Design of DRL Based Adaptive Routing Protocol for Bidirectional Communication Between UAVs and UGVs

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Abstract: The recent developments in coordinated networks, specifically of Unmanned Aerial Vehicles (UAVs) and Unmanned Ground Vehicles (UGVs) are found as game changer for autonomous systems. Existing routing protocols are typically designed for UAV networks or for UGV networks, separately. The seamless integration of these networks is essential to enhance situational awareness as UAVs can provide bird's-eye view of the surrounding and UGVs can gather detailed ground level data. Deployment of these networks requires designing of the customized routing protocol enabling flawless communication between coordinated UAV network and UGV network platforms and a simulation framework to test it. This paper presents a design, implementation, and optimization of routing protocol engineered for specific requirements of coordinated network consisting of UAV and UGV. This novel protocol design integrates the Greedy Perimeter Stateless Routing (GPSR), for combining GPSR strategies, and Deep Reinforcement Learning (DRL) to optimize packet routing. A simulator is developed in Python to simulate and test the proposed protocol. Simulation result confirms that the proposed protocol establishes the shortest and most efficient paths making it suitable for the many applications. By addressing the critical challenges in routing strategies for integrated UAV-UGV network, this research work paves the way for intelligent and adaptive communication solutions in dynamic environment.

1 INTRODUCTION

UAV (Unmanned Aerial Vehicles) are widely referred to as drones (Laghari, Jumani, et al. , 2023) and UGV (Unmanned Ground Vehicle) are known as mobile robots. Network of UAV is commonly known as FANETs (Flying Ad-Hoc Networks) and network of UGV is called RANETs (Robotic Ad-Hoc Networks). FANET and RANET are advanced iterations of Mobile Ad-Hoc Networks (MANETs) (Ahmed, Mohanta, et al. , 2022). These platforms leverage a variety of wireless communication technologies, including Bluetooth, Wi-Fi, and cellular networks for communication among them and form ad-hoc network autonomously(Sharma, et al. , 2020), (Hussein, Yaw, et al. , 2022). UGV are widely employed in reconnaissance, surveillance, traffic monitoring applications, border patrol and search and rescue operations. UAVs have become essential tools in various fields, ranging from military and law enforcement operations to civilian applications such as disaster response, agriculture, and filmmaking. Their versatility and adaptability make them invaluable assets for tasks requiring aerial surveillance, data collection, and monitoring in both urban and remote environments (Altshuler, Pentland, et al. , 2018).

Integrating UAVs and UGVs will revolutionized various industries, ranging from surveillance and reconnaissance to disaster response and transportation. In dynamic and three-dimensional environments, traditional routing protocols often fail to adapt to the unique requirements of UAV-UGV networks, leading to inefficient communication, increased latency, and potential safety hazards.

One of the main advantages of integrated UAVs and UGVs communication is improved situational awareness and decision-making capabilities. UAVs equipped with sensors can be used to collect and transmit data to UGV, which can then use the data to generate maps and models of the affected area. Mobile UGV equipped with sensors and actuators can be deployed to perform tasks such as delivering

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medical supplies or clearing debris, based on the information received from the UAV (Rubio, Valero, et al. , 2019), (Gielis, Shankar, et al. , 2022).

Integrated UAV-UGV communication can also enhance network coverage. UAVs can serve as flying stations, providing aerial communication to UGV and other ground-based devices that may not have direct line-of-sight communication with each other. This can help to overcome obstacles and terrain challenges that may limit the range and performance of the individual UGV networks.

Another significant advantage of integrated UAV-UGV communication is the ability to optimize resource usage and energy efficiency. UAVs can use their mobility to optimize the network topology and larger area while UGV can be used to offload computational tasks from UAVs, reducing their workload and energy consumption (Hua, Wang, et al. , 2019).

Integrated UAV-UGV communication will enable new and innovative applications and services that were previously impossible or impractical to achieve. The combination of UAVs and UGVs communication allows the efficient coordination of UAVs and UGVs, enabling several uses, including land mines map generation in battle field and package delivery monitoring and rescue operations (García, Reina, et al. , 2018).

A literature review is conducted to investigate the potential of existing routing protocols in effectively managing integrated communication between UAVs and UGVs. During the process of review it is observed that there is a gap of non-availability of routing protocols for communication between UAVs and UGVs is an emerging challenge in the field of autonomous and robotic systems. This issue arises due to the unique characteristics and operational environments of UAVs and UGVs, which create distinct networking requirements that are not fully addressed by existing routing protocols.

