Hindawi
Security and Communication Networks
Volume 2022, Article ID 5702529, 16 pages
https://doi.org/10.1155/2022/5702529

Research Article

A Novel Cooperative Relaying-Based Vertical Handover Technique for Unmanned Aerial Vehicles

Zeeshan Haider,[1] **Syed Mushhad Muztazhar Gilani**,[1,2] **Tauseef Jamal**,[3] **Shumaila Javaid**,[4,5] **Hamza Fahim**,[4,5] **Omar Cheikhrouhou**,[6,7] **and Monia Hamdi**[8]

[1]*University Institute of Information Technology, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, Pakistan*
[2]*Department of Computer Science, University of Agriculture, Faisalabad, Pakistan*
[3]*Department of Computer and Information Sciences, Pakistan Institute of Engineering and Applied Sciences, Islamabad, Pakistan*
[4]*Department of Control Science and Engineering, College of Electronics and Information Engineering, Tongji University, Shanghai 201804, China*
[5]*Frontiers Science Center for Intelligent Autonomous Systems, Shanghai 201210, China*
[6]*CES Laboratory, National School of Engineers of Sfax, University of Sfax, Sfax 3038, Tunisia*
[7]*Higher Institute of Computer Science of Mahdia, University of Monastir, Mahdia 5111, Tunisia*
[8]*Department of Information Technology, College of Computer and Information Sciences, Princess Nourah bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia*

Correspondence should be addressed to Syed Mushhad Muztazhar Gilani; mushhad@uaar.edu.pk and Shumaila Javaid; shumaila.javed01@gmail.com

Received 2 June 2022; Accepted 24 July 2022; Published 21 September 2022

Academic Editor: Irshad Azeem

The real-time monitoring and autonomous decision making through unmanned aerial vehicles (UAVs) are the potential applications of future networks. Vertical handover in future networks is a mechanism to switch communication between different network access technologies like Wireless Local Area Network (WLAN), Worldwide Interoperability for Wireless Microwave Access (WiMAX), Third-Generation (3G), Fourth-Generation (4G), and Fifth-Generation (5G) mobile technologies. These technologies have significant importance in providing fast, reliable, and timely communication. However, during a vertical handover, an inadequate delay and packet loss can cause considerable disruption in maintaining communication sessions and results in intolerable end-to-end delay, disconnectivity, and poor packet delivery ratio. The proposed work addresses the vertical handover method in UAVs communication by designing a relay-based vertical handover technique. The relay UAVs is an assistant node, requiring an organized and intelligent deployment that assists in vertical handover and communication by minimizing the average packet loss and average delay from source to destination. Moreover, a multicriteria handover parameter triggering is used for seamless and more extended network coverage. Extensive simulations using S-shaped and U-shaped trajectories are designed and simulated for relay-based vertical handover performance evaluation. The results obtained show that our proposed relay-based handover method offers seamless connectivity and high-performance experienced during the vertical handover process. The extensive comparison with state-of-the-art techniques proves that the proposed method is better in terms of 18% handover success rate, 21% end-to-end delay, and 29% packet loss.

1. Introduction

Unmanned aerial vehicles (UAVs) are considered the advanced future network technology with benefits of extensive coverage, mobile base stations, and fast unmanned aerial vehicles deployment with affordable cost [1]. The broad characteristics of UAVs extended their applicability for various applications such as surveillance, firefighting, cargo, emergency response, agriculture, and mobile hotspot [2–4]. With the ultimate desire to maintain a ubiquitous networking paradigm, UAVs need to be incorporated with adequate intelligence to enable communication seamlessly and efficiently among different access technologies. However, the improved communication among UAVs is restricted by a few primary challenges, such as handover and authentication. In the existing literature [5–7], two main techniques are highlighted for handover procedures to change network access technology. First is horizontal handover, in which the same type of network access technology is used to switch communication for end devices. Additionally, horizontal handover is fast but expensive in terms of deployment that has a limitation of short-distance communication. The second is the vertical handover that addresses switching communication sessions between two different access technologies (such as a change from WLAN to WiMAX networks or WiMAX to WLAN networks). At the same time, the vertical handover is experienced worst for the fast-moving devices (e.g., vehicles, UAVs) that need reliable communication from source to destination [8]. In Figure 1, horizontal and vertical handovers are illustrated for both ad hoc and centralized communication.

In ad hoc communication mode, devices can directly communicate with each other without any access point [9]. However, in the case of fast-moving devices, it degrades the quality of service (QoS) performance of the network in terms of delay, bandwidth, and packet loss. In contrast, the centralized mode of communication handles all communication through some centralized architecture that benefits extended coverage, while it has the disadvantage of a single point of failure. To overcome these issues, emerging cooperative communication can provide a promising alternative to utilize the benefits of both modes of communication optimally for efficient communication. The intermediate nodes between source and destination in cooperative communication are called relays [10]. In relay node-based communication, the relaying node overhears channel and all signaling exchange between source and destination nodes, if the relaying channel is high signal-to-noise ratio (SNR), then this intermediate node is selected and deployed as relaying node. These nodes have a significant role in maintaining seamless communication between two UAVs that cannot communicate directly due to distance, obstacle, and interference limitations. Due to cooperative communication, two major benefits can be achieved [11]. First is high diversity gain that results in high throughput. Second is the extended network coverage that results in excellent network lifetime and scalability.

In the existing literature, significant attention has been given to the handover decision algorithms [12]. The work presented in [13] focused on the false handover initiation and ensured the true need for handover. In [14], the importance of finding the exact location of the base station for an effective handover process is emphasized to minimize failure and increase the success rate of the handover. In [15], a handover decision was made using velocity, network geometry, and received signal strength indication (RSSI). Authors in [16] highlighted that user-based location played a vital role in decision making and maintained a database that improved the failure rate of handover decision making. In another work [17], delay, bandwidth, and jitter are considered for handover decision making. However, the drawback of this approach was the absence of a specific method to determine the weight of the decision metrics. Another approach using RSSI-based handover decision is described in [18], in which cells compare the RSS level of source and destination nodes. If the RSS level is lower than the preset limit, then vertical handover is initiated. In [19], RSS-based vertical handover is improved by taking additional bandwidth parameters and signal-to-noise ratio (SNR). However, the author did not focus on false handover and interference issues that are of prime importance. Another work [20],executed the vertical handover using signal to interference and noise ratio (SINR). However, this method exhibited poor performance for the seamless connectivity for mobile users. The internode distances criteria is used in [21], in addition to RSS-based vertical handover decision making, in which if the distance exceeds from set threshold limit then vertical handover was initiated; however, the false handovers and packet loss were not considered.

The vertical handover using fuzzy logic was proposed in [22], which results in a better user-perceived satisfaction value called quality of experience (QoE) and enhanced battery life. The handover decision based in [23], a multicriteria approach is introduced based on the Euclidean distance for decision-making that checks for all possible ideal solutions. In these approaches, the fuzzy logic was used to calculate the metric values for handover decision making, further, the TOPSIS [24] method ranked the cell weight. However, due to the complexity of the hybrid approach, the delay increases, leading to a higher link failure. In [25], a fuzzy analytic hierarchy process approach was designed for handover decision making. In this approach, the target base station calculates the cost of the cell, one with a lower cell cost is

Different cooperative relaying-assisted handover methods are discussed in the literature. For example, in [26], a horizontal handover scheme is designed for cellular and ad hoc relaying integration. In this approach, when a mobile station enters an area of an overloaded cell, it maintains connectivity using an ad hoc relaying station. Once the base station channel gets free, the handover procedure is executed for that mobile station. However, the drawback of this scheme is its high delay cost that keeps the mobile station on hold until existing users vacant the channels.

The work presented in [27] focused on enhancing the horizontal handover between the APs by using a relay station that assists the mobile stations in maintaining their connectivity at the dead ends (i.e., no overlapping AP coverage exists). In [28], a similar approach was presented for vertical handover from WLAN to the cellular network with relaying node assistance to maintain the connectivity until the cellular network has a free channel for the mobile station. The relaying concept is also used for device-to-device (D2D) communication for data offloading in [29]; in the proposed D2D approach, when a mobile station exits from the cellular coverage, it is linked with existing cellular servicing mobile station for data downloading till the handover is completed that leads to improved channel quality and network coverage. Moreover, cooperative relaying is also analyzed in the existing literature to minimize the delay during the handover process. In [30], the RSSI-based horizontal handover is introduced that acquires the target station information from the neighbouring vehicle, which helps in reducing handover time Internet Protocol

