm for HetNet model with multiple HD-MRs was studied in [151] and the performance is analyzed in terms of outage probability and energy efficiency and shows that the proposed model outperforms the selection combining and fixed MR based maximum-ratio combining (MRC) diversity technique in terms of energy efficiency. Fig. 10 shows the comparison of the coverage probability of energy efficient algorithm, selection combining, and fixed MR based MRC diversity with respect to spectral efficiency for downlink communication. It is observed that the proposed energy-efficient algorithm has almost the same coverage probability as the fixed MR based MRC diversity technique. Fig. 11 shows the comparison of the energy efficiency of an energy-efficient algorithm, selection combining, and fixed MR based MRC diversity with respect to the power transmitted by each MR for train users in downlink communication. It is observed that proposed energy-efficient algorithm has 8% more energy efficiency (EE) than the fixed MR-based MRC diversity technique at 2.5 dB transmit power of MR. Table 6 summarizes some of the relevant research articles on energy efficiency maximization.

VI. OPEN RESEARCH CHALLENGES AND FUTURE DIRECTIONS

In order to achieve effective mobility management in high-speed scenarios, this study identifies the following topics as possible research directions:

TABLE 5. Comparison of literature based on employing new technique.

References	Objective/ Identified work	Proposed work/Algorithm	Performance achieved / Research Outcome
Yang et al. [141]	In dense networks for high mobility users, coverage probability and handover cost were low.	Used an mm-wave based network and added the small cells in the decoupled architecture of the C/U plane.	Coverage probability got increased and the HO cast got reduced
Liu et al. [49]	To analyze the performance of HSR by using MIMO system	The average cell capacity for uplink communication is calculated by taking the effect of antenna loss and small and large scale fading into account	Get higher average cell capacity and ergodic capacity using co-located antennas
Zhang et al. [51]	High transmit power required in high-speed train for uplink communication	Proposed an improved power allocation method for Nakagami-m fading in high SNR environments after analyzing the data reception and channel condition matching issue in HSR.	The improved technique can be used to optimize power in accordance with the various fading statistics, that the moving train encounters
Chen et al. [52]	To provide the data services to train users in HSR over wireless channels on demand.	The scheduling of data services on demand to HSR through wireless channels was proposed using a new Checker algorithm.	Checker algorithms provide relatively better performance
Zhang et al. [142]	To investigate the effectiveness of the train-ground communication system using MRs installed on the train's rooftop and working in the FD mode.	Developed a sequential quadratic programming approach which uses the Lagrange function for bandwidth distribution optimization of track-side BS and MR	The proposed technique can successfully increase the capacity while using an anti residual self-interference (RSI) technique.
Khan et al. [140]	To increase the coverage probability and system throughput of vehicular and non-vehicular user in high mobility scenario	Proposed a high mobility system using NOMA technique with one MR on the top of the train.	Improvement in the performance of the system level throughput and coverage is observed in comparison with the orthogonal multiple access (OMA) technique
Liu et al. [143]	To study the simultaneous wireless information and power transmission (SWIPT) based cooperative NOMA system, in which the near-user closer to the BS works as a relay to assist the far-user.	Suggested a joint design for power splitting factor and power allocation coefficients to enhance the outage performance of near-user and thus system performance	The proposed system significantly enhances the near-user's performance and benefits from a better system throughput.
Liu et al. [144]	To apply the Relay Selection (RS) technique in NOMA system for cooperative networks, where communication between the BS and paired users takes place with varied priorities via multiple relays.	To achieve the QoS requirements of users, a unique two-stage RS technique has been developed that takes into account the utilization of the instant channel conditions on the user request.	The suggested RS technique provides an enhancement in outage performance compared to the RS techniques already in use
Yang et al. [145]	To propose the RS algorithm in two-user NOMA based system model for better outage performance	Two different types of two-stage AF and DF RS techniques were suggested for cooperative NOMA.	The suggested technique achieve full diversity order for both AF and DF relaying and surpass cooperative OMA in terms of outage probability.
Xu et al. [146]	To investigate the effect of multiple RS technique for cooperative NOMA systems	Proposed the two best RS techniques, namely the max-weighted-harmonic-mean and two-stage weighted-max-min schemes.	The proposed schemes perform better than suboptimal RS techniques under the limitations of adaptive and fixed power allocations at the relay.
Cao et al. [147]	To ensure that NOMA systems can communicate securely and reliably with untrusted users	Suggested the two optimum RS schemes based on DF and AF relay known as the DF protocol based optimal Relay selection (DORS) and AF protocol based optimal Relay selection (AORS) techniques, which are based on the DF and AF relaying, accordingly.	The outcomes show that the benchmark schemes are greatly outperformed by both the DORS and AORS techniques, who also achieve the desired positive secrecy capacity probability and the same secrecy outage probability at high SNR
Dong et al. [148]	To investigate the effect of train velocity and cell radius when train is moving along the railway track which follows straight line	Proposed the concept of average transmission rate over space and studied the bounds on two functions based on power-space.	If the cell radius or velocity of train increases, the power of BS must be exponentially increased.
Do et al. [149]	To increase the overall performance of CEU in NOMA-based two users system model	An on/off scheme for FD and HD relay is proposed. The effectiveness of single and two-hop links are considered from the BS to the CEU which is taken into account when deciding whether to turn relaying on or off.	The suggested techniques increase the sum throughput of NOMA systems with two users, as well as providing considerable outage performance improvements to CEU.