In this work, we aim to address the issue by enhancing the existing position-based routing protocol, GPSR (Greedy Perimeter Stateless Routing), originally used for UAV-UAV communication. The newly developed protocol will enable seamless data transfer in integrated UAV-UGV networks, meeting the unique demands of these heterogeneous systems. Furthermore, the proposed protocol will be adaptive, energy-efficient, and capable of managing dynamic topologies effectively.

In summary, this work will focus on integrating advanced technologies such as Machine Learning (ML) and Artificial Intelligence (AI) with position-based protocols like GPSR. The proposed solutions will be validated in practical scenarios to optimize the performance, energy efficiency, and adaptability of networks comprising UAVs and UGVs.

Section II discuss the related work accomplished by the research in the domain of modifying network routing protocol for UAV network or UGV network individually. Section III provides a brief introduction of GPSR routing protocol and DRL. Section IV outlines the network model and methodology employed. The results are presented in section V followed by discussion on result in section VI. Finally conclusions are drawn in section VII.

2 RELATED WORK

Literature review is conducted to assess the suitability of position-based routing protocols for integrated UAV-UGV networks and to explore the integration of machine learning algorithms into existing protocols.

Salazar (Salazar, et al. , 2023) recommend exploring additional Ad Hoc routing protocols, such as AODV and DSDV, alongside OLSR to compare their efficiency in a FANET network for traffic monitoring. Conducting this comparative analysis would provide a more comprehensive understanding of the performance of different protocols in various scenarios. Future research could focus on incorporating advanced technologies like machine learning algorithms or artificial intelligence to enhance the decision-making processes within the FANET network. These technologies have the potential to optimize route planning, resource allocation, and overall network performance. Additionally, further studies could involve real-world implementation and testing of the proposed FANET network in a smart city environment. This would help validate the simulation results and evaluate its practical feasibility and performance under realistic conditions.

Kumar (Kumar, Raw, et al. , 2023), modified the Greedy Perimeter Stateless Routing (GPSR) protocol to develop the Utility Function-based Greedy Perimeter Stateless Routing (UF-GPSR) protocol for Flying Ad-hoc Networks (FANETs). This modification aimed to optimize the greedy forwarding strategy by considering multiple crucial parameters of UAVs, such as residual energy ratio, distance degree, movement direction, link risk degree, and speed. Future research could involve integrating machine learning techniques to enhance the routing decision process in UF-GPSR. By leveraging machine learning algorithms, the protocol could adapt to dynamic network conditions more effectively, leading to improved routing performance. Additionally, future studies could focus on deploying UF-GPSR in practical FANET environments to assess its performance under realistic conditions. Field trials and experiments would provide valuable feedback on the protocol's effectiveness and feasibility for diverse applications.

Charles (Charles, 2022) proposed a method to enhance network quality and throughput while simultaneously creating an energy-saving approach with excellent quality of service. This paper introduces an energy-efficient protocol designed to develop a faster, miniaturized, and more efficient routing method compared to existing protocols. The proposed routing protocol, EEQRP, is evaluated and compared using Network Simulator-2 (NS2). The results demonstrate that EEQRP provides lower average latency, greater power savings, and a higher packet delivery rate than current protocols. Future research could explore integrating machine learning or artificial intelligence techniques into the EEQRP protocol to enhance its decision-making capabilities and further optimize energy efficiency.

Karp and Kung (Karp, Kung, et al. , 2003) introduced GPSR (Greedy Perimeter Stateless Routing) as an innovative routing protocol for wireless datagram networks. GPSR makes forwarding decisions based on the positions of routers and the destinations of packets, utilizing greedy forwarding with local topology information. When greedy forwarding is not feasible, the protocol switches to perimeter routing. GPSR is designed to scale efficiently with the number of network destinations, outperforming shortest-path and ad-hoc routing protocols in this regard. In environments with frequent topology changes due to mobility, GPSR leverages local topology information to quickly adapt and establish new routes. Extensive simulations in mobile wireless networks demonstrate the scalability of GPSR, especially in densely deployed wireless networks. Future research could focus on investigating the implementation and performance of GPSR in real-world wireless network scenarios to validate its effectiveness beyond simulations. Additionally, exploring enhancements to GPSR to improve its adaptability to dynamic network conditions and optimize routing decisions in diverse environments using machine learning techniques could be highly beneficial.