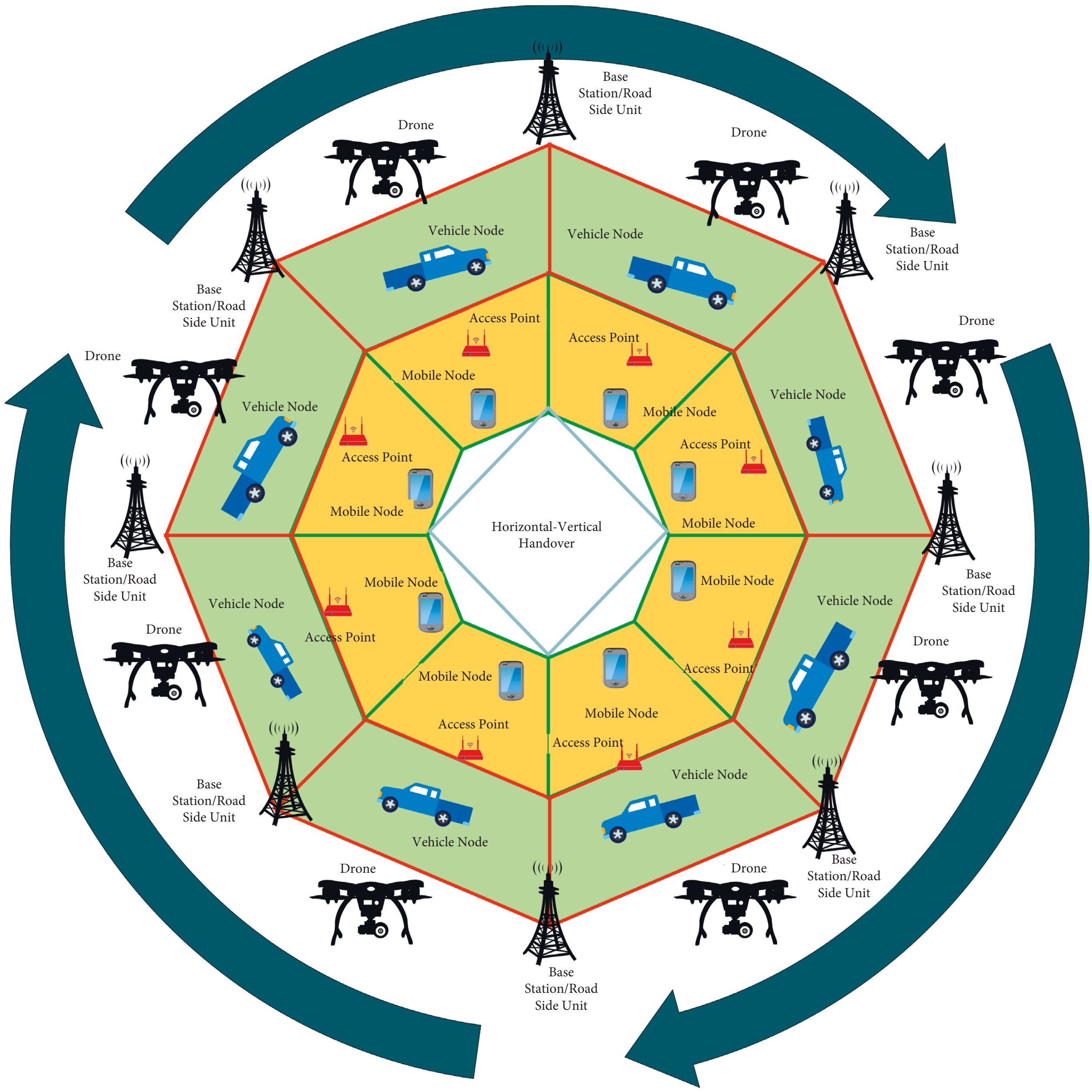

Figure 1: Horizontal and vertical handovers conceptual model.

(IP) address allocation. In [31], the control information of neighbouring BS stations are relayed to a fixed boundary relay. As a result, the mobile station timely receives the control information that helps minimize the handover delay and fast handover. In [32], neighbour vehicles are used as a partner of handover operation. The proposed partner node assists in executing prehandover signaling. Due to the partner node, the VANET handover delay is minimized. However, packet loss and the handover success rate are not analyzed. A secure vertical handover is proposed [33] where a received signal strength and user preference-based parameters are considered. Furthermore, the communication between mobile node, mobile router, foreign agent are secured using a lightweight secure algorithm are demonstrated.

The above-provided discussion of the existing scheme highlights that the existing schemes does not consider the UAV's fast mobility and seamless handover with joint performance and reliability parameters. As per our knowledge, the proposed work is the first of its kind approach for UAVs vertical handover considering high performance and reliability. Most of the existing work available in the literature considered the static relay model for handover execution. However, the limitation of the static model is it does not address the dynamic nature of the movements of the nodes while executing vertical handover, which is one of the important research challenges that compromise the performance of the communication and results in unnecessary false handover triggering. The proposed vertical handover strategy integrated with cooperative networking using the dynamic relying model is one of the first works that truly improves handover communication for fast-moving UAVs communication.

In view of the above, the main focus of this research work is to handle UAV's vertical handover issues for seamless connectivity and fast handover using cooperative relay technology. The primary contribution of the presented work is to design an intelligent relay-based vertical handover (VHO) procedure that will have timeliness, reliability, and high performance. The proposed method consists of two phases: first is the deploying intermediate nodes as a relay using the dynamic relay model [34]. The second phase deals with the handover information gathering, handover decision, and execution steps for vertical handover using the cooperative relaying technique. The significance of VHO method is the use of the relay node that performs all handover procedures on behalf of the source node that actually needs handover for its seamless connectivity and communication. The multicriteria VHO method consists of different phases.

Initially, a requirement for handover decision is made, and if it fulfills the prerequisite criteria of distance threshold and received signal strength indication (RSSI), then relay selection among n intermediate UAVs is initiated. Relaying is adopted for a fast and seamless handover experience with optimal overhead. The primary contributions are summarized as follows:

(1) Designing of a novel vertical handover method using the cooperative relaying mechanism, in which the relay node performs all handover signaling steps on behalf of the source node that does not reduce the workload of the source node but also helps improve the handover experience.

(2) Implementation of the dynamic cooperative relaying for efficient communication between source and destination, especially when both nodes are not in the line of sight with each other.

(3) Evaluation of the performance of the VHO method using extensive simulation for cooperative relaying-based handover by considering different UAVs trajectories that validate the high performance and reliable connectivity.

The rest of the paper is organized as follows: Section 2 discusses the literature review in detail. Section 3 describes the considered system model and briefly demonstrates UAVs' architecture for vertical handover operation. Section 4 is related to the implementation of dynamic relay modeling and the description of the relay-based algorithm. Results and discussion are presented in Section 5. Finally, Section 6 concludes the findings and highlights future directions.

2. Relay-Based Vertical Handover Technique

This section discusses the network model, system architecture, and the working of the proposed handover mechanism in detail.

2.1. Network Model and Definition. The considered FANET can be expressed by a graph $G = \{V, E\}$, where V is the set of vertices representing flying UAVs and relay nodes and E is the set of edges connecting vertices. E can be defined as $E = \{(i, j) \in V | (i \neq j) \wedge (d(i, j) \leq \mathrm{TR})$, where $d(i, j)$ is the Euclidean distance between ith and jth flying UAVs and TR is the transmission range. The one-hop neighbours of a UAVi, expressed as $N(\mathrm{UAV}i)$, are the set of UAVs and relay nodes in the direct transmission range of a UAVi, given as

$$N(\mathrm{UAV}i) = \{\mathrm{UAV}j \in V | d(\mathrm{UAV}i, \mathrm{UAV}j) \leq \mathrm{TR}\}. \quad (1)$$

2.1.1. Definition 1: Handover Decision. The increase in RSSI between the UAVs also changes the channel state information, and when the distance is greater than the threshold, handover takes place, as given below:

$$\mathrm{HOD} = \begin{cases} d(i, j), & \geq \text{threshold switch to wimax}, \\ d(i, j), & \langle \text{threshold don't change}. \end{cases} \quad (2)$$

2.1.2. Definition 2: Relay Node. The relay node is the VHO assistant node in the proposed scheme. The primary function of the relay node is to execute VHO on behalf of the source UAV and make the connection with access points when handover is triggered.

2.1.3. Definition 3: UAVs Communication Standard. In the proposed scheme, we assume that UAVs can communicate on network WLAN, which is 802.11 based protocol and can also communicate through WiMAX network, which is WiMAX-based protocols.

2.1.4. Definition 4: Inter UAV Distance. In the proposed scheme, the first VHO triggering point seamless handover is taken as 400 ft. when the distance exceeds this threshold, the VHO is triggered.

2.1.5. Definition 5: RSSI Threshold. In the proposed scheme, the second VHO triggering point seamless handover is taken as -70dBm. when the received signal level exceeds this threshold, the VHO is triggered.

2.2. Handover System Architecture. The inter UAV communication is based on the WLAN-based 802.11 protocol and WiMAX 802.16 protocol. It is assumed that all UAVs can carry out both types of communication (i.e., WLAN and WiMAX). When the distance between the UAVs reaches the predefined threshold, the UAV communication shifts to WiMAX-based network to facilitate long-distance communication. The considered system model consists of four phases, and a brief demonstration of the four phases is discussed in the given section. We also visually represent the system model using Figure 2 for better comprehension.

