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A REVIEW ON MOBILITY AND HANDOVER MANAGEMENT IN FUTURE WIRELESS NETWORKS

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ABSTRACT:
Future wireless networks (FWNs) offers high data rates, low latency, and enhanced throughput. However, the dense deployment of small cells (SCs) in these networks increases network complexity, leading to frequent handovers (HOs) and potential service disruptions. Advanced technologies such as millimeter wave (mmWave), Terahertz (THz), reconfigurable intelligent surfaces (RIS), and unmanned aerial vehicles (UAVs) are integrated in FWNs to meet rising Quality of Service (QoS) demands. Despite these advancements, ensuring seamless mobility remains a challenge due to issues like HO failures (HOF) and service degradation, necessitating effective mobility management. This paper presents a brief review of existing surveys on HO and mobility management, highlighting their key contributions and limitations. Additionally, it examines major FWN technologies including HetNet, mmWave and THz, UAV, and RIS, and their impact on mobility and HO processes. Furthermore, the paper explores HO mechanism, key control and decision parameters, performance metrics, and associated challenges in mobility management for FWNs. Finally, it outlines potential strategies to enhance mobility management efficiency in these networks.
Keywords: FWN, HetNet, HO Optimization, Mobility Management, RIS, UAV

INTRODUCTION

Future wireless networks (FWNs), including 5G and beyond (B5G/6G), aim to meet growing demands for high-speed, low-latency, and massive connectivity services. Technologies such as heterogenous networks (HetNets), millimeter wave (mmWave), Terahertz (THz), unmanned aerial vehicles (UAVs), and reconfigurable intelligent surface (RIS) play a key role in enabling enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable low-latency communication (URLLC) [1 – 3]. However, these advancements also introduce new challenges, especially in mobility and handover (HO) management due to increased network heterogeneity, small cell density, and frequent user movement. Traditional HO schemes often fail to ensure seamless connectivity, resulting in HO failures (HOFs), ping-pong effects, and QoS degradation [4 – 6]. This paper reviews various existing surveys and key enabling technologies that impact mobility and HO in FWNs. It covers HetNets, mmWave/THz bands, UAV-assisted communication, and reconfigurable intelligent surfaces (RIS), discussing their potential and associated mobility challenges.

The main contributions of this paper are as follows.

- Presents a concise evaluation of existing surveys on HO and mobility management, highlighting their key contributions and limitations.
- Examines the impact of advanced technologies such as HetNets, mmWave/THz, UAVs, and RIS on mobility and HO processes FWNs.
- Investigates HO mechanisms, control parameters, performance metrics, and outlines potential strategies to improve mobility management efficiency in FWNs.

1. Existing Survey

Effective mobility management is vital for seamless HO in dense network environments. Several survey papers have addressed this topic, each contributing unique insights while leaving certain gaps. Below, we review six

notable surveys on HO and mobility management, with their key contributions and limitations. We then outline the scope of our work and how it advances beyond these existing works.
In [7], the authors review HO and mobility management in B5G networks, with a strong focus on machine learning (ML) applications. They discuss mobility challenges arising from higher frequency bands (HFB), dual connectivity (DC), UAVs, and HO decision parameters. However, aspects such as RIS, mobility under high user/base station (BS) density, and advanced channel modeling are not addressed. In [8], the authors examine HO in ultra-dense small cell (UDSC) networks, emphasizing UAVs and ML-based schemes for improved connectivity. While it highlights intelligent mobility management, it lacks discussion on the effects of HFB, user density, and HO decision parameters.

In [9], various HO optimization techniques, enabling technologies, and ML/RIS/UAV applications are explored. The study underscores future directions for ML and RIS but overlooks challenges from massive UE/IoT devices, and advanced channel modeling considerations. The authors in [10] surveys ML techniques in 6G wireless systems including device-t-device (D2D), and vehicular networks, focusing on resource allocation and HO. While it emphasizes ML and UAV integration, but have not considered critical elements like RIS, multi-connectivity (MC), and realistic channel modeling for improvement.