Namdev (Namdev, Goyal, et al. , 2021) proposed a Whale Optimization Algorithm-based Optimized Link State Routing (WOA-OLSR) for Flying Ad-hoc Networks (FANET) to address the challenges of energy efficiency and communication security. The study concluded that the WOA-OLSR communication scheme offers a more efficient and secure solution for FANETs, enhancing performance and reliability in communication networks involving drones and UAVs. Future improvements could involve integrating machine learning or artificial intelligence techniques with the WOA-OLSR algorithm to further optimize routing decisions, enhance network performance, and adapt to evolving network dynamics in FANET environments.

Cappello (Cappello, , et al. , 2022) presented a comprehensive framework that integrates Flying Ad Hoc Networks (FANET) with 5G networks to provide interconnected services that can be sequenced, taking into account physical device constraints and traffic flow requirements. Future research could explore the integration of machine learning algorithms to enhance the optimization model for Virtual Function placement and chaining, with the aim of further improving energy efficiency and service satisfaction probabilities.

Hosseinzadeh (Hosseinzadeh, , et al. , 2023) proposed a position forecast-based greedy perimeter stateless routing approach called GPSR+ for Flying Ad Hoc Networks (FANETs). This approach consists of two main steps: neighbor discovery and a greedy forwarding algorithm. In the neighbor discovery phase, GPSR+ employs a position prediction mechanism based on historical data. To predict positions, weighted linear regressions utilized. Future research could focus on enhancing this prediction technique by incorporating lightweight machine learning methods. Machine learning could provide more accurate and adaptive position forecasts, thereby improving the overall performance of GPSR+ in dynamic FANET environments. By leveraging advanced machine learning algorithms, GPSR+ could better handle the mobility and variability inherent in FANETs, leading to more efficient routing decisions and increased network reliability.

Future research should prioritize the development of ad-hoc networks tailored for integrated UAV-UGV systems. This includes the integration of advanced technologies such as machine learning and artificial intelligence with position-based protocols like GPSR. Emphasis should be placed on validating these solutions in practical scenarios to enhance the network's performance, energy efficiency, and adaptability. In highly dynamic nature of networks involving UAVs and UGVs, position-based routing protocols like GPSR are particularly well-suited for such applications.

3 BRIEF ABOUT GPSR AND DRL

GPSR is a routing protocol offering Greedy and Perimeter Forwarding modes for efficient packet delivery. By selecting the nearest node to the destination and employing the right-hand rule when necessary, GPSR aims to optimize routing paths. However, its reliance solely on distance metrics can result in elevated delivery failures. While GPSR assigns global routes to nodes through a greedy algorithm, it's associated with high overhead and diminished delivery ratio beyond a certain threshold. Notably, GPSR's suitability diminishes in urban settings characterized by local loops, limiting its effectiveness in such environments (Abbas, Ahmed, et al. , 2022), (Choi, Hussen, et al. , 2018), (Sugranes, Razi, et al. , 2022), (Wen, Huang, et al. , 2018). The GPSR algorithm includes two different packet forwarding techniques. In GPSR, a greedy forwarding technique is widely applied technique while perimeter forwarding is best suitable where a greedy technique cannot be applied(Houssaini, Zaimi, et al. , 2017).

In GPSR each packet is marked with its destination's location by its originator. When a node receives a packet, it examines the geographic location of the destination and compares it with the positions of its neighbouring nodes. The node then makes a locally optimal choice of the next hop by selecting the neighbor that is geographically closest to the packet's destination among its radio neighbors. The process continues iteratively as each node forwards the packet to the next hop that is closer to the destination until the packet reaches its intended destination. This method aims to curtail the number of hops essential for packet delivery and refine the routing path based on geographic location. GPSR includes three basic routing algorithms: Distance Vector (DV), Link State (LS), and Path Vector. In the DV method, every node recognizes its route to a desired destination by seeking details shared on regular interval by its neighbouring LS approach involved nodes, to broadcast about status alteration across the whole network topology. As stated by researchers, both the DV and LS strategies might undergo from minor inaccuracies in a router's perceived network condition, likely leading to routing loops or connectivity issues. Moreover, the intricacy of messages within the DV and LS routing algorithms can be effected by two factors: rate of change of network topology and the number of routers operating within the routing zone (Karp, Kung, et al. , 2003). Greedy forwarding is an effective technique but it may generate suboptimal routes in network topologies, where packets temporarily move farther from the destination (Feng, Zhang, et al. , 2016).

DRL (Azar, et al. , 2021) engages in training a computational agent to communicate with an environment to optimize cumulative rewards through iterative process. In the framework of UAVs and UGVs network, DRL models are trained to cater real-time packet routing decisions depending on routing tables and sensor data. It considers various factors such as velocities of UAVs or UGVs, obstacles, positions of UAVs or UGVs and other relevant environmental factors. It requires a suitable representation of the state space. For taking real time packet routing decisions state space consists of the current positions, velocities, and orientations of UAV and UGV.