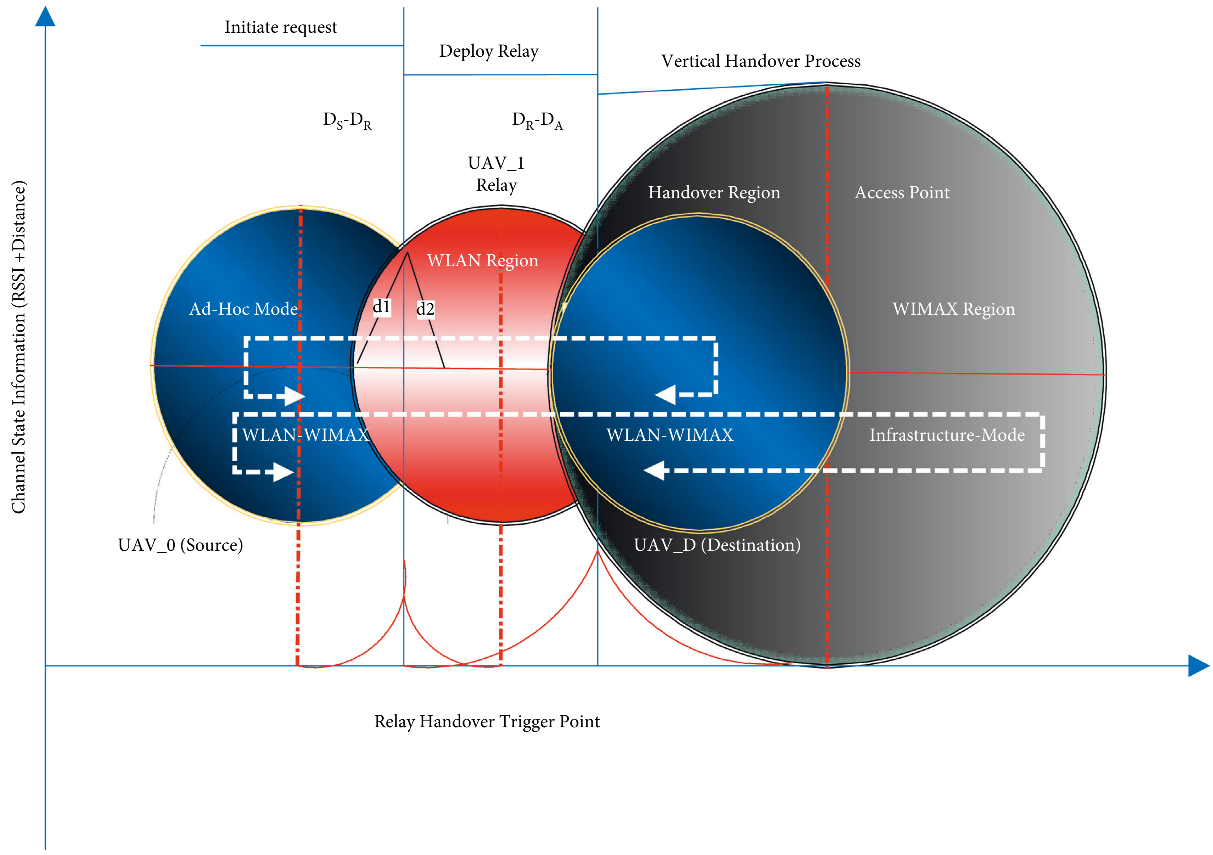

Figure 2: Relay-based vertical handover system model.

2.2.1. Handover Initiation Phase. The increase in inter UAV distance also changes RSSI for UAV communication. This change of channel state help decides whether the handover process is to be initiated for efficient QoS communication, if the RSSI is lower than the threshold limit, then the UAV checks for intermediate nodes its state to the nearby base station about the availability of the channel. The sender UAV broadcasts its address and receiver signal strength indicator (RSSI) to the neighboring relay node. In response to the UAV's VHO initiation request, the relay node sends a response message. The UAVs in the network can have the capability to keep track of the distance among UAVs using the CSI indicator, which triggers the reverse vertical handover (WIMAX-WLAN) process where UAV can once again communicate in ad-hoc mode. The common coverage area is where UAVs have both types of network access.

The handover plot is where handover initiation will take place. When the relay node receives a handover request from a UAV, it replies after coordination with the access point and availability of the free channel for performing VHO. Algorithm 1 and Algorithm 2 further demonstrate the logic of the proposed vertical handover mechanism through relay node communication.

2.2.2. Relay Selection and Deployment. Relay selection and deployment are crucial for seamless connectivity as inaccurate relay selection can severely impact cooperative relaying. Therefore, in our proposed relay-based approach, relay selection for the handover process is of prime importance to avoid unnecessary handover. In the existing literature [35–42], most relay selection approaches are based on CSI and historical information. However, both selection criteria have severe issues as it is hard to measure CSI due to rapidly varying channel conditions and fast movement of UAVs also challenges UAVs selection based on the historical information. Therefore, in our proposed handover process, relay selection is performed based on the local and stable information to avoid periodic broadcasts that cause overhead. Moreover, our relay selection approach is opportunistic and solely relies upon the overhearing frames.

In this work, to avoid unnecessary handover, each node maintains neighbor's information based on interference, mobility factor (m), and history factor (h). This way, a stable node can be used as a relay for transmission. Furthermore, the relaying initiation signal is embedded in handshake messages to avoid additional control messages as shown in equation (2).

Equation (2) shows our proposed selection factor (S), where is I is the interference factor.

$$S = \frac{(H \times M)}{(1 + I)}, \quad S \in [0, 1], \tag{3}$$

where the mobility factor M is the ratio between an exponential moving average of the pause time of the node and the maximum detected pause time (MM), which is initiated to a

```
//Relay node Selection and deployment//
Input: Relay Node Location R (XR, YR), Relay Pool (U = 1, 2, 3, . . ., n), RSSI Threshold (RS_Th), Inter UAV Distance (D_Uo, D_U1, D_Un), SNR
Output: Optimal vertical handover Success rate (VHO_Success Probability), 0 ≤ V_S ≤ 1
  Initialize periodic time = Δt;
    for each m ϵ [0, M] do
    if i = 0 then
    Compute Source node location and velocity (C_0 [mth Slot], V_0[mth slot]);
    Deploy relay node at C_0 (m + 1);
    if Update message of relay fails then
    Pick another Relay node from pool U_i; T_update
    Update T_update = t;
    endif
    elseif i ϵ [1, n] then
    Get update message from source node U_0;
    Compute C_i [m + 1];
    Synchronize Trajectory along Source node
    endif
    end for
```

ALGORITHM 1: Relay selection and deployment.

```
/ * Received Signal strength indication, signal to noise ratio, Channel state information parameters, inter UAV distance inputs are given to Algorithm 2 for handover triggering. * /
Monitor RSSI, SNR, and CSI and inter UAV distances (Source to relay, relay to destination)
//Handover Triggering based on Distance and RSSI-based information //
    if (Distance between UAV || RSSI) < D threshold ||(RSTh) then
    Initiate vertical handover
    Select Relay at location Ci[m + 1];
    Request Base Station (BS) to reserve slot for node U0;
    BS reply to Ui with reserve slot for U0;
    end if
    else if U0 also Compute BS > RSSI threshold
    U0 send vertical handover request through Ui
    BS allocate resource to Uo on behalf of Ui
    Confirmation sent to relay node Ui and source node U0
    U0 initiate authentication
    BS responds to authentication
    U0 send confirmation message to relay node
    end if
```

ALGORITHM 2: Vertical handover using cooperative relaying.

time unit [43]. H is the ratio of successful transmission duration to the maximum duration of any successful transmission. The aim is to select a relay with an excellent channel to the destination. The factor I refer to is interference level, computed by relays total transmissions. Additionally, relays aim is to reduce additional blockages.

The existing approaches used a static model of relying on that does not address the dynamic movement of the nodes. We have designed our approach using the dynamic relaying model for better synchronization to overcome this issue, as shown in Figure 3.

The considered scenario is also highlighted in Algorithm 1, where two types of trajectories are considered for use cases. In use case 1, U-shaped relaying model is adopted for

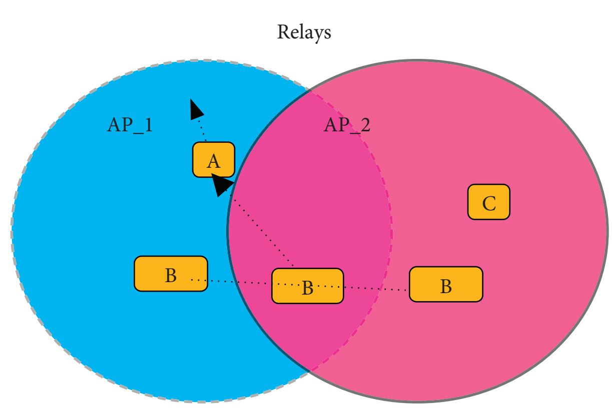

FIGURE 3: Avoiding unwanted handover.

seamless handover and efficient link stability. In U-shaped relay deployment, all relaying nodes synchronize their movement as per source and destination nodes until the handover is completed. Hence, we have an alternate path for source-destination transmission. The same opportunistic relay selection procedure is used to use a relay (s) for the handover process. However, relaying is initiated reactively for the opportunistic relay selection, where relays are only used when the direct link fails, and the relay is used for assistance.

2.2.3. Handover Execution Phase. The handover process is executed after the suitable relay selection and deployment. The prerequisite for the vertical handover process is two parameters (i.e., RSSI and inter UAVs distance D), and they both are used for vertical handover triggering. The distance D threshold value is set to 400 ft, while the RSSI minimum value is set to −70 dBm according to the required minimum RSSI value for reliable packet delivery. When inter UAVs distance and RSSI value from source UAVS to destination UAVD reach the threshold limit, they enter a critical region where vertical handover occurs. The relaying node during the deployment phase records the source UAV's and destination UAV's MAC address for handover resource allocation from the WiMAX base station. In the considered scenario, the following assumptions are made:

(i) Relay nodes are equipped with both types of radio modules, WLAN 802.11 and WiMAX 802.16 protocol.
(ii) Relay nodes can communicate using both modules for resource allocation on behalf of source UAVs for better vertical handover assistance.
(iii) Relaying nodes selected for assistance works simultaneously on WiMAX as well WLAN mode.
(iv) Relay nodes are trustable nodes to ensure privacy.
(v) Algorithm 1 is used for relay selection and deployment.
(vi) Algorithm 2 is used for vertical handover using cooperative relaying.

The complete handover mechanism can be elaborated as below:

(1) When a source UAV selects one relay node as handover assistance, it requests the relay node to perform a handover request with the WiMAX base station on its behalf. The source UAV request consists of preauthentication [44] with the WiMAX base station. After authentication, the relay node is responsible for performing preregistration with the WiMAX station. The relay node also stores the IP and identity of the source UAVs, destination UAV_D, and authentication information.
(2) If the selected relay node can satisfy the request, it replies with a "prob" success response. Once the relay node gets authenticated and preregistered with the WiMAX base station, it requests to allocate resources for source UAVs vertical handover and send the connection information to the source UAV.
(3) The relay node sends the base station response about the handover process (i.e., new IP and authentication information) to the source UAV.
(4) Then, the source UAV replies after changing mode to the WiMAX radio interface, and due to the preregistration information, the source UAV is quickly authenticated with the WiMAX base station.
(5) After the successful handover, the source UAVs swiftly attaches with the WiMAX base station without any authentication or preregistration, resulting in fast handover. The exact process is carried out for destination UAV_D using relay-assisted handover. If the destination UAV_D is already in the WiMAX range, it directly authenticates itself with the WiMAX base station. In Figure 4, flow diagram of the complete process is shown.