A. ARCHITECTURAL SUPPORT

GSM-R, the very first commonly deployed high mobility network architecture, exclusively offers narrow-band services to railways [40], [45], [46]. By utilizing the different aspects of high mobility systems [8], [16], new network architectures such as LTE, MRs [48], C-RAN [37], [60], and HetNet with

TABLE 6. Comparison of literature based on Energy Maximization using suitable technique.

References	Objective/ Identified work	Proposed work/Algorithm	Performance achieved / Re- search Outcome
Khan et al. [151]	To maximize the energy efficiency in high-speed scenario	Proposed an energy-efficient algorithm using multiple cooperative MR system models	Observed the better energy efficiency in comparison with traditional diversity models.
Soh et al. [152]	Small cells are deployed densely and randomly, and their operation is not coordinated, which reduces HetNet's energy efficiency.	Proposed energy efficient network using sleeping strategies for BSs and small cells which was based on stochastic geometry based model	Small cells result in higher EE, depending on the kind of sleeping strategy, but gain reaches saturation as small cell density rises.
Song et al. [153]	To minimize energy consumption at base stations during HO	Proposed a HO scheme that aids in BS energy consumption in HetNets and formulate the HO problem using constrained Markov Decision Process	Reduction of unnecessary handover and improvement in the energy consumption
Kanwal et al. [154]	Limited resources lead to call blocking and interference. Frequency reuse causes high outage probability in HetNet.	Analyzed the reduced early handover scheme for call blocking and outage probabilities when different data rates are present.	Improvement in energy efficiency and reduction in call blocking and outage probabilities
Mukherjee [155]	To reduce the handover delay for reliable communication	Proposed HO technique for reliable communication	Energy Efficiency and delay metrics were improved
Peng et al. [156]	To reduce the energy consumption of BS by switching off strategy	Used Random sleeping algorithm to decrease the energy consumption under power consumption of mobile user	Energy efficiency got improved
Abdulkafi et al. [157]	To increase the EE in HetNet	EE of HetNet was analyzed using theoretical model and sleep mode strategy was used to reduce the energy consumption.	The improvement in EE occurred up to 33% and 68% for medium and low traffic respectively
Vereecken et al. [158]	To optimize the energy consumption in ultra-dense network	Proposed the heuristic to assess mobile access networks and also used the sleep mode strategy for EE improvement.	Energy efficiency improved by reducing power consumption
Saker et al. [159]	To enhance the EE of HetNet while maintaining the QoS of users	Markov Decision Processes and sleep strategy based model is studied	Energy efficiency improved
Gan et al. [160]	To decrease the energy requirement in HetNet	To reduce overall energy consumption, proposed and heuristic method and offline solution	Energy consumed in HetNet can be decreased by the suggested algorithms.
Ren and Tao [161]	To decrease the energy consumption and blocking ratio of users in HetNet	Presented a decentralized sleep method to decrease energy consumption in HetNet	In comparison to the present dynamic sleep scheme, the over-all energy consumption can be lowered by 8.6%, and the user blocking ratio can drop from 2.7% to 1.7% at a given user density.
Zhang et al. [162]	To reduce the power consumption while maintaining QoS for C/U plane decoupling-based architecture	A probabilistic sleeping method was proposed and optimized in which database station went to sleep on the basis of the probability of traffic load	Up to 30% energy saving is achieved using the proposed method.
Chu et al. [163]	To analyze the trade-off between spectrum efficiency (SE) and EE in DF two-way multi-relaying due to the high SE of two-way relaying.	Proposed the optimization technique of RS and power allocation jointly for DF multi-relaying networks, which distributes optimal power to each node to increase EE and SE	In terms of EE and SE, the suggested method performs better than the conventional optimum RS strategies.
Umehara et al. [115]	To achieve the trade-off between the throughput of CEU and efficiency of the system frequency	Proposed NOMA with a SIC using weighted proportional fair and fractional frequency reuse-based multiuser scheduling in the cellular downlink.	Improvement in the performance of the system level throughput and experience of CEU which will be helpful for getting future traffic demands
Ding et al. [164]	To take into consideration using MIMO technique with NOMA systems	Precoding and detecting matrices based design is proposed for MIMO-NOMA	A combined power allocation and precoding design can increase MIMO-performance. NOMA can perform better than traditional OMA.
Ding et al. [165]	To analyze how well the co-operative and non-cooperative NOMA with OMA systems perform.	Proposed cooperative NOMA based approach in which some users have prior knowledge about other user's messages	The cooperative NOMA performs better than the OMA and non-cooperative NOMA.
Lv et al. [166]	To analyze the NOMA to multicast cognitive radio (MCR)	Proposed the MCR-NOMA technique which uses secondary multicast users as relays to increase the effectiveness of networks. and also proposed the scheduling technique for secondary user	cooperative MCR-NOMA performs better than non-cooperative MCR-NOMA in terms of diversity, coverage, and mutual outage probability.
Dong et al. [167]	Power efficiency is low in the high mobility scenarios of HSRs and power allocation (PA) is also unfair along the time	A temporal proportional-fair PA algorithm is proposed	A trade-off is obtained between the power efficiency and power consumption by fairness along the time.
Al-Abbasi et al. [168]	To optimize the downlink energy efficiency (EE) of a two-tiered cloud radio access network based on NOMA	A numerically generated optimal solution is evaluated with the sub-gradient solution and unoptimized solution, which uses the false positioning method.	The suggested sub-gradient solution offers better performance in comparison with other methods for NOMA systems.