In summary, GPSR's dual approach of greedy forwarding and perimeter forwarding offers a comprehensive solution for routing in dynamic ad-hoc networks. Upcoming studies could enhance GPSR by integrating DRL methodologies. DRL could facilitate GPSR to adaptively grasp optimal routing schemes from dynamic network state, in-turn improvement in decision-making processes and routing performance. This unification of DRL with GPSR forms a routing protocol suitable for bidirectional communication between UAVs and UGVs.

4 PROPOSED METHODOLOGY

While designing a bidirectional network model for UAVs and UGVs communication, the unique requirements of both the networks are considered. Main objective is to create an integrated system that facilitates seamless communication and collaboration between UAVs and UGVs. Following are the design considerations,

- Let us consider a network, consisting of UAVs and UGVs, each equipped with Global Positioning System (GPS) and a processor capable of data processing, trans-receiver, caching and storage.
- The proposed network consisting of a set of ‘n’ flying nodes (UAV_i i=1,2,3…n) and ‘m’ mobile ground nodes (UGV_j j=1,2,3…m).
- Let ID_{UAVi} and ID_{UGVj} be a unique identification assigned to UAV_i and UGV_j respectively.
- Transmission radius of UAV_i and UGV_j is considered as R_i.

- Communication within the network of UAVs and UGVs is initiated using a specially designed Hello packet tailored for the network.
- Position of flying nodes and unmanned ground vehicle are respectively (x_i, y_i, z_i) and (x_j, y_j).

Seamless communication between UAV and UGV networks requires periodic updates of network topology information, which can be achieved using Hello Packets. Hello Packet is typically used in a network to establish and maintain neighbor relationship between nodes and continuous information exchange (Aljabry and Suhail, 2022). In the proposed network, nodes are initially categorized and identified as GP-AV for UAV nodes and GP-GV for UGV nodes. The GPSR method starts by identifying neighbouring nodes by means of the transmission of hello packets. During the hand shaking of hello packet, each node collects data about its neighbors such as geographic positions, validity time and node types (GP-AV or GP-GV). This data helps the GPSR protocol to form a local map of the network topology, which is essential for decision making for forwarding the packet. The neighbor discovery process assures that every node maintains an updated table of nearby nodes and their corresponding positions, required for effective greedy forwarding. In greedy forwarding, every node leverage position details to forward data packets to the neighbor closest to the destination. If greedy forwarding fails (e.g., when a packet reaches a local maximum with no neighbor closer to the destination), the protocol switches to perimeter routing to navigate around obstacles and continue forwarding the packet towards its destination. Subsequently, the ID of both UAVs and UGVs, referred to as ID_{UAVi} and ID_{UGVj} respectively, disseminates a hello message within its transmission radius (R_i) to inform neighbouring nodes, including UAVs and UGVs, about its remaining energy and position. Following the exchange of hello messages referred in figure 1.

Source ID	Node Type (NT)	Coordinates UAV$_i$ (x_i, y_i, z_i) /UGV$_j$$(x_j, y_j)$	Time Stamp(TS)	Current Energy (E)
ID Hear (ID_H)	Validity Time (VT)	SI (Sharing Information)		Hello ID(IDH)

Figure 1: Hello Packet Format for Proposed Network.

Following are the fields of Hello Packet

- Source ID (IDS): Unique identifier for the UAV/UGV sending the "Hello" packet.
- ID Hear (IDH): Identification information hearing other UAV/UGV.
- Node type (NT): Identification whether hello packet generated from UAV or UGV (IDP).
- Validity Time (VT): Time for which hello packet is valid.
- Position (P): Include the current geographic coordinates (latitude, longitude, altitude) of the UAV/UGV.
- Sharing Information (SI): Sharing information with nodes.
- Time Stamp (TS): Indicate the time at which the "Hello" packet was sent.
- Energy (E): Residual Energy of UAV or UGV.
- IDH: Hello identification number.

Table 1: Neighbor table format of nodes.