In Figure 2, relay-assisted handover is visually depicted, where the source UAV moves to the outside radius of WLAN operation. The relay node represented with a dotted circle in Figure 2 performs handover for the source UAV. Similarly, the destination node is outside the direct coverage of the source UAV, but it is inside the boundary of a relay node. So, both source and destination perform vertical handover using our relay-assisted handover approach. The signaling procedure is also highlighted in Figure 5 for better procedure picture.

3. Experiments

In this section, we demonstrate the simulation environment and performance metrics thoroughly. Moreover, we also discuss the simulation results extensively to highlight the effectiveness of the proposed scheme.

3.1. Simulation Environment and Configurations. The effectiveness of the proposed relay-based vertical handover mechanism is evaluated using available network tools/simulators [45]. The considered simulation scenario has 03 UAVs (i.e., source node UAV0, relaying node UAV1, and the destination node UAV2) randomly distributed in a 500 × 500 meter area. The relaying mechanism is constructed using relaying handover. The location of the access point is selected near the destination UAV2. Suppose a UAV wants to collect the data from sensors network out of the direct range of the transmission. It cooperatively chose the intermediate nodes using Algorithm 1. This process helps in optimal relay selection. Afterward, vertical handover is executed using Algorithm 2. UAV speed in the trajectory module is set at 15 m/s, the communication radius of each UAV is 200 meters, and the location update of UAV0 is set to be 0.5 seconds. Initially, source and destination nodes are operating on the 802.11 protocol. We have used different versions of the 802.11 protocol as per high, medium, and low traffic requirements. For example, for low traffic demand, we used the 802.11b version. The simulation parameters are also

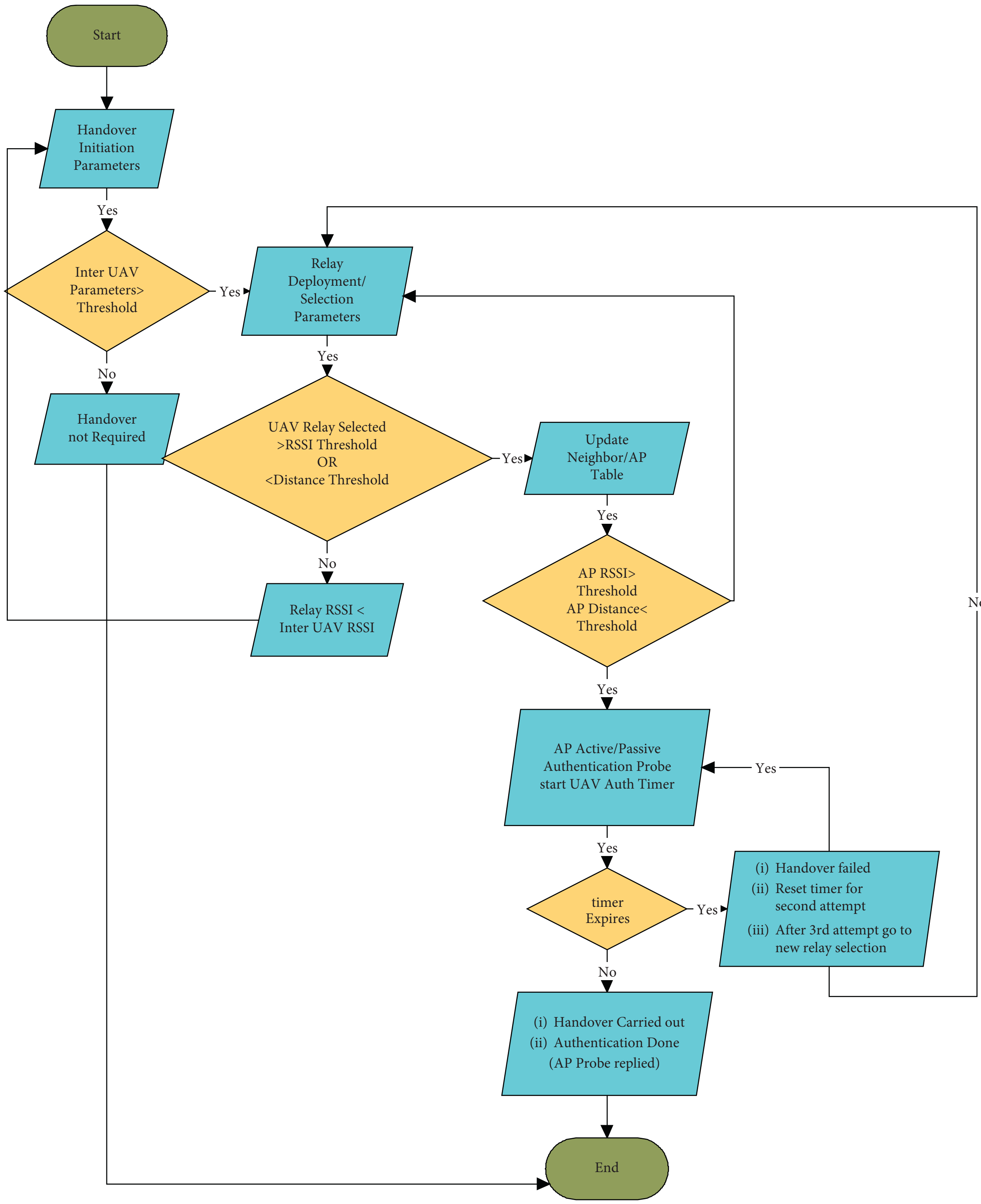

Figure 4: Relay-based vertical handover flow diagram.

shown using Tables 1–3 and Figure 6 visually represents the considered topology for better understanding.

Moreover, we also verify the performance of our proposed scheme using two different trajectories (i.e., U-shaped and S-shaped trajectories) to highlight the handover experience in both trajectories considering their advantages and limitations. For example, the U-shaped trajectory is more suited for the target application areas due to its high effectiveness for line of sight (LoS) communication and less interference when more than one intermediate relays are involved. However, U-shaped trajectories are not suitable for short or narrow landscape areas due to implementation

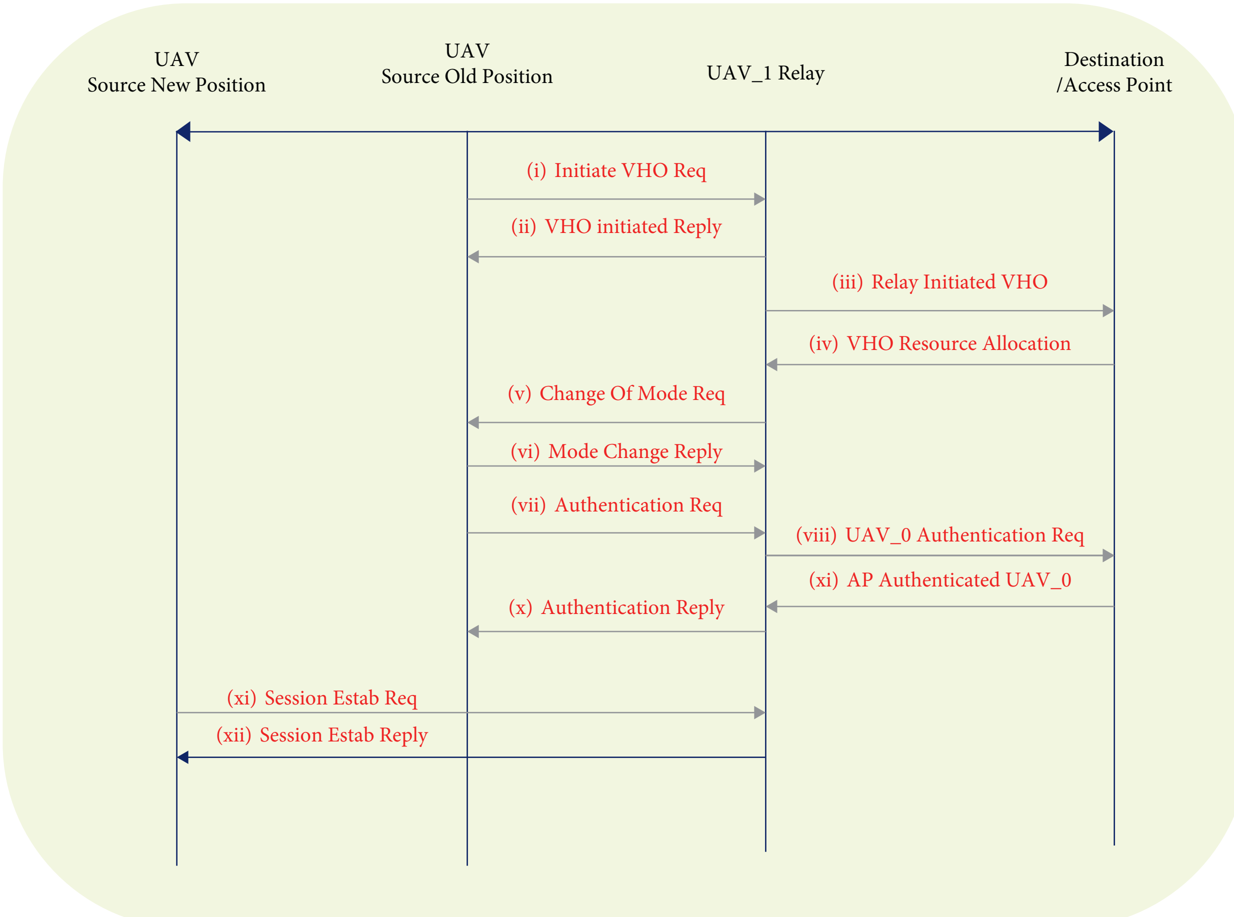

Figure 5: The vertical handover signaling procedure.

