Routing Protocol in UAV

Ayush Singh
Btech CSE

SAP: 1000013079
DIT University
Dehradun, India
1000013079@dit.edu.in

Deeksha Chauhan
Btech CSE(AI&DS)

SAP: 1000013074
DIT University
Dehradun, India
1000013074@dit.edu.in

Vani Latwal
Btech CSE (AI&DS)

SAP: 1000013386
DIT University
Dehradun, India
1000013386@dit.edu.in

Dr.Surabhi Patel
Advisor,Assistant Professor
DIT University
Dehradun, India
surabhi.patel@dituniversity.edu.in

Ankit Raj Kumawat
Btech CSE(AI&DS)

SAP: 1000012768
DIT University
Dehradun, India
1000012768@dit.edu.in

Abstract

Unmanned aerial vehicles (UAVs) are used for many operations, such as search and rescue operations, surveillance, and environmental monitoring. To enable effective communication and data transfer, efficient routing protocols must be invented. UAV routing protocols are accountable for determining the best routes for data transmission and ensuring that the UAVs stay connected to the network. These protocols need to take into account factors such as the location of the UAVs, the available bandwidth, and the quality of the communication links. One important classes of UAV routing protocols are on basis of the use of wireless ad hoc networks. These protocols enable the UAVs to interact efficiently with each other, without the need for a central network Infrastructure. As UAVs are at risk of cyber-attacks, security should be the priority while creating routing protocols. Besides, they need to be energy-efficient to maximise the UAVs' flight time. It is critical to design an efficient and secure routing protocol for enabling good communication and easy data transfer. In this review paper, we are trying to summarise UAV routing protocol and its types. We will also be discussing various UAV networks for the different types of UAV protocols. UAV protocols are categorised as proactive, reactive, energy-aware, cluster, topology, and position-based routing. The choice of routing protocol depends on the circumstances and environment

3. Introduction

Over the past few decades due to the ongoing rapid advancements of technological sectors and its supporting industries whether directly or indirectly dependent on them have led to development of cheaper alternatives of components required for Un-manned Aerial Vehicles more prominently known in the society as drones for examples being Wi-fi interfaces, sensor equipment's, global positioning system API's et-cetera. Such cheaper alternatives have enabled the society as well as the researchers to try and expand the range of application of UAV's in the field of not only military but also it's civil counterparts. Some examples of such are Construction and Infrastructur" Ins'ection in Construction Inductry, Precision agriculture in Agriculture, Automated Forest Restoration in Forestation as well as Governmental Departments, Cryospheric Research, Grid Lines Inspection of Power & Pipe Lines for a few in civilian domains whereas Smuggling, Anti-terrorism, Enemy Detection, Surveillance and Reconnaissance, Maritime Boundary Monitorization, Search & Rescue, Arms and Ammunition Monitoring et-cetera when military domain is in concern. Microsoft in recent years developed Farm-Beats which enables farmers with access to its Microsoft Azure Cloud and AI Technology support which empowers them with data-driving decisions which can help them increase their agricultural yield, along with lowered gross cost, and a huge reduced environmental impact of agricultural production as shown in fig 1.1.

fig 1.1 Farm Beats

In a same way Walmart R&D researchers also developed a method to use UAVs to complete the Warehouse Inventory Management with the help of automated AI-enabled nodes to operate to complete random inventory check which earlier Walmart employees used tot ake amost 7-8 days to complete but with the help of their system reduced to almost one day. In current rapid developing world scenario developing a way to create a UAV fibre has a lot of advantages and added cons too, where on one hand it helps the society in tasks where humans particu;ar;y cannot reachout easily and efficiently in time constraint required, it also poses a con of increased air traffic at a lower layer in the atmosphere which may lead to an interference which the local flying fauna. Nonetheless creating this fibre has a lot of other challenges such as making a peominent and efficient network which can constantly maintain the network for the UAV's to continuously perform the tasks and deploying large number of different types of UAV gauranteeing a collision-free environment for them to operate seamlessly.

UAV's can broadly be classified under three classes according to Size, Range, Group(as classified by department of defense). On basis of size, there are three sub divisions as mentioned:

1. Very Small/Micro/Nano UAV which spans from 2 cm to 50 cm in size because of their small size enabling them with camera and IR sensors they function well as surveillance and reconnaissance drones
2. Small/Mini UAVs they span from about 50 cm to 2 m in length and are also called as fixed wing style.
3. Medium UAVs with the wingspan spanning upto almost 10 m and gross weight reaching till 10 kgs they are usually used for delivery and load carrying applications
4. Large UAVs with wingspan upto 15-20 m and weight 100Kgs they are usually Payload Carriers used by defense organisations.

On the basis of Range,

1. Short-Ranged UAVs whose target radius is less than 250 km and flight time being almost 34 hours,
2. Medium-Ranged UAVs having an target radius from 200 to 1000 km,
3. High-Ranged UAVs which fly at greater altitudes and stay in flight for extended periods of time. And lastly on the basis of Group it is classified by Department of defense as mentioned in Fig. 1.2.

Category	Size	Maximum Griss Takeoff Weight (Lbs)	Normal Operating Altitude	Airspeed (Knots)
Group 1	Small	0-20	<1200 AGL*	<100
Group 2	Medium	21-55	<3500	<250
Geoup 3	Large	<1320	<18000 MSL**	<250
Group 4	Larger	>1320	<18000	Any Air Speed
Group 5	Largest	>1320	>18000	Any Air Speed

*AGL = Above Groud Level
**MGL = Mean Sea Level

fig 1.2 Group-wise Classification (DoD)

For constructive cooperation and seamless collaboration between UAV's an inter-UAV wireless communication is of significance which is called Flying Adhoc Network (FANET).

The network is of significance but so is the type of the structure it is formed into and according to structure there are two types of networks 1, In Single UAV network there is only a singular UAV connected to the ground station receiving instructions 2. In Multiple UAV network there are multiple UAVs being connected to the ground station receinving instructions from it but also from each other so as to define how the instructions are to be sent and also how to be shared between UAV's, use of Routing Protocols are necessary[1]. However there are challenges latched to it when developing it some of them whose topology is really dynamic in UAV network, range restriction between UAV and base ground station, High mobility of the UAV resulting in development of apecial different network measures incorporating routing protocols such as Mobile Ad-hoc Network (MANET) and Vehicular Ad-hoc Network (VANET) it helped transmission of instructions to the UAVs but owing to the Increased= mobility of the UAVs It limited network performance and dependability resulting in development of netwoks even further as shown in figure 1.3.

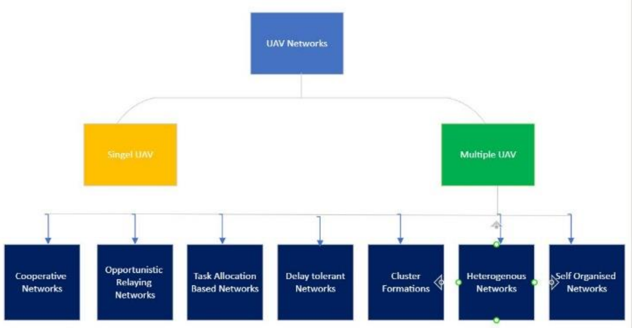

Fig 1.3 Types of UAV Networks

UAV Routing protocols have been 6 types under Flying Adhoc Network which are as mentioned, 1. Pro-active Routing Protocols 2. Reactive Routing Protocols 3. On-Basis of Topology 4. On-Basis of Energy 5 5. On-Basis of Position 6. Cluster Routing Protocols as displayed in figure 1.4 below

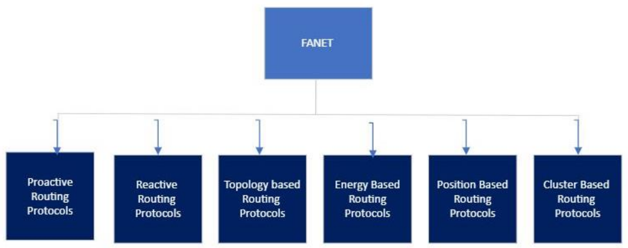

Fig 1.4 FANET Routing Protocols

In this study, Pro-active Routing protocols, Reactive Routing Protocols and Protocols on the basis of topology, position, energy and cluster have been thoroughly surveyed and very substantively contrasted in perspectives of distinguishing qualities, traits, competitive advantages, and restrictions.

2. Challenges of UAV

2.1 Technological Gap

Endurance decreases as payload increases, so missions may not be completed. Drones with fixed wings are energy efficient but have the disadvantages of hovering and speed control. Flying a single drone may also result in difficulties in flying in extreme cases it can also lead to failure due to technical and climatic reasons.[2] Drones also suffer from windy weather and adverse climate change. Spray drones are effective when spraying in a small area, but when spraying in large quantities, efficiency decreases, and operating costs increase.[1]

2.2 Safety, Privacy and Security issues

Few of the life-hazard issues posed by the heightened use of drones have highlighted safety and security issues and concerns. Air-worthiness, malicious activity, and disturbance with public property are major safety concerns that make drone use a serious problem.[3] This is because current approaches to addressing these issues do not match reality and do not guarantee the safe use of drones. Air traffic controls must be established and constantly checked upom to avoid interference in airspace. Jamming attack can disrupt UAV.