ID	NT	Hello Message Information				PP	VT
		Hello ID	Reg Time	Position	RE		
ID	UAV / UGV	ID_{H0}	t_0	$x^0_j\ y^0_j\ z^0_j$	RE_j	$x_j(t)$, $y_j(t)$, $z_j(t)$	VT_j
		ID_{H1}	t_1	$x^1_j\ y^1_j\ z^1_j$	RE_j		
		….	…	…	…		
		ID_{Hn}	t_n	$x^n_j\ y^n_j\ z^n_j$	RE_j		

These hello packets, containing the node information such as identity, position, type, residual energy, and neighbours, are broadcasted at regular interval to notify other nodes of their presence and comprise of vital information such as node type, unique ID of the transmitting node, time stamp etc. Based on the information, extracted from the hello messages received from adjacent UAVs and UGVs compiles a list of its neighbouring nodes. This information is then registered in its neighbouring table of nodes, as illustrated in the format depicted in Table 1. Neighbouring table holds information about adjacent nodes.

- ID: Unique ID of adjacent UAV/UGV.
- NT: Type of adjacent neighbor i.e. UAV/UGV.

- Hello ID: Hello packet identification no.
- Reg Time: Time at which corresponding hello packet transmitted.
- Position: Geographical Position of UAV/UGV.
- RE: Residual Energy of the neighbouring UAV/UGV.
- Predicted Position (PP): Predicted Position of UAV/UGV with the help of DRL model.
- Validity Time (VT): Time for which Hello Packet is valid. It is an indicator of network life.

Developing an ad-hoc network for bidirectional communication between coordinated UAV and UGV involves a systematic approach to ensure effective collaboration between these autonomous systems. Let the network comprised of UAVs and UGVs as nodes, communication need to be established through various channels, including UAV-UAV, UGV-UGV, and UAV-UGV. For establishing the communication between the nodes, integration of Greedy Perimeter Stateless Routing (GPSR) and Deep Reinforcement Learning (DRL) protocols are used. Initially, GPSR determines the routing paths based on the geographic positions of nodes and the destination. Each node in the network represented by the 'Node class', comprising of the unique attributes such as ID, coordinates (x, y, z) in 3D space, and node type indicating whether it is a UAV (i) or UGV (j).

The communication process is initiated by transmitting a hello packet. Further, the routing function identifies the nearest neighbours based on Euclidean distance, which is essential for establishing communication paths. To optimize routing decisions, the network uses an integration of GPSR and DRL. GPSR utilizes greedy forwarding decisions, choosing the nearest neighbor as the next hop. In cases where direct greedy forwarding is not possible due to obstacles or unreachable areas, GPSR switches to perimeter forwarding mode. This determines the routing path, total distance, hop count, forwarding strategy, and node types involved in the communication process. DRL augment GPSR by continuously learning from the network conditions and environment. It adapts to changes in topology, traffic, and obstacles in-turn enhancing communication efficiency and reliability. The DRL model uses a Sequential architecture having dense layers to learn and fine-tune routing decisions.

A simulator is developed to test the proposed communication protocol. The predefined function chooses an action index, based on anticipated action probabilities from the DRL model, facilitating in decision-making during routing. The 'angle function' calculates angles between vectors and supports Perimeter Forwarding which is triggered if Greedy Forwarding fails, 'packet handling function' divides the message into individual words and generates a packet for transmission. Meanwhile, 'network update functions' dynamically updates the node coordinates and emulate the communication process by updating node coordinates and printing information about nodes within the communication range.

Through the collaborative working of GPSR and DRL, UAVs and UGVs establish robust communication links, enabling seamless data exchange and coordination within the network. The simulation of coordinated communication between UAVs and UGVs networks engage in designing and testing a framework having the capability to interact and collaborate with both aerial and ground vehicle.

5 RESULTS

Testing of the proposed protocol is conducted in two modes through the specifically developed simulator. In the first mode, a data string is forwarded through the network, and various network parameters, such as hop count, latency are measured. In the second mode, the number of transmitted data packets is varied, and corresponding network parameters are calculated.

For the simulation purposes in mode one, let the node 2(UAV) wishes to communicate with the node 12(UGV) as illustrated in figure 2. The message "hello test message is transmitted between node two and node twelve" is transmitted, which is segmented as: "hello", "test", "message", "is", "transmitted", "between", "node", "two", "and", "node" and "twelve". After initializing the network, each node sends a hello packet to share information about itself. When a packet is transmitted, the script prints routing details, including the forwarding strategy used (either 'Greedy' or 'Perimeter') and the types of nodes involved in the forwarding process.

Simulator	Python
No of UAV Nodes	6
No of UGV Nodes	6
Mobility Model	Random Way Point
Communication radius	150 meter
Speed of UGV Nodes	15-25 Km/hour
Speed of UAV nodes	60-90 Km/hour

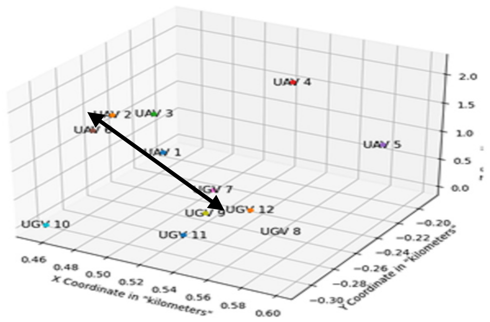

Figure 2: Simulation environment for integrated UAV and UGV network.