Furthermore, [11] reviews UAV communication and ML integration for mobility prediction and trajectory planning. However, it focuses solely on UAV-induced mobility challenges, neglecting broader HO factors and the combined role of UAV-RIS and MC. Finally, [12] presents an overview of HO and mobility in FWNs, highlighting HO control parameters (HCPs), HO parameters, and various schemes such as ML and SDN. It also outlines future directions involving UAVs, MC, and channel modeling, but does not take into account the integration of UAV-HetNets and UAV-RIS as potential solutions for improving mobility performance in FWNs.

In this paper, we provide a concise review of existing surveys on HO and mobility management, highlighting their main contributions and limitations. We explore emerging technologies such as HetNets, mmWave and THz bands, UAVs, and RIS for enabling seamless HO in FWNs. Additionally, HO mechanism, key HO control and decision parameters, performance metrics, and associated challenges in mobility management for FWNs are discussed, followed by potential strategies to enhance mobility management in these networks.

2. Enabling Technologies for Mobility and HO in FWNs

Mobility and HO management is crucial for ensuring high QoS and minimizing HO issues such as latency and service disruptions. The extensive deployment of small cells (SCs) and the use of higher frequency bands, like mmWave and THz, support increased data rates and network capacity. However, these also introduce challenges, including frequent HOs, HO failures (HOF), beam coverage issues, and the ping-pong effect. To address these, advancements in HO management are essential. This section explores key technologies, such as HetNets, mmWave and THz bands, UAVs, and RIS which are transforming wireless communication. These technologies are critical for enhancing Mobile Broadband (eMBB) services and enabling seamless communication for mMTC and URLLC.

3.1. Heterogeneous Networks

FWNs face growing demands due to higher bandwidth requirements, non-uniform user distribution, and diverse traffic patterns. These challenges make it difficult to ensure consistent Quality of Service (QoS) and mobility performance. HetNets offer an effective solution by integrating high-power macrocells for wide-area coverage with low-power small cells (SCs) such as femtocells, picocells, and microcells for localized, high-capacity service [13]. HetNets address two key limitations in traditional networks: limited coverage due to obstacles blocking macrocell signals and inadequate capacity in densely populated areas. Network densification, combined with spectrum expansion, enhances both coverage and capacity. Small Base Stations (SBSs) within SCs improve user experience in indoor environments such as homes and offices. While HetNets significantly enhance overall network performance, they introduce increased HO complexity and mobility management challenges in FWNs.

3.2. Milimeter Wave and Terahertz Bands

The mmWave (30–300 GHz) and THz (0.3–3 THz) frequency bands play a vital role in enabling FWNs by offering ultra-high throughput and ultra-low latency. These bands provide extensive bandwidth, supporting significantly higher data rates and capacity compared to current cellular networks—even a small portion of mmWave spectrum can deliver hundreds of times more throughput [14]. However, signals at these frequencies suffer from low diffraction, severe propagation losses, and are highly susceptible to blockages and weather conditions. In urban environments, these limitations can cause HO failure (HOF) rates up to 40 times higher than those in sub-6 GHz bands. To mitigate such issues, technologies like directional beamforming, massive MIMO (M-MIMO), frequency reuse, and RIS are employed to enhance line-of-sight (LoS) connectivity and overall network performance [15]. While sub-6 GHz bands offer coverage over several kilometers, mmWave and THz communications are typically limited to about 200 meters in LoS conditions, necessitating dense small cell (SC) deployment. These challenges underscore the importance of well-structured network architectures and advanced algorithms for efficient 5G and beyond-5G (B5G) management.

3.3. Unmanned Aerial Vehicles

UAVs have emerged as a promising solution for FWNs due to their cost-effective deployment, flexibility, and ability to establish reliable line-of-sight (LoS) communication links, thereby enhancing HO key performance indicators (HO-KPIs), data rates, and user connectivity [16]. Originally developed for military applications such as surveillance, UAVs have evolved—thanks to advancements in wireless communication—into aerial base stations (BSs) or relays. They provide wireless coverage in areas where terrestrial infrastructure is unavailable, insufficient, or damaged, while also improving overall network capacity, coverage, reliability, and energy efficiency. UAVs can dynamically adjust their trajectory and altitude to respond to traffic demands and channel conditions, ensuring better LoS connectivity, especially for cell-edge users [17]. Compared to small cells (SCs), a single UAV can replace multiple SCs while maintaining comparable throughput, significantly reducing co-tier interference and HO rates associated with dense SC deployments. Despite these advantages, UAVs face several challenges, including optimal 3D placement, limited battery life, interference management, and the complexity of modeling dynamic air-to-ground channels, particularly in obstructed, low-altitude urban environments. Furthermore, the high mobility of both UAVs and users in FWNs, combined with the use of high-frequency bands and limited coverage areas, can complicate the HO process, leading to increased HO frequency and failure rates.