2.3 Lack of Controlling Bodies and Regulations

For a long time, UAVs have been used for defense purposes, but sanctions, insufficient regulations and flaws have stopped widespread acceptance of UAVs. The evolution and accelerated use of UAVs in commercial applications must address regulatory challenges to ensure safe and authorized use. International regulation bodies such as the International Civil Aviation Organization (ICAO) and European Aviation Safety Agency (EASA) encourage countries and organizations to develop regulations and requirements for civil aviation companies. Several countries are working in this direction and have proposed rules.[1,2]

2.4 Communication

Communication in autonomous UAV clusters is a major challenge due to frequent topology changes affecting the high-speed, routing mechanisms of mobile nodes. As a result, the quality of service deteriorates. Power is a critical issue for UAV nodes. These issues affect network performance.

2.5 Connectivity

Link failure brings limited network lifetime. Communication links between UAVs are extremely vulnerable.

2.6 Spectrum Management.

Spectrum unavailability can cause the loss of command and control of aircraft. Spectrum remains vulnerable to unintentional and intentional interferences.[2]

2.7 Energy Efficiency

UAVs are highly constrained in payload. Battery Design are limited for Energy optimization in drones. Usage of energy over the aviation is totally dependable on power of battery.[2]

3. **Routing Protocol on UAV**

3.1 Proactive Routing Protocol

Table is another name for the proactive routing protocol (PRP) in [3]. Each node in this style of routing protocol periodically updates one or more tables that depict the entire network architecture. This routing system offers the benefit of having instant access to routes when required because of its proactivity. However, since control messages are delivered needlessly regardless of whether there is no data flow, network speed can suffer as a result of the added overhead associated with updating information. Active routing techniques are therefore not ideal for highly dynamic large-scale and transportable UAV networks. Second, many routing systems also have poor failure responses when the network topology changes or connections break. [3]
Proactive routing protocols' key benefit is that they constantly possess the most up-to-date information. To keep routing tables updated, routing messages must be sent between all communicating nodes. Each node in this system stores data as tables, and whenever the network topology changes, the tables must be updated to reflect the changes. To ensure they always have access to routing information, nodes share topology information. Finding new routes does not cause a delay in route discovery. Effectively eliminating transmission delays, proactive routing algorithms pre-compute routes to all network destinations so nodes can start transmitting data right away.
In PRP, start route search process first, then perform data collection and transmission.
Active routing protocols include DSDV (Destination Sequence Demandbhy6 797 Vector), OLSR (Optimized Link State Routing Protocol)

3.1.1 Destination Sequenced Demand Vector (DSDV)

DSDV is a development of the distance vector method in [4]. Since DSDV is a routing protocol started by the destination, each node in the network stores a routing table that includes the sequence number (a unique identifier for each data packet sent by the destination), the destination (aside from the ID node in the network, which serves as the source node for sending the message), the node ID (the node that sent the message), the next node (the next node on th" rou'e of the node ID to destination, specifying the nod" fro' Ih the message This table is initially empty, each node periodically exchanges its table, then using neighboring nodes' routing tables, each node maintains its shortest distance to a particular destination.
With a few small adjustments to make it better suited for UAV ad hoc networks, it is based on the Bellman-Ford algorithm. Each drone in DSDV is required to identify all data from every other drone linked to the network. To prevent routing loops, the routing database will periodically update the sequence number across the network. The route with the highest sequence number and the most recent usage takes precedence over the one with the lowest sequence number.

Advantages:

- Ease of implementation
- Preserves minimum distance to each destination
- No routing setup delay
- Preserves update information

Disadvantages:

- More storage require.
- No more control message overhear.
- Unnecessary broadcast, as tables are swapped periodically even without link error

This protocol is not suitable for highly dynamic networks where topology changes more frequently. Also it support single path routing and does not support multipath routing.

3.1.2 Optimized Link State Routing Protocol (OLSR)

Link state algorithm-based Optimised Link State Routing (OLSR) is proactive in nature[4]. Because it minimises the frequency of retransmissions and compresses the quantity of the information delivered in messages, OLSR is an improvement over pure link-state protocols. Considering the number of hops, it offers the most efficient path. In order to achieve this, the protocol effectively floods its control messages via a multipoint overlay approach. By simply designating a subset of links with its neighbours as the multipoint relay selector and only declaring a node’s multipoint relays to retransmit its broadcast messages, OLSR, unlike DSDV, minimises the amount of control packets. Therefore, in reaction to link failures and node join/egress events, the protocol does not produce additional control traffic. Link state algorithm-based Optimised Link State Routing (OLSR) is proactive in nature[4]. Because it minimises the frequency of retransmissions and compresses the quantity of the information delivered in messages, OLSR is an improvement over pure link-state protocols. Considering the number of hops, it offers the most efficient path. In order to achieve this, the protocol effectively floods its control messages via a multipoint overlay approach. By simply designating a subset of links with its neighbours as the multipoint relay selector and only declaring a node’s multipoint relays to retransmit its broadcast messages, OLSR, unlike DSDV, minimises the amount of control packets. Therefore, in reaction to link failures and node join/egress events, the protocol does not produce additional control traffic.

The route from a source to a destination is made up of a sequence of hops made possible by multipoint relays. In OLSR, HELLO messages are received by nodes one hop away and broadcast to everyone of their neighbours. They contain information about their neighbours and their link state, but they are not sent to other nodes. Each node creates its MPR selection table after getting the HELLO message. Subsequent HELLO messages broadcast by a particular node identify multipoint relays for that node.[4]

Advantages:

- Moreover, OLSR is a flat routing protocol. It does not require a central management system to manage its routing process.
- The proactive quality of the OLSR protocol, which provides all routing information to all participating hosts on the network.
- The OLSR protocol does not require the link to be reliable for control messages, because messages are sent periodically and delivery need not be in order.
- Neighbor information is kept at each node, so that in the event of a link failure, it is easy to identify the next neighbor.
- Throughput increases.
- Reduced redundancy

Disadvantages:

- However, since a drawback of the OLSR protocol is that it requires each host to periodically send updated topology information throughout the network, this increases the bandwidth utilization of the protocol.
- OLSR requires considerable bandwidth and CPU power to calculate the best path through the network.
- Requires more storage throughput
- Link quality is not met, if response to hello message is received, link is assumed to be connected
- Not suitable for applications that sleep most time to reduce energy saving equipment

3.2 Reactive Routing Protocol

The reactive routing protocol (RRP), sometimes referred to as the on demand routing protocol, finds or keeps a route as needed. Whenever necessary, it decides on routes. In this kind of routing, the route is only found when it is necessary or useful. There is no need to calculate a route between two nodes if there is no link between them because the routing table is updated on a regular basis.[4]
When a node needs to send data, reactive routing builds the path. Since no periodic control packets are sent to maintain the route, this kind of routing system uses less

bandwidth. But it also lengthens the end-to-end latency. Flooding of route request packets is used for route discovery. In comparison to proactive protocol, reactive protocol delivers packet data more effectively.
Two different message kinds are created in this routing model: a route request message and a route reply message. To find the path, a Route Request message is sent from the source UAV to all nearby UAVs using a flooding technique. Each UAV then follows the same procedure until it reaches the destination UAV. While utilising a unicast communication mode, the Route Reply message is initiated by the destination UAV and sent to the source UAV.[2]
In this routing approach, there is no need to revive all tables in the network. Reactive routing protocols are bandwidth efficient because there are no periodic updates. The main fallibility of RRP is that it takes long time to find the route; as a result high latency may occur in the network during the optimal route finding process.

There is no need to resuscitate every table in the network using this routing strategy. Because there are no routine updates, reactive routing techniques consume less bandwidth. RRP's primary flaw is that it takes a long time to select a route; as a result, considerable latency may develop in the network during the process of determining the best route.