For each transmitted packet, the script provides detailed information on the packet number and its data, the path taken by the packet, and the hop count, as shown in the Table 2. It consists of packet data, details of the chosen path, and hoping count taken by the individual packet, to reach the destination. It is observed that packets with sequence numbers 4 and 6 require the highest number of hops to transmit data from node 2 to node 12. It indicates that these packets become trapped in a loop, leading to what is known as a deadlock loop. After the completion of each packet transmission network parameters are measured for each transmission, as shown below in the Table 3. From Table 4 it is seen that are out of 11 packets, 8 were successfully delivered, while 3 experienced failures. The failures occurred with packets having Sr. No 4, 7, and 10.

Table 2: Path of test message indicating nodes involved in the network

Packet	Packet Data	Path Chosen	Hop count
1	hello	[2, 4, 6, 4, 11, 9, 2, 1, 6, 2, 3, 10]	11
2	test	[2, 7, 1, 5, 6, 11, 9, 2, 8, 10]	9
3	message	[2, 10]	1
4	is	[2, 3, 9, 7, 4, 8, 6, 12, 2, 3, 12, 1, 11, 8, 9, 2, 12, 7, 12, 9, 3, 12, 11, 12, 3, 1, 5, 6, 1, 11, 8, 2, 7, 6, 12, 8, 4, 12, 6, 7, 12, 7, 2, 9, 6, 9, 7, 9, 12, 4, 7, 1, 12, 5, 12, 1, 12, 9, 4, 11, 2, 6, 12, 1, 11, 5, 10]	66
5	transmitted	[2, 1, 6, 3, 11, 2, 11, 1, 3, 2, 12, 9, 5, 10]	13
6	between	[2, 3, 6, 12, 7, 1, 9, 7, 9, 1, 8, 12, 8, 11, 1, 12, 11, 6, 1, 4, 9, 12, 11, 3, 2, 12, 5, 4, 3, 6, 9, 8, 5, 1, 8, 12, 1, 2, 8, 3, 7, 9, 12, 8, 7, 6, 10]	46
7	node	[2, 9, 4, 9, 2, 9, 12, 7, 3, 7, 8, 7, 1, 5, 9, 11, 12, 11, 4, 7, 4, 3, 12, 10]	23
8	two	[2, 3, 4, 12, 2, 7, 10]	6
9	and	[2, 9, 11, 2, 12, 11, 2, 11, 6, 4, 1, 11, 2, 11, 10]	14
10	node	[2, 3, 11, 2, 10]	4
11	twelve	[2, 9, 2, 11, 3, 12, 2, 5, 11, 12, 11, 1, 10]	12

The delivery time fluctuates based on distance and other network conditions. Packets with longer distances (e.g., packet 6: 4.20 km, 5.25 sec) generally took more time to deliver. The longest delivery time was for packet 6 (5.25 sec) over a distance of 4.2 km. Latency is generally equal to or slightly greater than the delivery time for successful packets. Failed packets showed higher latency values, indicating potential retransmission. After concluding the simulation, the outputs provide the final path traversed by the packets.

Table 3: Performance of routing protocol in transmission of test message for each packet

Packet	Packet Data	Total Distance(km)	Delivery Status	Delivery time (sec)	Latency (sec)
1	hello	1.26	Success	1.62	1.62
2	test	0.942	Success	1.06	1.06
3	message	0.107	Success	0.15	0.157
4	is	5.75	Failure	7.04	7.04
5	Trans-mitted	1.39	Success	1.51	1.51
6	between	4.20	Success	5.25	5.25
7	node	1.82	Failure	2.65	2.65
8	two	0.375	Success	0.89	0.89
9	and	0.982	Success	1.83	1.84
10	node	0.315	Failure	0.61	0.61
11	twelve	1.22	Success	1.54	1.55