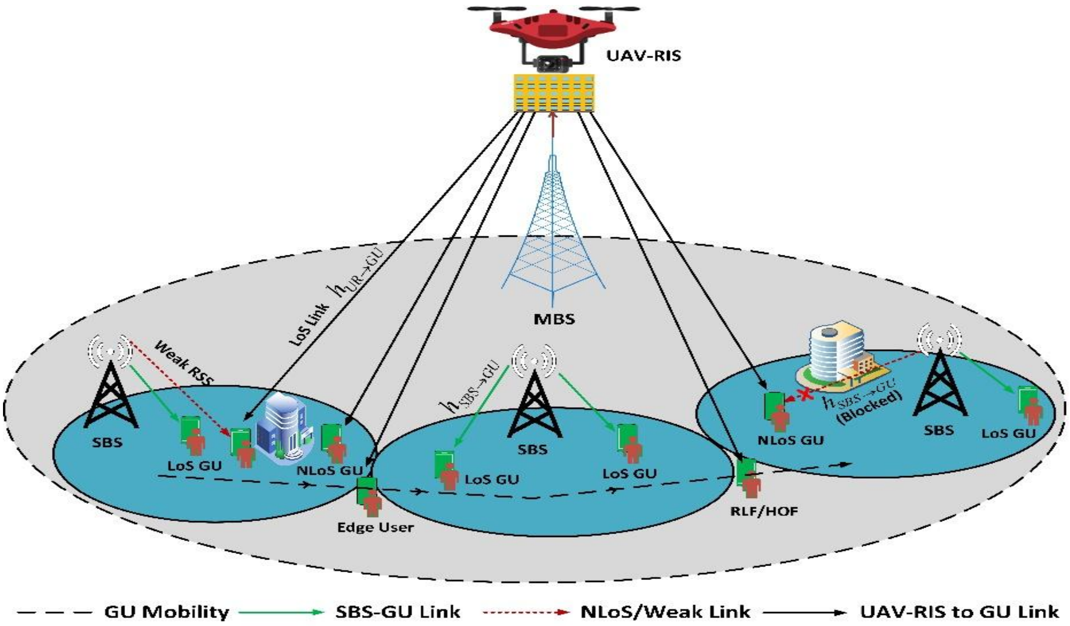

Figure 1: UAV-RIS Technology for GUs Mobility Management

3.4. Reconfigurable Intelligent Surface

FWNs rely on high-frequency bands such as mmWave and THz to meet growing demands for high data rates and ultra-low latency. However, these bands suffer from limited penetration and are highly dependent on line-of-sight (LoS) paths, which are difficult to ensure in dense urban environments with frequent blockages. To enhance LoS probability, reduce unnecessary HOs, and improve mobility performance, RIS has emerged as a cost-effective and energy-efficient solution [18]. RIS, composed of passive reflecting elements, can intelligently manipulate incident electromagnetic waves by adjusting reflection coefficients or phase shifts, enabling controlled beamforming to improve signal quality and reduce interference [19]. They can be deployed on walls, buildings, or mounted on UAVs to extend coverage and strengthen connectivity in FWNs.

A RIS-assisted HO scheme leveraging deep reinforcement learning (DRL) was proposed in [20], significantly reducing HO rates and enhancing spectral efficiency through joint optimization of beamforming and RIS phase shifts. Recently, the integration of UAVs with RIS (UAV-RIS) has gained traction due to their combined ability to dynamically adapt coverage by optimizing both UAV trajectories and RIS configurations. Mounting RIS on UAVs overcomes the limitations of fixed RIS installations, which may lack direct LoS to base stations (BSs) or users. UAV-RIS systems can position themselves to establish optimal LoS links, improving coverage, capacity, and HO efficiency in HetNets. Figure 1 illustrates HO and mobility management by utilizing UAV-RIS technology in FWNs.