3.2.1 Dynamic Source Routing (DSR)

In, et al. created a test platform for FANETs using the Dynamic Source Routing (DSR) protocol. It enables a network to operate autonomously, without the need for external infrastructure, and to configure and organise itself. DSR is mostly utilised for multi-hop wireless mesh networks and is chosen for its reactive nature. When sending data, the source in DSR just looks for a path to the destination in a scenario. For FANETs, where the topology is unstable and the UAV mobility is high, DSR is more acceptable than proactive techniques. Due to the rapid mobility of UAVs, proactive routing table updating is not always the best option. However, repetitive path finding by reactive method before each packet delivery can also be exhaustive.[1]

3.2.2 Ad Hoc On-Demand Distance Vector (AODV)

Because of its reactive function, AODV only finds a route when it is needed and does not save routes to destinations that are not currently being communicated with. The AODV routing protocol includes three stages:Route discovery, packet transmission, and route maintenance are the first three. When a source UAV wants to transfer a packet, it first launches a route discovery operation to find the desired recipient's position before forwarding the packet through a chosen route without encountering a loop. To fix connection failure, there is a phase of route maintenance. This routing technique employs a sequence number to locate the most recent, most efficient path to the desired location. An expiration time is used to maximize route's freshness. In this method, intermediate UAVs also update their routing tables. However, network congestion is an issue with AODV due to the high dynamic nature of FANETs system.

3.2.3 Time-slotted on-demand Routing

For FANETs, a time-slotted on-demand routing protocol is also suggested. Ad-hoc On-Demand Distance Vector Routing (AODV) is essentially the time-slotted form of this routing technique. While time-slotted on-demand protocol uses designated time slots during which only one UAV can transmit data packets, AODV sends its control packets in random-access mode. This form of routing improves the efficiency of the useable bandwidth, prevents packet collisions, and raises the packet delivery rate.

<u>Advantage:</u>

- The protocol ensures a limit of the data delivery delay that can facilitate time-bounded operations for UAV-aided VANET scenarios.
- Require minimal routing information.
- It requires less routing overhead.
- It consumes less resource due to the absence of large routing protocol.

<u>Disadvantage</u>

- High latency time in route finding.
- Excessive flooding can lead to network clogging.
- Generates bigger control packets because of on demand route discover.

3.3 Position-Based Routing Protocol

Position-based routing protocols (PBRP) are based on the knowledge of geographical positions. It is a promising approach to routing in wireless mobile ad hoc networks (MANETs), where nodes communicate with each other directly without any fixed infrastructure. This protocol uses the physical location of the nodes to determine the route for data transmission. Though it doesn't require the establishment or maintenance of routes.

In PBRP, each node knows its physical location using GPS or other localization techniques. When a node wants to transmit data to another node, it first determines the physical location of the destination node. Then, it identifies the neighbor nodes that are closest to the destination node and forwards the data to one of these neighbors. The neighbor node that receives the data continues this process until the data reaches the destination node. It is a perfect routine for highly dynamic UAV communication networks.

PBRPs use the physical location of nodes to determine the route for data transmission, which makes them more scalable and efficient than other routing protocols. The information on the positions can be collected in different ways such as the direction and strength of the received wireless signals and through interfacing with a low-power Global Positioning System (GPS) and a satellite updating the positions of the nodes by sending signals to this GPS device

Position-based routing can be classified into two categories: (1)Single-path-based & (2) Multi-path-based. Both single- and multi-path-based routing protocols are categorized further into heterogeneous networks, delay-tolerant networks (DTNs), and non-delay-tolerant networks (Non-DTNs).

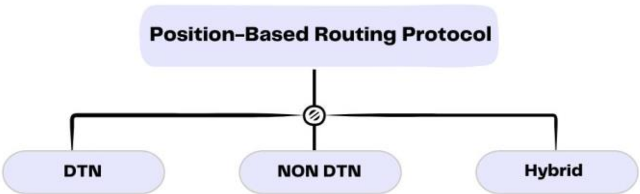

Fig 3.1 Types of Position-Based Routing Protocol

3.3.1 <u>Single-Path Heterogeneous Routing</u>

3.3.1.1 UAV-Assisted VANET Routing Protocol (UVAR)

UVAR is a position-based routing protocol as it uses geographic location information of vehicles and UAVs to make routing decisions. In this protocol, each vehicle and UAV is given a unique ID and a geographic location using GPS or other location-sensing technologies. The information on the location is used to calculate the distance between nodes. It helps to determine the best route for transmission.
It uses a combination of distance-based and direction-based routing to make routing decisions. It uses a technique called zone-based routing in which the network is divided into different zones in which each node is assigned to a UAV.

<u>Advantages</u>:

- It reduces routing overhead and communication delay by using only location information to make routing decisions.
- It provides better scalability as it helps easily partition the network into smaller zones that can be easily handled independently.
- It can significantly improve the performance and reliability of VANETs, especially in areas with limited infrastructure coverage.

<u>Disadvantages</u>:

- Delays due to use of carry and forward method

3.3.1.2 Connected-Based Traffic Density Aware Routing Protocol (CRUV)

CRUV uses the concept of traffic density to make routing decisions that enhance performance. In this protocol, location information speed, and direction of each vehicle are transferred to adjacent vehicles within its transmission range. Based on this information, the protocol calculates the traffic density in each network zone. The traffic density is estimated by estimating the number of vehicles in a particular zone and their average speed.
Then, CRUV decides to avoid congested zones and select the least congested path for packet transmission. It uses a combination of distance-based and traffic-density-based routing to make routing decisions.

<u>Advantages:</u>

- It is a PBRP that aims to improve the efficiency and reliability of Vehicular Ad-hoc Networks (VANETs)
- It can reduce communication delays and increase the network's throughput.

<u>Disadvantages</u>:

- It does not consider real distribution and delivery delays.

3.3.2 Single-Path Delay-Tolerant Network Routing (DTN)

3.3.2.1 Location-Aware Routing for Opportunistic Delay-Tolerant Networks (LAROD)

LAROD is a PBRP, designed for Delay Tolerant Networks (DTNs). DTNs are the type of network where end-to-end communication between nodes is not always possible due to intermittent connectivity and long communication delays.

Similar to CRUV, it shares the information of the location with the neighboring nodes within the range. Based on this, it calculates the distance and direction of other nodes and selects the shortest route for transmission. It also uses a combination of distance-based and distance-based routing. LAROD uses a location prediction mechanism to predict the future location of the nodes by studying the previous patterns. It is a machine learning algorithm that is used to learn the movent patterns of the nodes and reduces communication delays.
LARODE into account the network's topology and divides the network into different zones. Here, each zone is assigned a unique zone ID, and the location of the information nodes is used to calculate the distance and direction to other nodes.

Advantages:

- It improves the efficiency and reliability of DTNs.
- LAROD reduces communication delays and increases the delivery ratio in DTNs.

Disadvantages:

- High delays for delivering using store-carry-forward, and higher overhead.

3.3.2.2 Deadline Triggered Pigeon with Travelling Salesman Problem (DTP-TSP-D)

DTP-TSP-D is a PBRP that is designed for Wireless Sensor Networks (WSN). It is based on Pegion Routing Algorithm which is a popular data-centric routing protocol for WSN.
In this, each node is assigned a deadline for data transmission, and the protocol aims to find the shortest path between the source node and destination node that is approved by the deadline constraint. This protocol uses a combination of distance-based and distance-based routing to solve the traveling salesman problem(TSP) easier. TSP problem is solved using a heuristics algorithm to find the solution.
The PBRP divides the network into zones and each zone is assigned a unique zone ID. To calculate the distance and direction to other nodes the location information is used.

Advantages:

- It improves the efficiency and reliability of WSNs
- DTP-TSP-D can improve the packet delivery ratio in WSNs and decrease communication latency.

Disadvantages:

- End-to-end delay may increase due to finding a new path.

3.3.3 Single-Path Non-Delay-Tolerant Network Routing

3.3.3.1 GPSR-Adaptive Beacon and Position Prediction (GPSR-ABPP)

GPSR-ABPP is designed for Mobile Ad-hoc Networks (MANETs). It is a single-path NON-DTN protocol. It is an extension of GPSR (Greedy Perimeter Stainless Routing) that aims to improve efficiency and reliability through adaptive beacons and position prediction mechanisms.
Each node broadcasts information about the location using adaptive beacons that are further sent at variable intervals depending on the node's mobility and communication patterns. The routing overhead is reduced by the adaptive beacons. The prediction mechanisms which is machine learning algorithms that study the node's movement patterns about the communication history to estimate the future location.
Similar to GSPR, it contains information about the location of neighboring nodes. This protocol uses a combination of distance-based and distance-based routing.

Advantages:

- It improves the efficiency and reliability
- It reduces communication delays.

Disadvantages:

- Low localization accuracy in the high network.

3.3.3.2 Adaptive Density-based Routing Protocol (ADRP)

ADRP is designed for Mobile Ad-hoc Networks (MANETs) that aim to improve efficiency and reliability by adjusting to changes in network density.
In this protocol, the information about the location and density of neighboring nodes is contained in the neighboring table that each node maintains. Density is calculated based on the number of nodes in a given area whereas the neighbor table is updated periodically.
Since this protocol is based on the density of the nodes. When density is low, a distance-based routing approach is used that determines the next hop based on the distance of the destination node. And when it's high, it uses a direction-based routing in this the next hop of the destination node is determined by the direction.