Table 1: Simulation parameters.

Parameter	Value
RSSI value	−70 dBm
Distance threshold	400 ft
UAV velocity	10 km/h
UAV altitude	50 ft
UAV communication radius	300 ft
Inter-UAV distance	100 ft, 200 ft, 300 ft, 400 ft, 500 ft, 600 ft, 700 ft
Trajectory shape	U And S shape
Authentication time	1 s
Registration time	1 s
WiMAX attachment time	0.2 s
WLAN detachment time	0.2 s
Relay node handover time	1 s
Relay handover completion	2 s
Packet size	256 bytes
Simulation time	300 sec

Table 2: WLAN 802.11 transmission range properties [46].

Scenarios	WLAN	Frequency (GHz)	Date rate (Mb/S)	Outdoor distance (ft)
S-shaped, U-shaped	802.11*b*	2.4	11	158
			5.5	220
			2	245
			1	328
S-shaped, U-shaped	802.11*a*	5	6–54	390
S-shaped, U-shaped	802.11 g	2.4	6–54	460

issues of U-shaped relays in such sites. In contrast, an S-shaped trajectory has high adoptability for various applications where LoS is purely affected by landscape dimensions such as rough- and sharp-edged terrain areas (i.e., mountains valleys surveillance) or dense areas (i.e., building, tree, and industrial tree use). However, S-shaped trajectory experiences more inter UAV interference than U-shaped trajectory, especially when intermediate relaying nodes are increased. The obtained result using the discussed trajectories provides more insights into the handover mechanism's performance in the diverse dimensions.

Furthermore, we compare our proposed handover mechanism with the existing schemes RSS and bandwidth-based vertical handovers schemes. To evaluate our proposed scheme's improvements and contributions, we use U and S-shaped trajectories for effective simulation results.

Table 3: 3G/4G (WIMAX) range properties [47].

Scenarios	WiMAX	Frequency (GHz)	Date rate (Mb/S)
S-shaped trajectory	802.16*e*	<6	NLOS up to 10 km LoS up to 30 km
U shaped trajectory	802.16*e*	<6	NLOS up to 10 km LoS up to 30 km
S-shaped trajectory	802.16 m	2–6	NLOS 5 km
U shaped trajectory	802.16 m	2–6	NLOS 5 km

Figure 6: Vertical handover simulation topology.

3.2. Performance Metrics. We have used the following metrics to evaluate the performance of the proposed handover mechanism.

3.2.1. Probability of Handover Success Rate (PHSR). It is the ratio of successful handover carried out using cooperative relaying divided by total handover attempts. Using equation (3), the probability of handover success rate is calculated. Where n is the total number of handover triggered and x is the successful handovers.

$$\text{PHSR} = \left(\frac{x}{N}\right). \quad (4)$$

3.2.2. End-to-End Delay. It is average time a packet has taken to reach its destination after going through relaying nodes—for example, the time consumed in reaching from source to relay node delay and then from relay node to the destination node.

3.2.3. Packet Loss. The count of total packets dropped during vertical handover from source to destination.

3.2.4. Optimal Relaying. It measures when, where, and how many relays are to be used for a seamless handover experience. The more relays addition means more delay from source to destination. Similarly, the proposed algorithm avoids unnecessary relay deployment and handover initiation if nodes are in direct range.

4. Results and Discussion

We evaluated the performance of the proposed mechanism in two trajectories to evaluate the experience of our proposed handover process. The obtained results are discussed separately in the given section.

4.1. U-Shaped Trajectory. In the U-shaped trajectory, vertical handover is initiated when source UAV U0 moves away from the range of destination UAV U_D, leading to increased packet loss and delay. When distance approach 400 ft value, the vertical handover is triggered. Similarly, when RSSI drops below −70 dBm, the vertical handover process also starts. We are using both distance and RSSI-based triggering for better and more accurate handover initialization. When any conditions (i.e., distance or RSSI) meet the criteria, the handover initialization occurs. Once the handover is initiated, two main steps are followed. First, the relay node deployment is performed as per Algorithm 1. Second, vertical handover over is executed using Algorithm 2. The 802.11*b* communication is shifted to WiMAX technology when the handover is completed. The obtained results for vertical handover in the U-shaped trajectory are described below.

4.1.1. Probability of Handover Success Rate for U-Shaped Trajectory. The probability of handover success rate for U-shaped trajectory with the different number of relays is represented using Figure 7, in which the probability success rate values are in the range of 0 to 1. The values closer to one signify a high success rate of vertical handover execution, while the values close to zero show a low success rate. From Figure 7, we can observe that the successful handover rate is less when distance is short 100 ft, 150 ft, or 200 ft). In contrast, when the distance is increased, the probability of success rate is also improved. Based on the provided result, we can see that the probability of success rate is highest with 1 relay for both short and long distances because relaying node helps in better link stability and can better enhance the internode communication.

4.1.2. Average End-To-End Delay for U-Shaped Trajectory. It can be observed from the U-shaped end-to-end delay shown in Figure 8 that when single relay UAV1 is used between source UAV0 and destination UAV2, then the average end-to-end delay is minimum for both short and long distances (i.e., 50 ft and 650 ft). However, when the number of relays is increased to two, four, and eight UAVs, the average end-to-end delay is increased to 1.8 seconds, 2.5 seconds, and 4.3 seconds, respectively. Furthermore, when the relay nodes are increased, the time relay nodes take to synchronize their movement with the source node also increases, affecting average end-to-end delay.

Based on the obtained end-to-end delay results, it is evident that when a large number of relay UAVs are deployed to cover a large area, it maintains a high network lifetime and a seamless handover experience. However, it also increases the end-to-end delay experienced.

4.1.3. Packet Loss for U-Shaped Trajectory. From Figure 9, we can see that before the handover is initiated, the packet loss was high due to increasing inter UAVs distance. However, the packet loss decreased significantly after the successful handover at 400 fts or RSSI drop below −70 dBm. Deploying a different number of relaying UAVs also influences packet loss as represented using Figure 10; when one UAV is used, the packet loss value is 32 bytes, which is decreased to 25, 19, and 15 bytes for two, four, and eight relay nodes, respectively. The significant improvement in the packet loss is mainly due to the relaying nodes dynamically updating their positions for maintaining a stable connection between the source and destination.

The U-shaped trajectory result proved that it is a highly adaptable trajectory for open and wide-area surveillance, data collection, and transmission. In the case of a single relay and multiple relays, it is concluded that performance parameters of the probability of handover success rate are close to 1. Similarly, the parameters of end-to-end delay are within the time constraint of seamless handover that should be less than 3 seconds. However, as we add more relays between source and destination, the delay factors increase accordingly. Furthermore, for the best handover experience, two relay nodes are optimal for seamless handover. Therefore, the optimal packet loss range observed in a U-shaped trajectory is when we deploy two relays for the handover process.

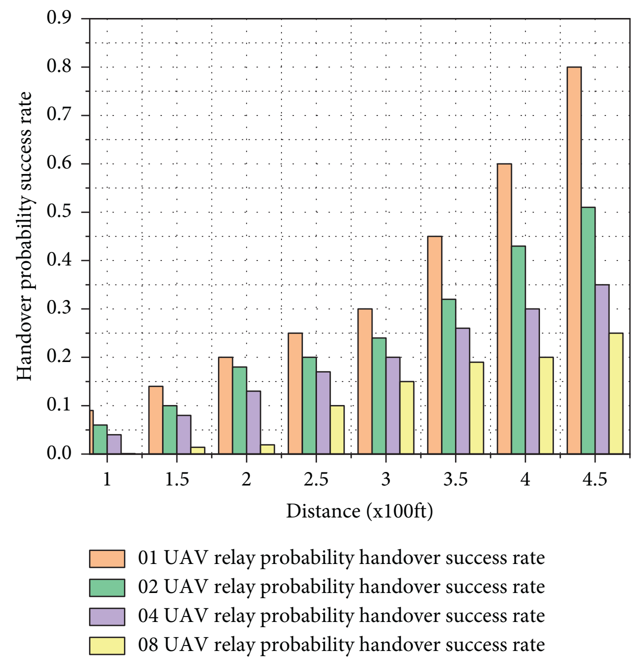

Figure 7: U-shaped trajectory probability handover success rate.

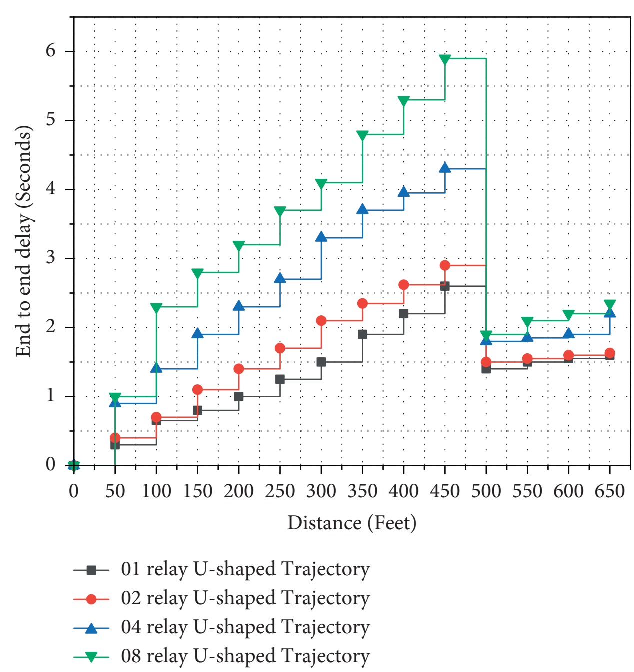

Figure 8: U-shaped trajectory vertical handover end-to-end delay.