4. Handover Mechanism and Challenges

Handover (HO) is essential for ensuring seamless connectivity as users move across wireless network cells. In cellular networks, HO occurs when signal quality from the serving base station (BS) degrades, prompting the device to switch to a target cell with better signal strength. Besides signal degradation, other triggers include load balancing, mobility patterns, and user speed. HO decisions are based on fluctuations in the received signal strength (RSS) from both serving and candidate BSs. RSS is derived from reference eignal received power (RSRP) and reference signal received quality (RSRQ), with RSRQ factoring in interference and noise. In 5G B5G, HO management focuses on optimizing HO control parameters (HCPs) based on HO decision parameters (HODPs) to improve HO key performance indicators (HO-KPIs), as detailed below.

4.1. HO Control and Decision Parameters

HO Margin (HOM) and Time-To-Trigger (TTT) are key HCPs that determine when and how a user equipment (UE) initiates HO. These parameters are tuned based on HODPs such as speed, RSRP, RSRQ, and movement direction to enhance HO-KPIs. HOM is the required RSS difference (in dB) between the serving and target cells to trigger HO, while TTT is the duration a UE must remain below the threshold before HO begins [21]. Effective HO requires joint optimization of all HCPs based on UE behavior. In HetNets, lower HOM and TTT values are preferred for high-speed UEs, while higher values suit slower ones. Due to their smaller cell sizes and frequent mobility, HetNets benefit from minimal HCP values to reduce HO failures (HOF) and ping-pong effects (HOPP), enhancing connectivity and reliability [22].

4.2. Handover Performance Metrics

Handover performance metrics, also referred to as HO Key Performance Indicators (HO-KPIs), are critical measurements used to evaluate the efficiency and reliability of mobility and HO processes within a network. These metrics reflect the quality of user experience and the effectiveness of mobility management. Key HO-KPIs are outlined below:

- **HO Rate**: This refers to the number of HOs occurring within a specific time interval. A high HO rate suggests frequent cell switching, often due to poor signal quality or high user mobility, while a low HO rate indicates that the UE remains connected to a single cell longer, reflecting stable connectivity. Maintaining an optimal HO rate is essential for ensuring reliable and efficient mobility support.
- **Handover Failure (HOF) Rate**: The HOF rate is the ratio of failed HOs to the total number of HO attempts within a given time frame. Failures may result from poor network planning, congestion, inter-cell interference, weak signal strength, outdated UE hardware, or ineffective mobility management.
- **Handover Ping-Pong (HOPP) Rate**: HOPP rate quantifies the frequency at which a UE switches back and forth between two cells. High HOPP rates are usually caused by fluctuating RSS and can lead to increased call drops and degraded user experience. A low HOPP rate indicates a more stable and well-optimized HO process.
- **Handover Interruption Time**: This metric measures the duration between disconnecting from the serving cell and establishing a connection with the target cell, during which the UE is unable to communicate with the network. Minimizing interruption time is vital for seamless connectivity.
- **Handover Latency**: Also known as HO execution time, this is the period from HO initiation to its successful completion. High latency suggests inefficiencies in the HO process, while low latency reflects rapid execution and effective support for user mobility.

4.3. Handover Issues

In FWNs, HO issues arise from the need to maintain reliable connectivity as User Equipment (UE) moves between base stations (BSs). The deployment of ultra-dense small cells (SCs) and the use of high-frequency bands in next-generation HetNets intensify these challenges. Common issues include high HO rates, HOF, radio link failures (RLF), HO ping-pong (HOPP), inter-cell interference (ICI), unnecessary HOs, load imbalance, and HO latency, all of which can disrupt real-time services like voice and video. High HO rates result from the limited coverage of small cells and rapid signal fluctuations. HOFs typically occur due to weak signal reception, often caused by too-late, too-early, or wrong-cell HOs. Delayed HOs (due to high TTT/HOM values) may reduce HOPP but increase RLF risk, while early HOs (low TTT/HOM) can raise HOPP and call drops. Wrong-cell HOs, frequent near cell edges, also lead to unstable connections. Minimizing HO latency is crucial for seamless connectivity in latency-sensitive applications such as online gaming, AR/VR. Addressing these issues requires intelligent HO algorithms that enable predictive HOs, interference mitigation, and coordination among BSs to ensure quality of service (QoS). Figure. 2 illustrates the causes and consequences of HO issues, while Table.1 links HCPs with specific mobility issues and HO-KPIs.