Advantages:

- It improves the efficiency and reliability of MANET
- It reduces communication delays.

Disadvantages:

- Route discovery time will be longer in a dynamic network

3.3.4 Single-Path-Greedy-Based Non-Delay Tolerant Routing

3.3.4.1 Robust and Reliable Predictive Routing (RRPR)

RRPR is a PBRP that is designed for Mobile Ad-hoc Networks (MANETs). It aims to improve efficiency and reliability. In this protocol, the information about the location and density of neighboring nodes is contained in the neighboring table that each node maintains. This protocol uses a combination of distance-based and distance-based routing. The prediction mechanisms which is machine learning algorithms that study the node's movement patterns about the communication history to estimate the future location.
RRPR uses a robustness mechanism that ensures that the protocol can handle the unpredictable nature of wireless communication. This protocol uses multiple paths to transmit data. This mechanism provides a backup path for each primary path, which can be used in times of failure or congestion.

Advantages:

- It improves the efficiency and reliability of MANET.
- It can increase the throughput and reduce communication delays.
- Increase route setup success rate

Disadvantages:

- Difficult to measure the node angel.

3.3.4.2 Distance-Based Greedy Routing (DSGR)

DSGR is a PBRP that can efficiently send data packets between a wireless network. This protocol mainly relies on the physical location of the nodes in the network, instead of using traditional IP addresses.
In this protocol , each node in the network maintains a local map of the network topology. A local map is used to determine the neighboring node which is closest to the destination to transmit a data packet to the closest destination node

Advantages:

- It is very efficient in finding the route to the destination node.
- It doesn't require the maintenance of complex routing tables or complicated algorithms.
- It can handle dynamic changes in the network topology such as failures or changes in the node

Disadvantages:

- Complexity of algorithm is huge

3.3.5 Multi-Path Non-Delay-Tolerant Network Routing

3.3.5.1 Reactive Greedy Reactive Protocol (RGR)

RGR is another PBRP that can efficiently send data packets between a wireless network. Similar to DSGR, it also relies on on the physical location of the nodes in the network, instead of using traditional IP addresses to determine the next hop location.

Each node in the network only maintains location information instead of the entire network topology. In RGR, to transmit a data packet to a destination, the discovery phase is initiated to find the route to the destination node. This provides a reactive approach, in which the node only looks for the route when it needs to transmit.

Advantages:

- It is more scalable than DSGR as it only maintains information about its neighboring nodes.
- It can handle dynamic changes in the network topology as it uses a reactive approach.

Disadvantages:

- It may take longer to find the route if the network topology is complex.
- It can result in increased latency and delay in transmitting.

3.3.5.2 Geolocation -Based Multi-Hop Routing Protocol (GLMHRP)

GLMHRP is another PBRP that can efficiently send data packets between a wireless network. It is a multi-hop protocol that allows packets to be sent to multiple hops to reach the destination node.
Each node in the network maintains a local map of the network topology that includes the location of neighboring. A local map is used to determine the next destination when a node needs to transmit the data.

Advantages:

- It provides a long-range transmission network.
- It can handle dynamic changes in the network topology such as failures or changes in the node.

Disadvantages:

- It is not efficient as other PBRPs as it requires multiple hops to reach the destination.
- It can result in increased latency and delay in transmitting.
- It requires more network resources.

3.3.6 Multi-Path Heterogenous Routing

3.3.6.1 Position-Aware, Secure, and Efficient Mesh Routing Protocol (PASER)

PASER is another PBRP that is designed for wireless mesh networks. It is a proactive protocol i.e. it maintains routing tables in the network, which contain information necessary for transmission.
PASER uses the physical location of nodes in the network to determine the next hop. Location is broadcasted periodically, and the routing table to its neighboring nodes allows them to keep it updated. PASER includes several security features to protect against attacks such as blackhole attacks or wormhole attacks

Advantages:

- It has the ability to handle multiple paths to the destination.
- It increases efficiency and reliability.
- It provides robust features which are resistant to attacks compared to other PBRP.

Disadvantages:

- It may be less efficient than other routing protocols.
- Traffic can result in latency.

3.3.7 Multi-Path DTN Routing

3.3.7.1 Location-AIDED Delay Tolerant Routing (LADTR)

LADTR is PBRP designed for Delay Tolerant Networks. DTNs are wireless networks where communication between nodes is intermittent. This protocol uses the physical location of the nodes for transmission, even when there is no direct communication path.
LADTR divides the networks into multiple regions, each region contains a set of nodes that can communicate with each other.
Nodes in the same region communicate by exchanging packets directly. However, if it needs to transmit to a different region, it uses a store-carry-forward mechanism to send it forward through intermediating nodes.

Advantages:

- The key advantage of LADTR is its ability to transmit data packets in DTN, where nodes may not be able to communicate directly with each other.
- As it uses location information, it makes it more efficient and reliable than other PBRP.

Disadvantages:

- It may be less efficient when communication is not intermittent as it relies on a store-carry-forward mechanism to forward through intermediating nodes.

3.4 Cluster based Routing Protocol (CBRPs)

This section provides a thorough analysis of cluster-based routing protocols for UAV networks in terms of their salient traits, distinctive qualities, possible benefits, and potential drawbacks. Clustering has many advantages, including scalability, reliability, fault tolerance, data aggregation, energy efficiency, coverage, connectivity, and reduced delay. As the number of UAVs in UAV networks rises, cluster-based routing protocols will be developed and used more frequently.[10]

Clustering is the division of a network into several linked clusters and sub-clusters. The clustering idea is a method for grouping nodes that are geographically close to one another. This is done largely to alleviate the resource scarcity problem of the FANET. Each cluster's cluster head (CH) performs the coordination function inside the sub-cluster. The clusters where each CH is placed are therefore thought of as having an interim Base Station (BS). Network nodes are organised into a series of overlapping clusters as part of the clustering process.[11]

Ad-hoc UAV network clustering is a potent network management strategy that may significantly improve the overall performance of ad-hoc UAV networks.

CBRPs will advance in complexity and have a big market. The two main types of clustering protocols now in use are probabilistic clustering and deterministic clustering. The choice in the former is produced using probabilistic models, whereas the decision in the later is deterministic.[11] To reduce transmission counts, aggregated data is given to the UAVs. Low end-to-end latency communication between vehicles is possible inside clusters.

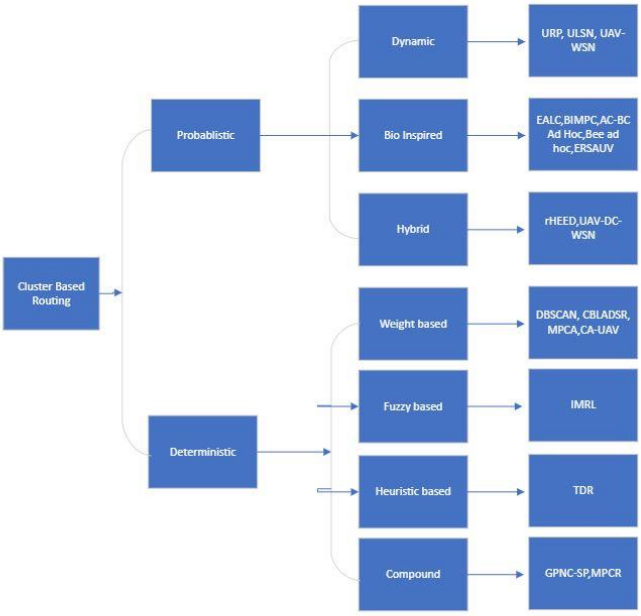

Fig 3.2 Classification of Cluster Based Routing Protocol

3.4.1 Cluster Based Routing Protocol based on Probablistic Clustering

Longer network lifespan is one of the main goals of probabilistic cluster-based routing. The CH is chosen at random in various probabilistic cluster-based routing algorithms. The probabilistic cluster-based routing protocols are carefully examined in this section.

3.4.1.1 Dynamic Clustering

Cluster formation and CH selection must be actively maintained for this type of clustering [12, 13]. Each node takes part in a CH selection setup, and several CH calculation techniques are applied..