4.2. S-Shaped Trajectory. For evaluating the handover experience in the S-shaped trajectory, the coordinates of flying UAV0 are set at (300, 0), as shown in Figure 6. For the

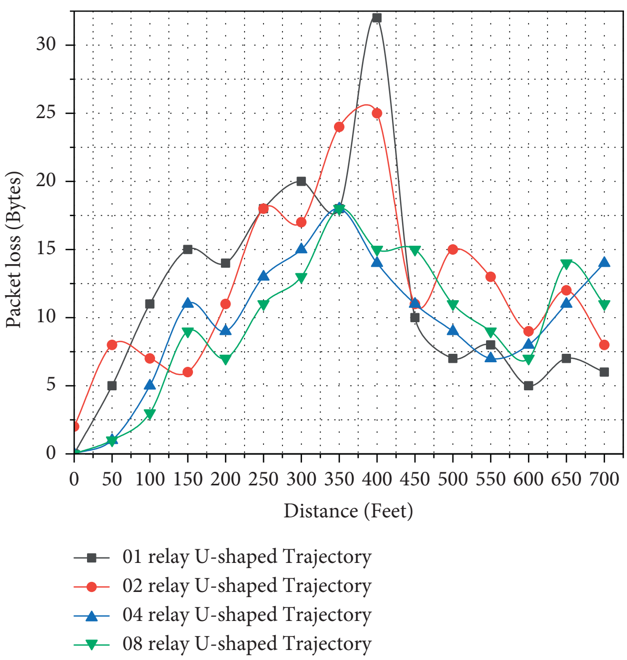

Figure 9: U-shaped trajectory vertical handover packet loss.

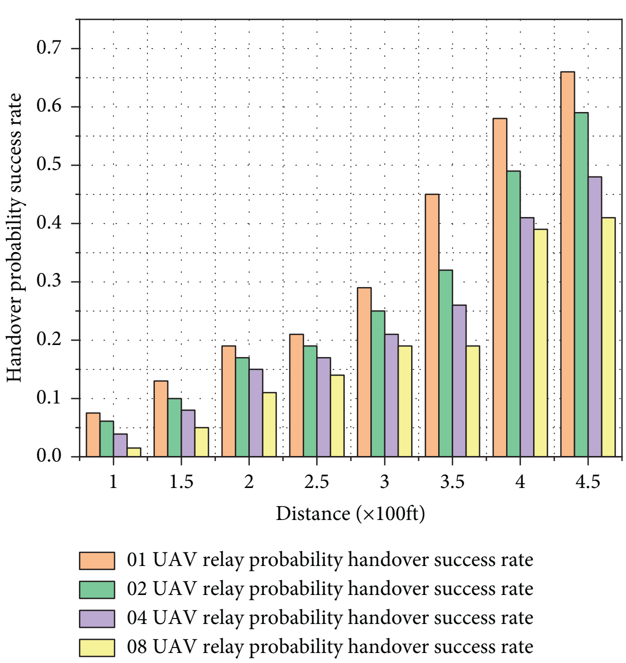

Figure 10: S-shaped trajectory probability handover success rate.

U-shaped trajectory, the velocity is set to 10 km/h, whereas the rest of the settings are the same as the U-shaped tajectory. The performance of the S-shaped trajectory is also analyzed under the numerical results heading.

4.2.1. Probability of Handover Success Rate for S-Shaped Trajectory. The probability of handover success rate for the S-shaped trajectory with a different number of relays is represented using Figure 10, with the probability success rate in the range of 0 to 1. The values closer to one signify a high success rate of vertical handover execution, while the values close to zero show a low success rate. From Figure 10, we can observe that the successful handover rate is low when distance is short (such as 100 ft, 150 ft, or 200 ft). In contrast, when the distance is increased, the probability of success rate is also improved because of the accurate triggering of the handover using distance and RSSI threshold. It can also be observed from Figure 10 that at 450 ft distance, when one, two, four, and eight relay nodes are used, the handover success rate is 0.7, 0.6, 0.45, and 0.39, respectively. Based on the provided result, we can see that the probability of success rate is highest with one relay for both short and long distances.

4.2.2. Average End-To-End Delay for S-Shaped Trajectory. It can be observed from Figure 11 that when single relay UAV1 is used between source UAV0 and destination UAV2, then the average end-to-end delay is minimum for both short and long distances (i.e., 50 ft and 450 ft). However, at the handover trigger point of 450 ft, the average end-to-end delay observed for one, two, four, and eight relays are increased to 2.9 seconds, 3.3 seconds, 4.9 seconds, and 6.5 seconds, respectively, because with the increase in the relay nodes also increases the time required by the relay nodes for synchronization with the source node, leading to increased end-to-end delay. Second, more nodes in the S-shaped trajectory cause self-interference that affects overall communication.

Based on the obtained end-to-end delay results, it is evident that when a large number of relay UAVs are deployed to cover a large area, it maintains a high network lifetime and a seamless handover experience. However, it also increases the end-to-end delay experienced.

4.2.3. Packet Loss for S-Shaped Trajectory. Figure 12 represents the packet loss experienced with different relays in the S-shaped trajectory. We can see from the obtained results that the packet loss value is 25 bytes when one UAV is used as a relay node. Whereas these values are reduced to 22, 17, and 34 bytes for two, four, and eight relay nodes, respectively. Thus, the decrease in the packet loss is due to the increase in the relay nodes that leads to better overall network connectivity and improved packet delivery. According to the obtained results, we can conclude that the S-shaped trajectory is efficient in narrow terrain areas due to the node's movement in fast turning points. Therefore, this Trajectory's handover success rate probability is in between 0.7 and 0.4 for considered relay nodes. The end-to-end best values are observed when one or two relay nodes are used. In contrast, the increased number of relay nodes can significantly reduce packet loss. However, increase the average end-to-end delay for overall communication. Based on the obtained results, we can observe that the two relay nodes provide the optimal packet loss value and do not significantly impact the average end-to-end delay.

4.3. Comparison of U- and S-Shaped Trajectory with Existing Techniques. In addition to the performance assessment of the proposed vertical handover procedure for the U-shaped and

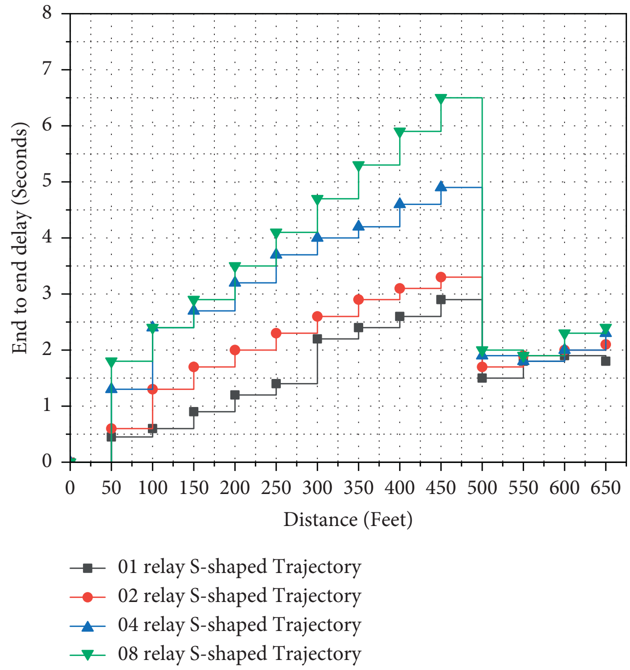

Figure 11: S-shaped trajectory vertical handover end-to-end delay.

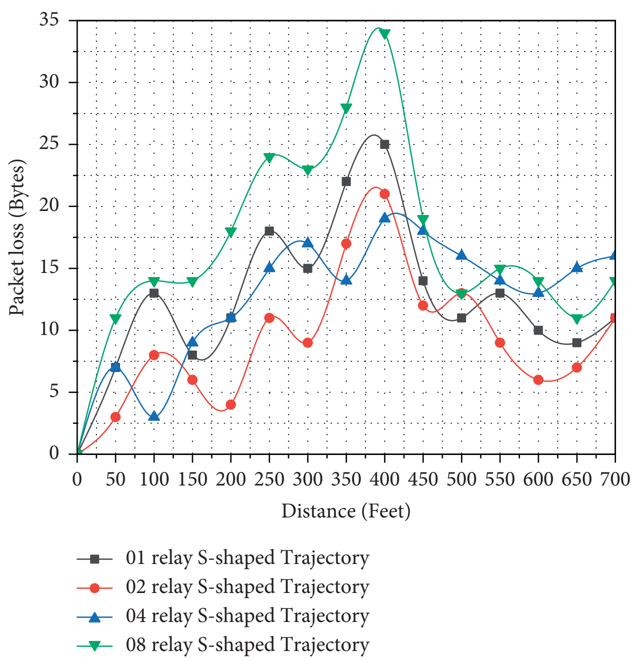

Figure 12: S-shaped trajectory vertical handover packet loss.

S-shaped trajectories, we also compared our proposed scheme performance with the state-of-the-art schemes. The comparison is carried out with CVHO-RSS [48] and CVHO-BW [49] schemes for UAVs vertical handover for keeping performance constraints of success rate, packet loss, and end-to-end delay.