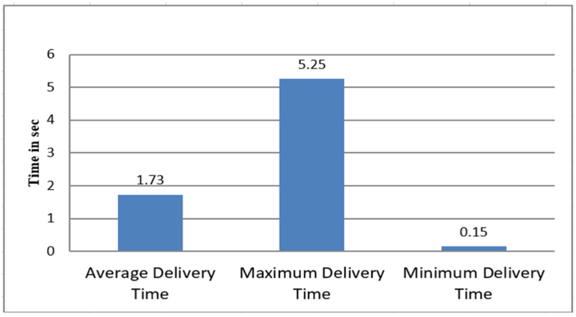

Figure 3: Delivery Time Statistics

Additionally, it provides delivery time statistics for successful packet transmissions, highlighting the minimum, maximum, and average times required for packet delivery, as shown in figure 3. The figure illustrates that the average time for successful packet delivery is less than 2 seconds, with the maximum delivery time being 5.25 seconds for packet sequence number 6, and the minimum delivery time being 0.61 seconds for packet sequence number 10. Finally, the packet delivery results, including successful deliveries, total number of packets, and packet delivery ratio are obtained. Table 4 summarizes the packet delivery results, showing that out of 11 transmitted packets, 8 were successfully delivered, resulting in a packet delivery ratio of 0.72.

Table 4: Packet Delivery Results for Greedy Node Forwarding Strategy including UGV and UAV

Parameter	Result
Successful Deliveries:	8
Total Packets Transmitted:	11
Packet Delivery Ratio:	0.72

To evaluate the performance of routing protocol in second mode distinct number of packets transmitted over the network and network parameters are evaluated. For experimentation 5, 10, 15, 20, 25 number of packets are transmitted over the network and its performance is evaluated w.r.t maximum hop count, average hop count, maximum latency, average latency and PDR between nodes two and node twelve. Node two is a UAV node and node 12 is UGV node. From figure 4, it is observed that the maximum hop count reaches 34 when transmitting 25 data packets, whereas it is reduced to 18 when transmitting only 5 data packets. Average hop count lies between 5 to 7.

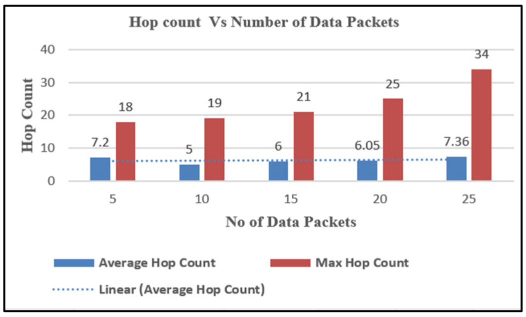

Figure 4: Maximum and average hop count under different number of data packets.

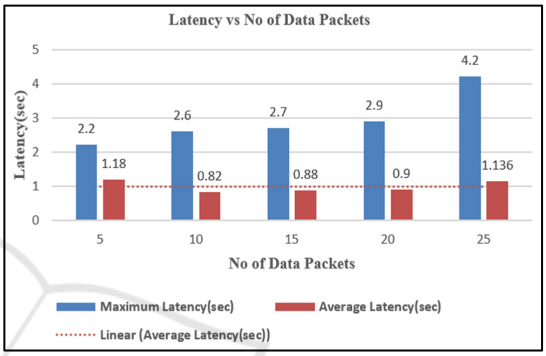

Figure 5: Maximum and average latency under different number of data packets

Figure 5 shows that the maximum latency is 4.2 seconds when transmitting 25 data packets, while it decreases to 2.2 seconds for 5 data packets. The average latency is approximately 1 second.Network achieves a PDR of more than 0.75 with varying number of packets as shown in figure 6.

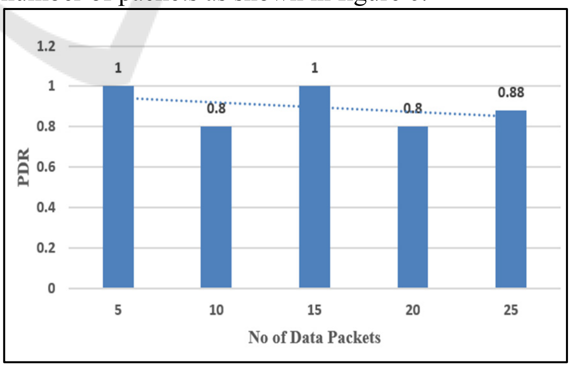

Figure 6: PDR under different number of data packets

The results demonstrate that average hop count for transmitting data between UAV and UGV nodes with varying no of packets lies between 5 to 7 and average latency with varying no of packets is less than 2 seconds.