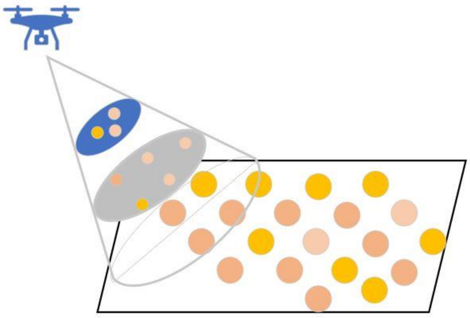

Fig 3.3 Dynamic Clustering Scheme in URP

3.4.1.1.1 UAV Routing Protocol

For the purpose of monitoring crop health, Uddin et al. [14] introduced URP, a UAV-assisted dynamic clustering method. A dynamic cluster-based routing system called URP tries to gather information from a particular area. In their investigation, a mobile sink node with a UAV platform gathers information from dispersed nodes using a predetermined or random path. A UAV activates all sensor nodes located in its neighbours with a beacon message, and it then forms a cluster by taking route and data kind into account. Cluster creation and selection of CH are dynamically carried out in URP. Each node takes part in the CH election process according to the probability that a Bayesian classifier determines for it. Figure 4 depicts the dynamic clustering technique in URP. Three categories of routing cluster nodes—cluster members (CMs), candidate clusters (CCs), and candidate CHs (CCHs)—are used to describe them. When a node is nominated to be a CH, CCHs and UAVs take part in the CH election process. The CH election procedure is calculated by a Bayesian classifier [13].

<u>Advantages:</u>

- In a rapidly built UAV network with no preexisting infrastructure, URP can be employed successfully. The use of dynamic clustering dramatically increases network longevity.

Limitations:

- URP is only meant to be used with WSNs that include a single UAV for crop health monitoring.

Potential application: URP can be used in agriculture to monitor crop health using UAV-based Internet of things (IoT) technologies.

Possible future improvements: Future URP improvements might take many different forms. Instead of using a single UAV, a group of UAVs can be used in concert. In URP, a single-hop transmission can be combined with a multi-hop transmission approach.

3.4.1.1.2 MOBILITY AND LOCATION-AWARE STABLE CLUSTERING (MLSC)

Flying ad hoc networks (FANETs) may also use mobility and location-aware stable clustering to boost network performance and resource efficiency. Unmanned aerial vehicles (UAVs), which are commonly used as nodes in FANETs and move in three dimensions, present special clustering issues. UAVs with comparable characteristics may be grouped in FANETs using mobility and location-aware stable clustering based on their altitude, speed, and trajectory. The clusters can use network resources like bandwidth and the power of batteries more effectively by grouping UAVs with similar features. This can enhance network functionality and lessen the possibility of network outages.
The conventional Ant Colony Optimisation (ACO) and Grey Wolf Optimisation (GWO) techniques are contrasted with the MLSC routing protocol. In this regard, the study first demonstrated the required number of CH UAVs for a given location to provide the most coverage with the least amount of power consumption. The study then recommended the k-means clustering method for finding settled CHs in the best possible way. In order to improve the stability of the cluster network, a cluster maintenance method was suggested that considers relative mobility and location.[10]

Advantages:

- Efficient use of resources: By assembling stable clusters of UAVs according to their mobility and position data, the MLSC protocol maximises resource utilisation. By using this strategy, UAVs may cooperate effectively and share resources like bandwidth and electricity.
- Adaptive clustering: The MLSC protocol makes use of a dynamic clustering technique that varies based on the movement of UAVs and network structure. This strategy minimises the cost and the complexity of managing stable clusters by ensuring that the clustering process is stable even as UAVs move in and out of the network.
- Load balancing: The MLSC protocol dynamically modifies the cluster size and membership to evenly spread the burden across UAVs. This strategy makes sure that UAVs can cooperate effectively and that resources are used to their fullest potential.
- Fault tolerance: Because the MLSC protocol is fault-tolerant, it can keep running even if certain UAVs stop working or leave the network. The protocol makes sure that the surviving UAVs can keep cooperating to keep stable clusters and complete the necessary tasks.
- Scalability: Because of its scalability, the MLSC protocol can manage networks of various shapes and levels of complexity. The protocol is easily adaptable to diverse applications' and surroundings' needs.

Limitations:

- Dependency on mobility and location information: In order to build stable clusters, the MLSC protocol significantly depends on precise mobility and position information. If this information is unavailable or is erroneous, the protocol may not be able to form strong clusters, which can have an influence on the network performance.
- Overhead: Due to the process of clustering, the MLSC protocol adds some overhead and may result in less bandwidth being available for data transmission. When the network is busy or there are several UAVs present, this overhead can become considerable.
- Complexity: The MLSC protocol is a complicated protocol that uses a lot of memory and processing power. In contexts with limited resources, it may be difficult to deploy and implement the protocol due to its complexity.
- Limited applicability: Because it was created exclusively for FANETs, the MLSC protocol might not be appropriate for other networks or applications that need alternative clustering algorithms.

- Security: There are no explicit security protections offered by the MLSC protocol to guard against cyberattacks like spoofing, eavesdropping, or data manipulation. The network's security may thus need the implementation of extra security measures.

Potential Application: Numerous possible uses for the (MLSC) algorithm in FANET include communication networks, disaster management, environmental monitoring, surveillance, and security. The MLSC algorithm's effective and reliable UAV clustering can be very useful for these applications.

Possible Future Improvement: Dynamic clustering, energy efficiency, scalability, resilience, and security are some of the areas where the (MLSC) algorithm in FANET may be improved. These developments could increase algorithm performance and broaden its application to more FANET situations.

3.4.1.1.3 UAV-BASED LINEAR SENSOR ROUTING PROTOCOL (ULSN)

The UAV-Based Linear Sensor Routing Protocol (ULSN) was developed for use in Flying Ad-hoc Networks (FANETs) using linear sensor nodes. Wireless communication is used by networks of unmanned aerial vehicles (UAVs), known as FANETs, to coordinate tasks. Linear sensor nodes are sensors that can detect and quantify certain physical characteristics and are arranged in a linear fashion. The ULSN protocol was created to maximise the efficiency of data routing from linear sensor nodes to the ground station or other network nodes. The linear sensor nodes are divided into segments by the protocol, and each segment is given to a particular UAV. The next step is for each UAV to gather data from the sensors In Its designated section and relay it to the base station.
A cluster-based linear-sensor routing protocol named ULSN was introduced by Jawhar et al. [15]. The ULSN intends to decrease the amount of energy consumed for data transmission and increase network longevity. Four different types of nodes are employed in ULSN: sinks, a single UAV, sensor nodes (SNs), and relay nodes (RNs). To send data to the closest RN, SN employs a multi-hop transmission. An RN serves as a CH to other RNs in its vicinity. The UAV node travels back and forth while gathering information from the RNs.

Advantages:

- Efficient use of resources: The ULSN protocol divides the linear sensor nodes into segments and allots each segment to a particular UAV in order to optimise data transmission. This strategy guarantees that each UAV exclusively gathers data from a certain area of the linear sensor nodes, lowering the UAVs' energy consumption and preserving resources.
- Multi-hop transmission: Each UAV serves as a relay for data sent by other UAVs according to the multi-hop data transmission method used by the ULSN protocol. By using this strategy, data transmission over great distances is made possible—even in setups where direct contact between nodes is not feasible.
- Energy conservation: By reducing the distance each UAV needs go to collect data from the linear sensor nodes in its designated segment, the ULSN protocol saves energy. This strategy contributes to lowering the network's total energy usage and extending the UAVs' operating life.
- Adaptive routing: Based on variables including UAV position, sensor node density, and available bandwidth, the ULSN protocol uses a routing table to select the best path for data transmission. With this strategy, the protocol is able to instantly optimise data delivery while adjusting to changes in the network architecture.
- Scalability: The ULSN protocol is easily adaptable to fulfil the requirements of diverse applications and settings since it is meant to be scalable, which means that it can accept networks of various sizes and complexity.

Limitation:

- Limited applicability: The linear sensor nodes used in FANETs are the focus of the ULSN protocol. As a result, it might not be appropriate for networks that employ various types of sensors or other forms of FANETs.
- Limited range: Data transmission using the ULSN protocol takes a multi-hop technique, which may have a restricted range and slower data rates. In applications where large data rates or long-distance communication are necessary, this can be a restriction.
- Security: There are no special security features offered by the ULSN protocol to guard against cyberattacks like spoofing, eavesdropping, or data manipulation. The network's security may thus need the implementation of extra security measures.
- Dependence on UAVs: The UAVs' availability and dependability, which can be impacted by elements like weather, battery life, and hardware malfunctions, are necessary for the ULSN protocol to function. Therefore, if the UAVs are unavailable or operate improperly, the network performance may be affected.

- Complexity: The ULSN protocol is a complicated routing protocol that uses a lot of memory and processing power. As a result, it might not be appropriate for applications with few resources.

Potential Application: Data may be gathered and transmitted from sensors to the sink node using the ULSN architecture.

Possible Future Improvement: The capacity of the various kinds of sensor networks may be increased. Future research can concentrate on providing effective algorithms for the best UAV routes and the utilisation of many UAVs per segment.[10]

3.4.1.1.4 UAV-WIRELESS SENSOR ROUTING PROTOCOL (UAV-WSN)

Martinez-de Dios et al. [16] suggested a cluster-based routing system, introducing the UAV-WSN. The WSN's operational results are used to adjust the UAV flight plan, and the UAV routing path depends on WSN operation to improve the performance of data location. These are the UAV-WSN's two primary cooperative behaviour. The authors used a flexible alliance between WSN and UAV for data collection. In terms of energy efficiency and network lifetime, the UAV-WSN routing protocol aims to surpass non-cooperative UAV-aided WSN routing. A distributed cluster approach is used in the UAV-WSN to group the WSN nodes.