4.3.1. Probability of Handover Success. In Figure 13, the comparison of proposed U- and S-shape-based vertical handovers are carried with existing schemes. It can be

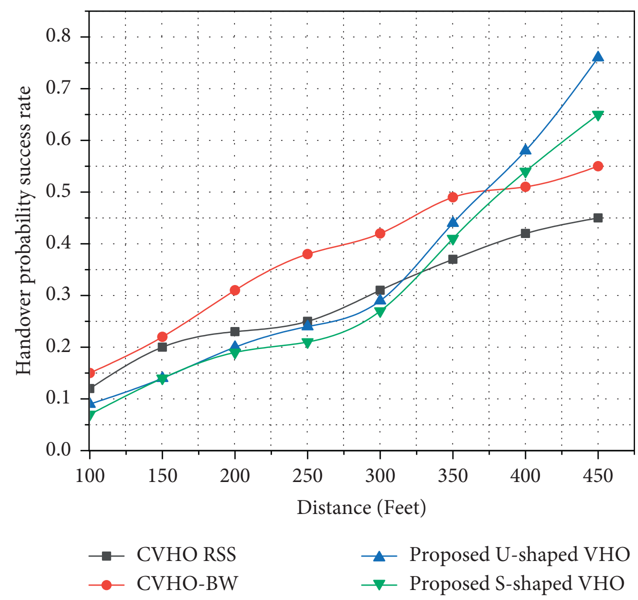

Figure 13: Probability handover success rate comparison with existing techniques.

observed from Figure 13 that at 450 ft distance between source and destination UAV nodes, the handover success rate for CVHO-RSS and CVHO-BW is 0.42 and 0.51, respectively. On the other hand, the U- and S-shaped trajectory-based handover rate of our proposed scheme is 0.76 and 0.65, respectively. Our proposed scheme experiences high success rate for both U- and S-shaped trajectories due to relay nodes assistance that helps them to perform well and results in accurate handover triggering.

4.3.2. End-To-End Delay. From Figure 14, it is evident that the end-to-end delay for S-shaped and S-shaped is less than CVHO-RSS and CVHO-BW based vertical handover scheme due to link stability and relaying node-based vertical handover execution. For example, at the handover trigger point of 450 ft, the U-shaped and S-shaped values are 2.4 seconds and 2.7 seconds, respectively. In contrast, the CVHO-RSS [50] and CVHO-BW [49] schemes experience a higher delay (i.e., 2.9 and 3.5 seconds, respectively).

4.3.3. Packet Loss. It can be seen from Figure 15 that packet loss values are higher in CVHO-RSS and CVHO-BW schemes, as in both these schemes, handovers are performed independently without any relay node assistance. Whereas in our proposed scheme, relay node cooperation helps in better connectivity, leading to better packer delivery at destination. The packet loss experienced for CVHO-RSS and CVHO-BW increased to 85% and 43% as the internodes distance increased to 450 ft. On the other hand, our proposed scheme experiences significantly low packet loss for both U- and S-shaped trajectories.

The comparison of our proposed scheme with the existing schemes proves that our proposed vertical handover procedure exhibits better performance and is more efficient

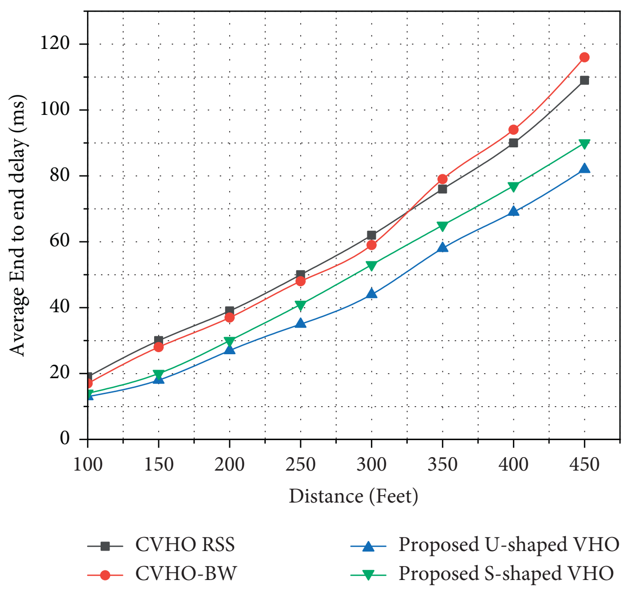

Figure 14: End-to-end delay comparison with existing techniques.

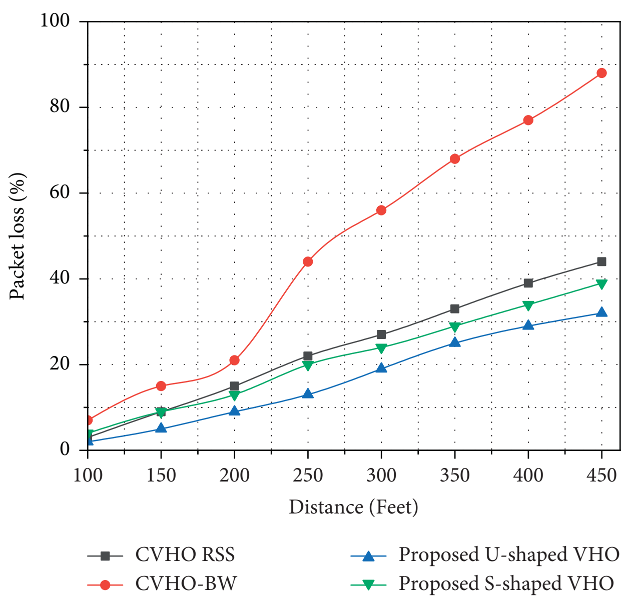

Figure 15: Packet loss comparison with existing techniques.

and adaptable for all the considered metrics for both trajectories than the CVHO-RSS and CVHO-BW schemes. In Table 4, comparison of proposed and existing techniques is shown. The obtained results for all the performance metrics clearly show that relay-assisted handover has a high potential for achieving fast, accurate, and seamless handover than the existing scheme.

5. Conclusion

The relay-based VHO solution attempts to make a fast and seamless vertical handover from 802.11 WLAN-based UAV network to WiMAX technology network. The proposed work is an effort to provide a vertical handover using relay assistance. Our proposed relay-assistant handover handles the vertical handover procedure through which all handover tasks are being performed. The obtained results demonstrate that our proposed scheme outperforms the existing schemes in terms of end-to-end delay, packet loss, and handover success rate for both U- and S-shaped trajectories that ultimately help in UAVs relay-based fast handover.

In the future, we will focus on providing a more diverse and robust handover solution to introduce higher diversity gain for reliable communication. Additionally, the real time and nonreal time application of voice, video, and data are to be implemented in future work. Moreover, we will also focus on the security aspect, as security is one of the critical issues of relay selection as the selection of malicious nodes can compromise the whole network. Therefore, we will include security aspects during relay selections in future work.

Table 4: Comparison of proposed and exising handover approaches.

Techniques parameters	Probability of handover success rate	End-to-end delay	Packet loss	Single relay	Multiple relays
CVHO-RSS [50]	No	Average	High	No	No
CVHO BW [49]	No	Low	Average	Yes	No
S-shaped trajectory [proposed]	Average	Low	Low	Yes	Yes
U-shaped trajectory [proposed]	High	Low	Low	Yes	Yes

Data Availability

All data generated or analyzed during this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

Acknowledgments

This research was funded by Princess Nourah bint Abdulrahman University Researchers, supporting project number (PNURSP2022R125), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

References

[1] Y. S. Wang, Y. W. P. Hong, and W. T. Chen, "Trajectory learning, clustering, and user association for dynamically connectable UAV base stations," *IEEE Trans. Green Commun. Netw.*vol. 4, no. 4, pp. 1091–1105, 2020.

[2] O. S. Oubbati, A. Lakas, F. Zhou, M. Güneş, and M. B. Yagoubi, "A survey on position-based routing protocols for Flying Ad hoc Networks (FANETs)," *Vehicular Communications*, 2017.

[3] J. Boubeta-Puig, E. Moguel, F. Sanchez-Figueroa, J. Hernandez, and J. Carlos Preciado, "An autonomous UAV architecture for remote sensing and intelligent decision-making," *IEEE Internet Comput*, vol. 22, 2018.

[4] L. Guezouli, K. Barka, and A. Djehiche, "UAVs's efficient controlled mobility management for mobile heterogeneous wireless sensor networks," *Journal of King Saud University - Computer and Information Sciences*, vol. 34, no. 6, pp. 2461–2470, 2022.

[5] S. B. M. Baskaran, G. Raja, A. K. Bashir, and M. Murata, "QoS-aware frequency-based 4G+Relative authentication model for next generation LTE and its dependent public safety networks," *IEEE Access*, vol. 5, pp. 21977–21991, 2017.

[6] X. Li, F. Liu, Z. Feng, G. Xu, and Z. Fu, "A novel optimized vertical handover framework for seamless networking integration in cyber-enabled systems," *Future Generation Computer Systems*, vol. 79, pp. 417–430, 2018.

[7] S. Santi, T. De Koninck, G. Daneels, F. Lemic, and J. Famaey, "Location-based vertical handovers in wi-fi networks with IEEE 802.11ah," *IEEE Access*, vol. 9, pp. 54389–54400, 2021.

[8] K. Hazra, V. K. Shah, S. Roy, S. Deep, S. Saha, and S. Nandi, "Exploring biological robustness for reliable multi-UAV networks," *IEEE Transactions on Network and Service Management*, vol. 18, no. 3, pp. 2776–2788, 2021.

[9] H. Zemrane, Y. Baddi, and A. Hasbi, "Mobile ad hoc network routing protocols for intelligent transportation systems," *International Journal of Smart Security Technologies*, vol. 8, no. 1, pp. 35–48, 2021.

[10] S. Ullah, G. Abbas, M. Waqas, Z. H. Abbas, S. Tu, and I. A. Hameed, "Eemds: an effective emergency message dissemination scheme for urban vanets," *Sensors*, vol. 21, no. 5, p. 1588, 2021.