6 DISCUSSION

Designing a bidirectional network for UAVs and UGVs involves integrating GPSR with DRL to enhance bi directional communication. The network includes UAVs and UGVs equipped with GPS and data processing capabilities, each identified by unique IDs. GPSR utilizes hello packets to establish neighbor relationships and build a local topology map for routing. DRL augments GPSR by adapting to network changes, optimizing routing paths, and improving communication efficiency. This integration ensures seamless data exchange and coordination in UAV-UGV networks. This technique proves efficient offering paths with fewer hops, thereby reducing End-to-End Delay. Final path selection involves evaluating each node for overall end-to-end delay, considering the position, current energy and timestamp. Upon network initialization, every node transmits a hello packet to exchange self-information. The test message's path within the network indicates involved nodes, packet data, the path taken, and hop count.

Moreover, the routing protocol's performance in transmitting test messages for each packet is assessed using diverse parameters. The evaluation reveals variations in the total distance covered for successful delivery of packet, with the “is packet” traversing the longest distance at 4.2 km. Result reveals that maximum hop count for successful deliveries is 46 which is corresponding to “ between packet” and least hop count is 1 which is corresponding to “message packet”. Delivery Status confirms successful delivery for all packets except “is packet”, “node packets”. Delivery Time exhibits variability, with the “between packet” recording the lengthiest delivery time at 5.25 seconds. From Table 3 it is seen that failed packets showed higher latency values as compared to delivery time, indicating potential retransmissions. The performance of the routing protocol during each packet transmission is illustrated in Figure 6. Delivery time statistics highlight the minimum, maximum, and average time required for packet delivery. The network achieved a packet delivery ratio of 0.72 (refer to Table 4). The integration of the GPSR protocol with the DRL technique demonstrates its efficiency in the coordinated UAV and UGV network, offering paths with fewer hops, thereby reducing End-to-End Delay. Final path selection involves evaluating each node for the overall end-to-end delay, considering position, current energy, and timestamp.

To further assess the performance of the routing protocol, the number of packets transmitted over the network and various network parameters are analyzed. For the experiment, 5, 10, 15, 20, and 25 packets are transmitted across the network, and their performance is evaluated. Figure 4 and figure 5 indicate that an increase in the number of packets, which corresponds to a larger data size or retransmissions due to packet loss, can result in a higher hop count and increased latency. Figure 6 shows that the Packet Delivery Ratio (PDR) is 0.88 for 25 data packets, while it is 0.8 and 0.75 for 15 and 20 data packets, respectively. This indicates that retransmissions are higher for 15 and 20 data packets compared to 25 data packets. Additionally, the increase in PDR for 25 number of data packets can be attributed to the network by acquiring more detailed information about the topology through exchange of hello packets.

7 CONCLUSIONS

In this paper, a network is designed to test the proposed UAV to UGV communication protocol. A Simulator is designed, developed and tested to establish the Bi- Directional Communication between UAV and UGV. A test message is segmented into eleven packets and transmitted between nodes 2 and 12 using integrated GPSR- DRL strategy to evaluate the performance of simulated network comprising of UAVs and UGVs. By integrating DRL, UAVs and UGVs can learn optimal routing strategies that adapt to changing environments and network conditions, improving packet delivery rates and reducing communication latency. The network's performance was evaluated based on the hop count, delivery time, and success or failure of each packet transmission. Out of the 11 packets, 8 were successfully delivered, resulting in a packet delivery ratio of 0.72. The analysis also provided detailed statistics on delivery times, mentioning minimum, maximum, and average values. By analyzing delivery time data, network operators and engineers can predict a range of critical performance parameters such as latency, congestion and QoS. This data helps to assess the reliability of the routing protocol in the simulated environment, if the delivery time consistently increases for certain routes, it may indicate suboptimal path selection. Moreover, sudden spikes in delivery time may indicate underlying issues with network stability. Benefits of unification of GPSR with DRL is the competency to evaluate historical and real-time data to predict traffic flow, change in network density and node mobility, enabling GPSR to take decisions and choose optimal routes.

Table 2 indicates that some of the packets are taking five times more hops than the total number of UAV or UGV nodes, suggesting that these packets are getting trapped in a loop. This leads to significantly higher network latency, a phenomenon known as a deadlock loop. There is a scope of minimizing deadlock loops to improve the efficiency of network resource utilization.

The integration of GPSR with DRL in designing a routing protocol for bidirectional communication between UAVs and UGVs marks an innovative development in network communication, bringing intelligence and improved adaptability. This method not only deals with the limitations of conventional routing protocols in dynamic and unpredictable environments but also unlocks new opportunities for more efficient and reliable communication in UAV-UGV networks. By continuously learning from the environment and adapting to the changing conditions, this DRL-based routing protocol ensures flawless and resilient communication between aerial and ground vehicles, even in dynamic scenarios.

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