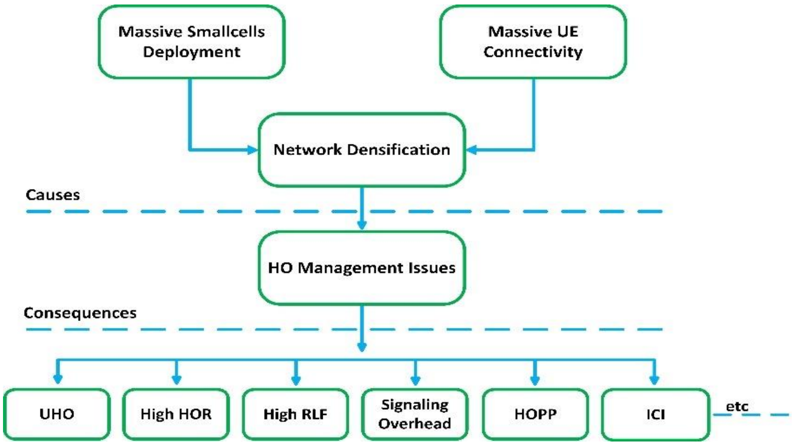

Figure 2: Handover Issues

Table 1: HO issues due to improper HCPs configurations

HO Issues	TTT Value	HOM Value	Affected HO-KPIs
Too-late HO	High	High	High RLF
Too-early HO	Low	Low	High HOPP
HO to wrong ell	Inappropriate	Inappropriate	High RLF or High HOPP

5. Future Research Directions

5.1. UAV-HetNet Integration:

Integrating UAVs into terrestrial HetNets enables enhanced coverage, reliability, and flexibility in FWNs. UAVs can act as aerial relays or base stations, dynamically supporting 5G/6G, Wi-Fi, and satellite networks, especially in dense, remote, or emergency scenarios. Future research should focus on optimizing HO mechanisms, cross-layer design, and intelligent network selection to fully exploit UAV mobility and adaptability in HetNets.

5.2. UAV-RIS Integration:

Although UAV-RIS systems have been explored for coverage and rate enhancement, mobility-aware designs remain underexplored. Joint UAV-RIS deployment can reduce HOF, HO latency, and signal outages by intelligently redirecting beams and supporting robust mobility management. Future work should incorporate user and UAV mobility effects in RIS optimization for seamless connectivity in dynamic environments.

5.3. Multi-Connectivity (MC):

MC enables a UE to connect with multiple BSs simultaneously, reducing HOFs and ensuring service continuity during HOs. Future research should explore dynamic MC strategies that adapt to user mobility, varying link quality, and network load, aiming to optimize HO performance, minimize latency, and enhance the robustness of mobility management in FWNs.

5.4. UAV Channel Modeling:

Accurate UAV-to-ground (U2G) channel modeling is essential for predicting connectivity and optimizing HO decisions. Unlike static BSs, UAVs operate in dynamic 3D environments affected by altitude, mobility, terrain, and urban density. Future work should focus on environment-aware, real-time channel models that account for line-of-sight (LoS)/ non-LoS (NLoS) dynamics, atmospheric effects, and urban obstructions to improve HO reliability and network performance.

CONCLUSION:

In this paper, a brief review of HO and mobility management in FWNs is presented. Various survey articles are reviewed, highlighting their key achievements and limitations. Additionally, several enabling technologies, such as mmWave, THz, UAV, and RIS are discussed along with their impact on HO and mobility in FWNs. The paper also explores the HO mechanism and impact of HO decision parameters on control parameters (HCPs) for improved HO-KPIs, as well as associated HO issues. Finally, potential research directions are outlined, including UAV-HetNet, UAV-RIS integration, Multi-Connectivity, and UAV channel modeling, aimed at improving the overall network performance of FWNs in terms of HO and mobility.

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