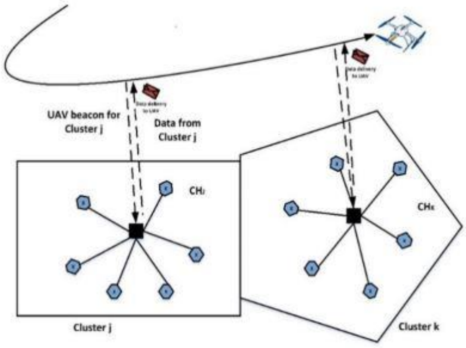

Fig 3.3 Cluster-Based UAV data collection.

The route plan for the UAV-WSN is shown in Fig3.3 There are two types of nodes: CH and CM. Sensor readings are gathered by the CM and occasionally sent to the CH. After receiving the signal from the lone UAV, CH sends the data. Every CM node monitors what is happening in the CH. Node I offers itself as a CH if it notices that its CH has not been active for a defined period of time. Zones for data collection are defined by CH placement. The UAV develops a flight plan using the zone data.

<u>Advantages:</u>

- Efficient communication: Applications for FANETs include surveillance, monitoring, and search and rescue, among many more. The UAV-WSN protocol can make it easier for UAVs and wireless sensors to communicate effectively, enabling rapid and reliable data transmission.
- Reduced energy consumption: FANETs must save energy since UAVs' batteries frequently have a finite lifespan. The UAV-WSN protocol can reduce the quantity of data exchanged between UAVs and wireless sensors, which can help save energy.
- Increased network lifetime: By lowering energy consumption and improving routing, the UAV-WSN protocol can help the network last longer. For applications that call for ongoing monitoring or surveillance, this is crucial.
- Improved scalability: Because the UAV-WSN protocol is scalable, it can manage networks of various sizes and levels of complexity. For FANETs, which may include hundreds or even thousands of UAVs, this is crucial.
- Real-time data transmission: Applications requiring real-time data transmission, including search and rescue operations, frequently employ FANETs. Real-time data transmission is supported via the UAV-WSN protocol, guaranteeing quick and dependable data delivery.

<u>Limitations:</u>

- Limited range: Large coverage regions of FANETs may lead to a limited operating range and slower data rates. In applications where large data rates or long-distance communication are necessary, this can be a restriction.
- Interference: The UAV-WSN protocol's performance may be impacted by interference from other wireless networks that FANETs are susceptible to. By picking the right frequency ranges and employing interference avoidance strategies, this may be reduced.
- Security: FANETs are susceptible to cyber-attacks such data tampering, eavesdropping, and spoofing. There may be a need to adopt extra security measures as the UAV-WSN protocol does not offer any special defences against these attacks.

Potential Application: Data from sensor nodes may be collected via UAV-WSN routing.

Possible future improvements: Expanding the multi-hop cluster could be conceivable for UAV-WSN's future development. Multi-hop clusters can simplify UAV routing, lower the number of clusters, but at the cost of a higher node energy consumption.

3.4.1.2 BIO-INSPIRED CLUSTERING

BIO-inspired clustering is a technique that creates clusters in a network by drawing ideas from biological processes. A significant number of unmanned aerial vehicles (UAVs) are grouped or clustered in FANET (Flying Ad-hoc Networks) using bio-inspired clustering.
The behaviour of social Insects like bees, ants, and termites served as the inspiration for FANET's bio-inspired clustering algorithm. These insects cooperate and communicate simply in order to plan their activity in huge numbers in order to accomplish shared objectives. In order to create effective clusters of UAVs, the bio-inspired clustering algorithm in FANET seeks to imitate these behaviours.The UAVs are separated into several groups or clusters by the algorithm according to their position, communication range, and battery state. A cluster leader oversees each cluster and is In charge of coordinating the UAVs In that cluster's operations. To coordinate network-wide operations and exchange information, the cluster head speaks with other cluster chiefs.

3.4.1.2.1 ENERGY-AWARE LINK-BASED CLUSTERING (EALC)

For FANET, the EALC routing protocol was introduced by Aadil et al. [17]. Short flight times and ineffective routing are two key issues with UAV routing that this routing system seeks to address. The authors applied K-means density clustering to tackle both issues. The lifespan of an ideal cluster is increased, and routing overhead is decreased. An adaptation of the K-means density method is used by EALC in the CHs election process. EALC employs two criteria, namely energy level and proximity to the neighbours, for the selection of an ideal CH as opposed to the usual K-means density approach, which uses just one variable for degree of neighbourhood. EALC selects the transmission power of nodes effectively in order to prolong the life of the cluster, increase energy consumption, and conserve node energy. For cluster formation time, cluster longevity, and energy consumption, EALC combines two bio-inspired algorithms: the ant colony optimisation (ACO) and grey wolf optimization-based clustering techniques. By grouping UAVs into clusters according to the link quality between them, the EALC algorithm is intended to reduce the energy consumption of the UAVs.In order for the EALC method to function, a graph representing the connections between the network's UAVs must first be constructed. Signal strength between both UAVs and their respective locations are used to assess the linkages. The method then creates strong link-connected clusters of UAVs using this graph.

A cluster leader oversees each cluster and is in charge of coordinating the UAVs in that cluster's operations. Based on its energy level, communication skills, and link quality with other UAVs in the cluster, the cluster head is chosen. To coordinate network-wide operations and exchange information, the cluster head speaks with other cluster chiefs.

The bulk of past research focused on statically weighting fitness-related variables, albeit this method can be biassed against fitness's function and yield incorrect results. If all nodes are within transmission range of one another, one node must be picked as a CH based on its fitness rating. In EALC, the nodes' energy level is considered as a fitness parameter. If Node A has an energy level of 90% while the remaining nodes have an energy level of around 50%, it is categorised as a CH. Another requirement is that node F may be chosen as a CH if it has a level of energy of 30% while others must have 50% but is closer to the other nodes.

<u>Advantages:</u>

- In EALC, choosing the right CH is dependent on transmission range and energy rather than a single static weight estimate. A lengthy CH improves network stability and lengthens network lifespan. EALC controls the transmission range and effectively clusters the network to optimise routing calculations and conserve UAV energy.[10]
- Energy Efficiency: EALC is made to optimise how much energy the network's UAVs use. The UAVs may interact with one another more effectively and avoid using energy-intensive long-distance broadcasts by grouping together in strong connection clusters. This can considerably lengthen the network's lifespan and lessen the frequency of battery changes.

- Improved Network Performance: By lowering network traffic and enhancing the UAVs' quality of service (QoS), EALC can help the network function better overall. In order to ensure that the UAVs inside a cluster have dependable and high-quality connections, the algorithm creates clusters depending on link quality.
- Scalability: Scalable algorithms like EALC can be employed in networks with many of UAVs. The algorithm creates clusters on-the-fly based on the UAVs' link quality, making sure the network is configured for maximum effectiveness.
- Robustness: The resilient algorithm EALC is capable of adjusting to alterations in the network architecture. The algorithm can swiftly create an additional cluster with the other UAVs that remain linked by strong connections if a UAV in the cluster goes out of range.
- Low Overhead: In terms of computing and communication resources, EALC has a minimal overhead. The technique just requires the unmanned aerial vehicles to communicate data on the quality of their links, which is a simple process that doesn't consume a lot of resources.

Limitations:

- The EALC protocol for routing only takes moderately mobile UAV nodes into account.[1]
- Limited coverage: Because the EALC algorithm is dependent upon the quality of the links between the UAVs, the network's coverage may be constrained. Due to poor link quality, UAVs spread out in a large area could have trouble being able to cluster together. This may restrict network coverage and lessen the algorithm's efficiency.
- High computational complexity: For the UAVs to form clusters and build a network of linkages between them, the EALC method needs a lot of computer power. This can be difficult in networks with many of UAVs since the algorithm's computational complexity can create a bottleneck.
- Communication overhead: UAVs must share connection quality data as part of the EALC algorithm, which might increase network communication overhead. The network's overall performance may be impacted by the increased latency and decreased throughput that might result from this.
- Limited mobility: The EALC algorithm is intended for networks with constrained mobility for UAVs. The link strength between the UAVs may be impacted if they move too rapidly or often change directions, which will make it challenging for the algorithm to be able to build stable clusters.

Potential Application: Peer-to-peer UAV communications can employ EALC.

Possible future improvements: In the future, it could be feasible to do effective routing with nodes that have extremely high mobility.