[11] Y. Su, X. Lu, Y. Zhao, L. Huang, and X. Du, "Cooperative communications with relay selection based on deep reinforcement learning in wireless sensor networks," *IEEE Sensors Journal*, vol. 19, no. 20, pp. 9561–9569, 2019.

[12] J. H. Bang, S. Oh, K. Kang, and Y. J. Cho, "A bayesian regression based LTE-R handover decision algorithm for high-speed railway systems," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 10, pp. 10160–10173, 2019.

[13] M. Ali Hassoune, Z. Mekkakia Maaza, and S. M. Senouci, "Vertical handover decision algorithm for multimedia streaming in VANET," *Wireless Personal Communications*, vol. 95, no. 4, pp. 4281–4299, 2017.

[14] F. Lemic, A. Behboodi, J. Famaey, and R. Mathar, "Location-based discovery and vertical handover in heterogeneous low-power wide-area networks," *IEEE Internet of Things Journal*, vol. 6, 2019.

[15] E. Demarchou, C. Psomas, and I. Krikidis, "Mobility management in ultra-dense networks: handover skipping techniques," *IEEE Access*, vol. 6, pp. 11921–11930, 2018.

[16] B. Duan, C. Li, J. Xie, W. Wu, and D. Zhou, "Fast handover algorithm based on location and weight in 5g-r wireless communications for high-speed railways," *Sensors*, vol. 21, no. 9, p. 3100, 2021.

[17] E. Zakaria, A. Taman, and A. Zekry, "A novel vertical handover algorithm based on Adaptive Neuro-Fuzzy Inference System (ANFIS)," *International Journal of Engineering & Technology*, vol. 7, no. 1, 74 pages, 2018.

[18] T. Ali and M. Saquib, "Performance evaluation of WLAN/cellular media access for mobile voice users under random mobility models," *IEEE Transactions on Wireless Communications*, vol. 10, no. 10, pp. 3241–3255, 2011.

[19] S. Alam, S. Sulistyo, I. W. Mustika, and R. Adrian, "Utility-based horizontal handover decision method for vehicle-to-vehicle communication in VANET," *International Journal of Intelligent Engineering and Systems*, vol. 13, no. 2, pp. 1–10, 2020.

[20] K. Kiran and D. Rajeswara Rao, "5G heterogeneous network (HetNets): a self-optimization technique for vertical handover management," *International Journal of Pervasive Computing and Communications*, vol. 17, 2021.

[21] S. Goutam, S. Unnikrishnan, and P. Lalit, "Analysis of handover decision in heterogeneous wireless networks based on user trajectory and operating frequency," *International Journal of Mobile Network Design and Innovation*, vol. 10, no. 1, p. 48, 2020.

[22] T. Coqueiro, J. Jailton, T. Carvalho, and R. Francês, "A fuzzy logic system for vertical handover and maximizing battery lifetime in heterogeneous wireless multimedia networks," *Wireless Communications and Mobile Computing*, vol. 2019, pp. 1–13, 2019.

[23] Z. Juwantara, M. Abdurohman, and S. Prabowo, "M2EW algorithm for increasing the degree of precision of vertical handover network selection," *International Journal of Intelligent Engineering and Systems*, vol. 10, no. 6, pp. 174–181, 2017.

[24] Q. Liu, C. F. Kwong, S. Zhang, and L. Li, "Fuzzy-TOPSIS based optimal handover decision-making algorithm for fifth-generation of mobile communications system," *Journal of Communications*, vol. 14, no. 10, pp. 945–950, 2019.

[25] M. Drissi, M. Oumsis, and D. Aboutajdine, "A multi-criteria decision framework for network selection over LTE and WLAN," *Engineering Applications of Artificial Intelligence*, vol. 66, pp. 113–127, 2017.

[26] H. Wu, S. De, C. Qiao, E. Yanmaz, and O. K. Tonguz, "Hand-off performance of the integrated cellular and ad hoc relaying (iCAR) system," *Wireless Networks*, vol. 11, no. 6, pp. 775–785, 2005.

[27] M. He, T. D. Todd, D. Zhao, and V. Kezys, "Ad hoc assisted handover for real-time voice in IEEE 802.11 infrastructure WLANs," in *Proceedings of the 2004 IEEE Wireless Communications and Networking Conference, WCNC*, Atlanta, GA, USA, March 2004.

[28] P. Khadivi, S. Samavi, H. Saidi, T. D. Todd, and D. Zhao, "Dropping rate reduction in hybrid WLAN/cellular systems by mobile ad hoc relaying," *Wireless Personal Communications*, vol. 39, no. 4, pp. 515–542, 2006.

[29] A. Orsino, M. Gapeyenko, L. Militano et al., "Assisted handover based on device-to-device communications in 3GPP LTE systems," in *Proceedings of the 2015 IEEE Globecom Workshops, GC Wkshps 2015 - Proceedings*, San Diego, CA, USA, December 2015.

[30] Y. Bi, "Neighboring vehicle-assisted fast handoff for vehicular fog communications," *Peer-to-Peer Netw. Appl*, vol. 11, no. 4, pp. 738–748, 2018.

[31] S. Jeon and S. Lee, "A relay-assisted handover technique with network coding over multihop cellular networks," *IEEE Communications Letters*, vol. 11, no. 3, pp. 252–254, 2007.

[32] H. Ahmed, S. Pierre, and A. Quintero, "A cooperative road topology-based handoff management scheme," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 4, pp. 3154–3162, 2019.

[33] V. R. Reddicherla, U. Rawat, Y. J. N. Kumar, and A. Zaguia, "Secure vertical handover to NEMO using hybrid cryptosystem," *Security and Communication Networks*, vol. 2021, Article ID 6751423, 12 pages, 2021.

[34] H. Lu, X. Wei, H. Qian, and M. Chen, "A cost-efficient elastic UAV relay network construction method with guaranteed QoS," *Ad Hoc Networks*, vol. 107, Article ID 102219, 2020.

[35] S. M. Hussain and K. M. Yusof, "Dynamic Q-learning and fuzzy CNN based vertical handover decision for integration of DSRC, mmWave 5G and LTE in Internet of vehicles (IoV)," *Journal of Communications*, vol. 16, no. 5, pp. 155–166, 2021.

[36] A. Imani, J. Haghighat, and M. Eslami, "Relay selection schemes for SWIPT-enabled cooperative wireless networks with partial CSI," *AEU-International Journal of Electronics and Communications*, vol. 146, Article ID 154104, 2022.

[37] A. Husen, M. H. Chaudary, and F. Ahmad, "A survey on requirements of future intelligent networks: solutions and future research directions," *ACM Computing Surveys*, vol. 55, 2022.

[38] O. Zytoune, H. Fouchal, and S. Zeadally, "A realistic relay selection scheme for cooperative MIMO networks," *Ad Hoc Networks*, vol. 124, Article ID 102706, 2022.

[39] J. Bao, J. Wu, C. Liu, B. Jiang, and X. Tang, "Optimized power allocation and relay location selection in cooperative relay networks," *Wireless Communications and Mobile Computing*, vol. 2017, pp. 1–10, 2017.

[40] Y. Jing and H. Jafarkhani, "Single and multiple relay selection schemes and their achievable diversity orders," *IEEE Transactions on Wireless Communications*, vol. 8, no. 3, 23 pages, 2009.

[41] C. Huang, G. Huang, W. Liu, R. Wang, and M. Xie, "A parallel joint optimized relay selection protocol for wake-up radio enabled WSNs," *Physical Communication*, vol. 47, Article ID 101320, 2021.

[42] M. A. Mohammed, H. M. Alshanbari, and A. A. H. El-Bagoury, "Application of the LINEX loss function with a fundamental derivation of liu estimator," *Computational Intelligence and Neuroscience*, vol. 2022, pp. 1–9, Article ID 2307911, 2022.

[43] T. Jamal and P. Mendes, "Cooperative relaying in user-centric networking under interference conditions," *IEEE Communications Magazine*, vol. 52, no. 12, pp. 18–24, 2014.

[44] Y. Kim, S. Pack, C. G. Kang, and S. Park, "An enhanced information server for seamless vertical handover in IEEE 802.21 MIH networks," *Computer Networks*, vol. 55, no. 1, pp. 147–158, 2011.

[45] A. Rovira-Sugranes, A. Razi, F. Afghah, and J. Chakareski, "A review of AI-enabled routing protocols for UAV networks: trends, challenges, and future outlook," *Ad Hoc Networks*, vol. 130, Article ID 102790, 2022.

[46] J. A. Carvalho, H. Veiga, C. F. Pacheco, and A. D. Reis, "Extended performance research on IEEE 802.11 a WPA multi-node laboratory links," *InTransactions on Engineering Technologies*, vol. 1, pp. 175–186, Springer, Singapore, 2021.

[47] D. Parambanchary and V. Malleswara Rao, "WOA-NN: a decision algorithm for vertical handover in heterogeneous networks," *Wireless Networks*, vol. 26, no. 1, pp. 165–180, 2020.

[48] L. Tuyisenge, M. Ayaida, S. Tohme, and L. E. Afilal, "A mobile internal vertical handover mechanism for distributed mobility management in VANETs," *Vehicular Communications*, vol. 26, Article ID 100277, 2020.

[49] M. Shiri and R. Berangi, "WLAN bandwidth support for relay-based upward handover in WLAN/cellular systems," *AEU - International Journal of Electronics and Communications*, vol. 116, Article ID 153067, 2020.

[50] S. Alam, S. Sulistyo, I. W. Mustika, and R. Adrian, "Handover decision for V2v communication in vanet based on moving average slope of RSS," *Journal of Communications*, vol. 13, pp. 284–293, 2021.