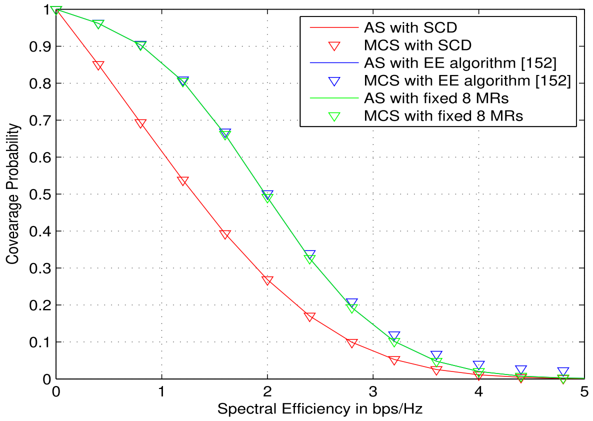

FIGURE 10. Coverage probability vs Spectral Efficiency.

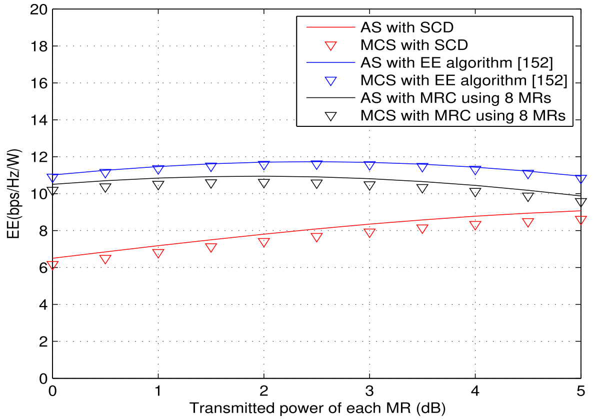

FIGURE 11. Energy Efficiency vs Transmitted power of each MR.

C/U-plane decoupling [59] can substantially enhance system performance. Therefore, the different aspects of high mobility systems can be used to design and optimize the network architecture. Recent researches show that architectural support using MR has the capability to overcome the effects of VPL, support group handover [119], and enhance the coverage and capacity in high-speed vehicular scenarios for vehicular and non-vehicular users [120], [121], [122]. Some of the major findings are listed below:

- Deployment of DAS-based architecture requires an efficient HO scheme between BS and adjacent cells to achieve seamless connectivity [61], but the potential for interference between adjacent cells increases, which can degrade the quality of the signal. Also, providing power to DAS BS can be a challenging task, especially in remote areas. To adjust the effect of signal obstructions, reflections, and shadowing on signal coverage and strength, adaptive beamforming, and signal processing techniques are required in DAS deployment.
- C/U plane decoupling requires effective synchronization between the C-plane and U-plane, which is a major challenging task in high-speed scenarios to avoid data loss, errors, and reduced system performance [53], [54], [55]. Also, C/U plane decoupling can impact the handover process as both C-plane and U-planes need to coordinate to provide uninterrupted service during handover [56], [57], [58], [59]. C/U plane decoupling requires predictive resource allocation, adaptive control strategies, and dynamic decision-making, which can be optimize using the integration of machine learning and artificial intelligence techniques. Also, optimization of energy consumption during control signaling and data transmission needs to be studied, as C/U plane decoupling should be more energy efficient.
- The major challenges of MR-based architecture are HetNet, interference, and fast signal fluctuation in high-speed scenarios, which tigers frequent HOs. Recently, various studies have been done on HetNet using single MR [109], [121], [140] and two MR diversity [119], [122]. However the performance of two HD-MR using equal gain combining and maximum gain combining has not been studied yet for downlink communication in HetNet scenarios, and the performance of two HD-MR using selection combining and maximum gain combining are not known for uplink communication. The performance of FD-MR in HeNet for uplink communication is not known. Also, the performance of FD-MR with relay diversity in HeNet is not studied for both uplink and downlink communication.

Network architecture for high mobility 5G communications is still in their developmental stages. The question of how to develop an efficient and effective architecture for high mobility-based 5G systems still persists today.

1) HANDOVER OPTIMIZATION TECHNIQUE

Several factors, including signal strength, signal quality, load balance, interference, and user mobility patterns, must be considered into account in order to make proper and timely handover decisions. It is a challenging task to balance these factors while avoiding unnecessary handovers. Also, security issues should be addressed during handovers to avoid unauthorized access or data interception. Handover technique is more challenging in HetNet due to the interference and heterogeneous characteristics of wireless networks [109]. The handover technique has to decide whether to switch to a small cell or stay in a macrocell based on signal quality, load, mobility patterns, and device requirements. Reduction of handover failure is required for seamless data transmission in high speed scenarios. The MR based architecture in HetNet supports group handover [119]. There is limited literature available for vehicular communication in HetNet. Predictive analytics based handover scheme using machine learning and artificial intelligence (AI) needs to be studied for such complex networks.

2) NEW TECHNIQUE

New techniques are being explored all the time for improving the efficiency, reliability, and scalability of mobility management. These techniques, however, come with limitations and future research possibilities. The performance, capacity, and user experience of wireless networks can be enhanced by using new techniques and by integrating technologies into mobility management systems. The performance of one HD-MR using the NOMA technique for uplink communication has not been studied. Also, MR diversity with the NOMA technique has not been analyzed yet for both uplink and downlink communication in HetNet scenarios. Integration of technologies like MIMO-NOMA [169], [170], [171] mmWave MIMO [172], [173], [174], [175], etc. can be used to manage mobility in high-speed scenarios.

3) ENERGY EFFICIENCY MAXIMIZATION

As per the literature review, minimization of energy consumption at base stations during handover is required to save battery life, and different types of schemes or algorithms need to be proposed for energy saving in a high mobility scenario [151]. An energy-efficient HetNet model with multiple FD MRs is not known. Energy savings with acceptable QoS are challenging in HetNet scenarios. The goal of research can be to find the tradeoff between energy and QoS. Also, energy efficient protocols need to be designed to provide seamless connectivity and QoS. Addressing energy maximization issues is crucial to ensuring sustainable and effective wireless communications that cater to both QoS and environmental considerations as high-speed communication becomes more widely used.

VII. CONCLUSION

In this paper, we have presented a systematic state-of-the-art high-mobility vehicular communication system with its viable research challenges and analysis. A potential management strategy with network architectures has been explored for efficient cellular communication in a high-speed vehicular environment. We reviewed the mobility management techniques in the literature to determine the key elements that must be included when designing a high-mobility system model. Firstly, we described the challenges of a high-mobility communication environment and highlighted current research priorities. We found that higher handover failure rate, low QoS, and high energy consumption are the major research issues of high-speed mobile communication systems and have investigated the key performance indicators in this scenario. Initially, the potential research challenges of a high-mobility communication environment are highlighted with research priority. We concluded that higher handover failure rate, low QoS, and high energy consumption are the major issues of a high-speed mobility communication environment. Further, we have explored the potential solutions to the research issues of high-speed mobile communication using new network architecture and techniques. We also discuss the challenges and future research directions based on the literature survey. Thus, the future generation communication networks (5G/B5G/6G) have been planned to deliver broadband services to a huge number of users simultaneously while moving at high speed. In addition, a new communication strategy needs to be developed using features of 5G, massive MIMO, Cognitive radio, NOMA, HetNet full-duplex transmission, etc., to achieve the objectives that can address the challenges and opportunities of high mobility scenarios.

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