3.4.1.2.2 BIO-INSPIRED MOBILITY PREDICTION CLUSTERING (BIMPC)

The BIMPC protocols for ad hoc UAV networks was introduced by Yu et al. [18]. BIMPC seeks to handle the rapid network topology change and high mobility issue in UAV networks. The BIMPC protocol for routing introduces Physarum polycephalum's foraging model and the UAV's mobility characteristics to the world of ad hoc networks.

UAVs are considered as a swarm that displays collective behaviour in the algorithm, which is based on the idea of swarm intelligence. The estimation stage and the clustering phase are the two primary stages of the BIMPC algorithm. The system predicts each UAV's future mobility in the prediction phase using bio-inspired methodologies based on its present position, speed, and other variables. Virtual clusters—groups of UAVs that are anticipated to move together in the future—are created using this prediction.

Cluster creation and maintenance are included in BIMPC[10]. Based on the virtual clusters created in the prediction phase, the algorithm creates actual UAV clusters during the clustering phase. The programme groups the UAVs into clusters based on their anticipated mobility patterns using a clustering technique, such as K-means or hierarchical clustering. It is anticipated that the current UAV can add up the stability of the established cluster and the value of one-hop neighbours; however, not all one-hop neighbour UAVs are within the current UAV's communication range. All UAV nodes must determine the value in order to become a CH.

All UAVs broadcast Hello packets to their neighbours as the cluster forms, creating a neighbour list in the process. The current UAV then assesses the link subsistence probability and mobility of the current and neighbouring UAVs after receiving two consecutive Hello signals from its neighbouring UAVs.

Advantages:

- BIMPC routing performs better at creating clusters and maintaining highly dynamic clustering in large-scale UAV networks. The BIMPC cluster architecture is more reliable and has less overhead in terms of routing.[10]

- Accurate mobility prediction: Based on their present position and other variables, the BIMPC algorithm effectively predicts the future movement of UAVs. This enables the algorithm to create more reliable and effective clusters.
- Scalability: The scalable BIMPC method may be applied in networks containing a significant number of UAVs. The algorithm is capable of handling dynamic surroundings and may modify the clustering in response to variations in the UAVs' patterns of movement.
- Energy efficiency: Due to the fact that it creates clusters based on anticipated movement patterns, the BIMPC algorithm is energy-efficient. This saves energy, which is important in UAV networks, and lowers communication overhead.
- Robustness: The BIMPC algorithm is strong and can deal with illegible or noisy data. The method can identify and recover from failing UAVs and can alter the grouping depending on changes in the mobility patterns of the UAVs.
- Flexibility: Because it is adaptable, the BIMPC algorithm may be used in a variety of FANET applications. The method has applications in network communications, surveillance, and disaster management, among others.

<u>Limitation:</u>

- The BIMPC routing protocol only takes moderately mobile UAV nodes into account.[10]
- Accuracy of mobility prediction: The precision of the mobility prediction determines how accurate the BIMPC algorithm is. Instable or ineffective clusters might result from inaccurate projections. As a result, the system needs precise information on the present position, speed, and other characteristics of UAVs in order to generate trustworthy predictions.
- Computational complexity: Due to its high computational complexity, the BIMPC method may be constrained in large-scale networks with several UAVs. To analyse and store the massive quantity of data needed for mobility prediction, the algorithm needs a lot of computing power and storage.
- Communication overhead: UAVs must exchange mobility data with one another in order to use the BIMPC algorithm, which might result in a considerable communication overhead. Particularly in large-scale networks, this may lead to greater energy consumption and worse network performance.
- Limited applicability: The BIMPC method may not be relevant to other networks or applications because it was created exclusively for FANET settings. In some FANET systems with particular traits, including highly dynamic environments or environments with few communication resources, it could also only have a limited application.
- Sensitivity to environmental factors: The accuracy of the BIMPC algorithm is sensitive to environmental variables, such as wind, temperature, and other meteorological conditions, that impact the movement of UAVs. These elements may have an impact on the stability of the generated clusters and the precision of mobility prediction.

Potential application: Ad hoc UAV networks that are vast and extremely dynamic can employ BIMPC routing.

Possible future improvements: UAV nodes travelling at high speeds will be taken into account for BIMPC in the future.

3.4.1.2.3 ANT COLONY-BEE COLONY AD HOC ROUTING (AC-BC AD HOC) AND BEE AD HOC ROUTING (BEE AD HOC)

Two routing protocols for Fanet that are modelled after how ants and bees in the wild behave are AC-BC AD HOC and BEE AD HOC. The protocols optimise routing and improve network performance by utilising swarm intelligence Leonov's [19, 20] recommendations for FANET included an anticipated strategy and routing on the basis of meta-heuristics that were inspired by ant and bee colonies. The AC-BC ad hoc RP was created to solve basic UAV concerns including mobility, topology management, and three-dimensional movement. The source with the most nectar is what the bee colony searches for. The formation of search spaces, the development of swarms of scout and forager agents, choosing of the primary locations from among the potential ones for neighbourhood assessment, and information sharing between scouts and foragers are some of the techniques that the routing model must take into account in order to develop this behavior. The BC algorithm is mostly used to locate potential search locations and the surroundings around them. The AC algorithms and BC algorithms vary primarily in that the source node makes all routing choices, whereas intermediary nodes do not[10].

<u>Advantages:</u>

- When compared to traditional routing protocols, the AC-BC ad hoc RP End-to-end performance is excellent in terms of latency, throughput, and routing overhead. When the topology of the UAV network changes, the routing is stable.

- Scalability: Both the AC/BC Ad hoc and the BEE Ad hoc are scalable and capable of managing massive networks containing a significant number of UAVs. The protocols, which can adapt to dynamic changes in network topology, leverage swarm intelligence to optimise the routing process.
- Energy efficiency: Both AC/BC Ad hoc and the BEE Ad hoc employ a dispersed strategy to transport the data packets, making them both energy-efficient. The protocols utilise the idea of path pheromones to determine the most effective path, which lowers energy consumption and increases the battery life of the UAVs.
- Robustness: Both the AC/BC Ad hoc and the BEE Ad hoc are resilient and able to manage node failures and dynamic network topology changes. The protocols employ swarm intelligence to adjust to network changes and discover alternative channels for data packet routing.
- Quality of Service (QoS): QoS assurances are offered for several forms of traffic, including real-time and non-real-time traffic, by both AC/BC Ad hoc and the BEE Ad hoc. For each type of traffic, the protocols apply the idea of path pheromones to choose the best route, ensuring the timely and reliable delivery of data packets.
- Low overhead: The fact that the data packets are routed using a dispersed strategy results in reduced overhead for both AC/BC Ad hoc and the BEE Ad hoc. The lack of a centralised controller required by the protocols lowers communication overhead and enhances network efficiency.

<u>Limitations:</u>

- In AC-BC ad hoc routing, the UAV may travel arbitrarily inside the communication zone, make decisions at random intervals, and the probability distribution alters with time.
- Complexity: Both the AC/BC Ad hoc and the BEE Ad hoc are intricate protocols that need a lot of compute power and storage to function. For the protocols to maintain the path pheromones and update the routing tables, a substantial amount of data processing and storage is needed.
- Sensitivity to environmental factors: Both the AC/BC Ad hoc and the BEE Ad hoc are susceptible to outside influences that may change how the swarm behaves. The performance of the routing protocols might be impacted by variables like wind, temperature, and other meteorological conditions.
- Security: Both AC/BC Ad hoc and the BEE Ad hocṁṣjoeu lack robust security features that would defend the network against intrusions. The protocols are susceptible to assaults such denial-of-service attacks, eavesdropping, and manipulation.
- Limited applicability: Because they were created exclusively for Fanet settings, AC-BC AD HOC and BEE AD HOC might not be relevant to other networks or applications.

Potential application: For very dynamic peer-to-peer UAV communication and traffic monitoring, the AC-BC ad hoc is appropriate.

Possible future improvements: Future hybrid cluster-based routing implementation may be made possible by combining ant and bee colony routing algorithms.

3.4.1.2.4 EFFICIENT ROUTING STRATEGY FOR UAVs (ERSUAV)

Yang et al. [21] presented an AC-based stochastic cluster routing approach called ERSUAV to develop a successful routing strategy for UAVs. With this method, WSN and UAV device clustering abilities are combined on a single platform. Assumptions include that all nodes in the network are stationary, CHs are GPS-equipped and aware of their locations, the UAV is aware of each CH's location, and the amount of data provided by each node is constant. From the sensor node I to the UAV, which gathers data by flying over the CH, the area is divided into a number of clusters.
Using UAVs and wireless sensor networks (WSNs), ERSUAV is a useful method for gathering data on farming in remote alpine areas. The optimum route for UAVs according to ACO was designed and built for the WSN hierarchy using ERSUAV.
The reduction of delay and energy conservation are the ultimate goals of ERSUAV. The distance between the nodes affects the latency and energy usage.
<u>Advantages:</u>

- When compared to traditional routing, the ERSUAV routing protocol exhibits superior scalability, shorter latency, and improved efficiency.

<u>Limitations:</u>

- Based on a centralized-based clustering approach, ERSUAV routing is created. The network lifespan of centralized-based clustering is constrained, and it is not the best way to choose the CH.

Potential application: In farmland-based WSNs, ERSUAV is appropriate for collecting data to monitor pH, soil moisture, humidity, and temperature.

Possible future improvements: ERSUAV could eventually be expanded to embedded systems.

3.4.1.3 HYBRID CLUSTER BASED ROUTING PROTOCOL

Wireless sensor networks (WSNs) employ a hybrid cluster-based routing protocol (HCBRP) that combines the benefits of flat and cluster-based routing methods. Typically, nodes in a WSN are grouped into clusters, with one node serving as the cluster head and the others as members of the cluster. Data is gathered by the cluster heads and sent to a main sink node in a cluster-based routing protocol. As a result, there will be less data to transmit, which can help save electricity.
However, there are some circumstances when a flat routing protocol could be more effective. Without the use of clusters, a flat routing protocol allows all network nodes to connect directly with the sink node.By dynamically switching between cluster-based and flat routing according to the requirements of the network, a hybrid cluster-based routing protocol incorporates the advantages of both of these strategies. This may aid in network latency reduction and energy efficiency optimisation.

3.4.1.3.1 RSSI-BASIS HYBRID AND ENERGY EFFICIENT DISTRIBUTED ROUTING (rHEED)

A hybrid distributed clustering that uses less energy, which is an upgrade of HEED, was presented by Okcu and Soyturk [22]. Twain the clustering step and the data collection period of the method are meant to use less energy. To get over the single CH issue, rHEED builds clusters that are more stable and evenly distributed. The authors of rHEED suggested a UAV-assisted WSN clustering approach. The lower dependability and higher energy consumption of the static sink node make it unsuitable. The usage of a mobile sink node powered by a UAV Is a successful technique for gathering sensor data. The authors concentrated on RSSI-based clustering in rHEED. It highlighted the issue with UAV-based sink nodes in their study, namely that certain network nodes can be unnoticed due to the direction and altitude of the UAV. Sensor nodes are planted haphazardly around the region and are ignorant of their position. A single CM causes a single CH to have more than one member, which is one of the limits of the HEED routing protocol. Without any type of control, the number of CHs varies dramatically, leading to uneven cluster growth and a lack of knowledge regarding the location of the sink node.
The protocol's objectives include network load balancing and energy economy.
The Received Signal Strength Indicator (RSSI) is used by rHEED to calculate the network's node-to-node distance. Based on its proximity to the cluster heads, each node chooses a cluster head in a hierarchical structure of nodes created using this information. The multi-hop routing route to the base station is then formed by the cluster heads. The nodes with the greatest amount of remaining energy are chosen to serve as cluster leaders in rHEED, which also integrates an energy-efficient strategy. The network's lifespan is extended as a result of the energy consumption being evenly distributed across the nodes.
In addition, rHEED uses a hybrid strategy that incorporates direct and indirect transmission. Data is sent directly from the nodes to the cluster head through direct transmission. When data is sent indirectly, nodes send it to their nearby nodes, who subsequently pass it on to the cluster head. By requiring fewer hops to reach the base station, this helps to reduce the energy consumption of the nodes.

<u>Advantages:</u>

- The Routing by rHEED selects the CH using the RSSI values from the UAV's and the persistent energy of a sensor node. The cluster provided by the rHEED RP is more dependable and uniformly dispersed.
- Energy- efficient: By choosing the nodes with the greatest amount of remaining energy to serve as cluster heads, rHEED adopts an energy-efficient method. The network's lifespan is extended as a result of the energy consumption being evenly distributed across the nodes.
- Load balancing: rHEED chooses cluster leaders based on their proximity to nodes and builds a hierarchy of nodes depending on the Received Signal Strength Indicator (RSSI). This aids in distributing the network's nodes' workload more evenly.
- Hybrid method: rHEED uses a hybrid technique that mixes direct and indirect transmission. By minimising the number of hops needed to reach the base station, this strategy helps to reduce the energy consumption of the nodes.
- Scalability: rHEED is scalable and can be used in large-scale networks.

Limitations:

- The rHEED route is only intended for WSN communication using a single UAV.
- RSSI-based: rHEED relies on the precision of RSSI measurements, which are susceptible to interference and attenuation from the environment. The accuracy of the node clustering and hierarchical structure may be impacted by this.
- Overhead: For cluster creation and maintenance, rHEED requires additional overhead, which might use more energy and bandwidth in the network.
- Limited applicability: rHEED was built for homogenous networks and could struggle in diverse ones.
- Single point of failure: Since rHEED depends on the cluster heads to send data to the base station, a failure or an offline cluster head might result in a single point of failure.

Potential application: A mobile sink node can receive aggregated data from the sensory node via the rHEED routing protocol. [10]

Possible future allevations: In the future, rHEED routing might be enhanced by utilising a multi-UAV-based idea. [10]

3.4.1.3.3 UAV ON BASIS of DATA COMMUNICATION FOR WSNs (UAV-DC-WSN)

Unmanned aerial vehicles (UAVs), commonly referred to as drones, are used to gather and transmit data from wireless sensor networks (WSNs) in a process known as Data communication for WSNs using UAVs (UAV-DC-WSN). A WSN is a network of inexpensive, compact sensors placed in a specific location to track environmental factors including pressure, temperature, humidity, and light. Due to its capacity to offer a flexible, quick, and affordable alternative for data collection and transmission, the usage of UAVs for data transfer in WSNs has grown in popularity. UAVs may fly over the WSN deployment region and gather sensor data, which they can then wirelessly communicate to a central base station or a distant server.
But there are certain difficulties with UAV-based data transfer for WSNs as well. These include the restricted flying length and data collecting capacity of UAVs due to their short battery lives. Additionally, unfavourable weather conditions like strong winds, rain, or snow can have an impact on UAVs and hinder their capacity to function efficiently.

UAV-DC-WSN is the name of the cluster-based delay-tolerant UAV routing that Jawhar et al. [23] suggested. In large-cluster networks, this routing focuses on the utilisation of a UAV for data collecting. The multi-hop routing strategy is avoided by the UAV-based routing model, resulting in considerable energy savings, an extended network lifetime, and enhanced node placement flexibility. The authors of UAV-DC-WSN suggested a store-and-forward model. The UAV travels across the vicinity of the sensor nodes in this routing model. As soon as the UAV enters the span of the sensor RN, the sensor begins to communicate data to the UAV, which then saves the data in its buffer memory.
The data that the UAV has acquired from a certain cluster is uploaded after it has finished its mission and reached the sink node. As seen in Figure 8, the authors had also recommended a round-robin routing of UAV using the same strategy.

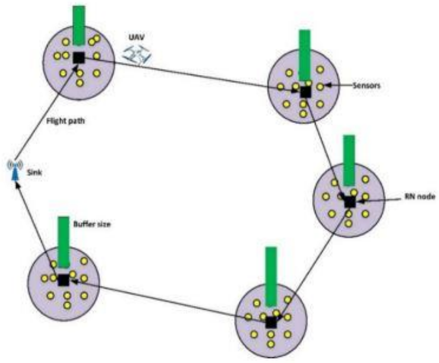

Fig 3.4 UAV-based collection in cluster network.

Round-robin scheduling is used by the UAV while moving between clusters in routing by UAV-DC-WSN. Between the clusters, the UAV travels at a steady pace. All clusters have the same communication time. The UAV could gather the data in the following flight cycle if any cluster has additional data in the buffer memory.

Advantages:

- The multi-path cluster routing used by the UAV-DC-WSN RP can provide network dependability in the event of node loss and can put up with significant delays.

Limitations:

- If RN has a big buffer, the UAV and RN node have a set interaction time., but owing to the time restriction, the UAV cannot gather all the data at once. Since RN must wait for the subsequent cycle, the network is further delayed.

Potential application: For situations where data may tolerate more significant delays, the UAV-DC-WSN RP architecture can be employed.

Possible future improvements: The UAV-DC-WSN RP was created to allow for the use of a single UAV to gather data in WSNs. The use of many UAVs might dramatically improve network speed and reduce routing time in the future.

3.4.2 Routing Protocol for Clusters based on Deterministic Clustering

It is a type of clustering in which the clustering algorithms assigns data points to cluster based on specific rules and criteria, without randomness. The resultant clusters are well-defined and make them useful in many applications. Kmeans clustering is one of the approaches used in deterministic clustering in which the algorithm partitions data into k clusters based on their distance to the mean of each cluster. Another method that is used is hierarchical clustering in this method it builds a tree-like structure of nested clusters by repeatedly merging or splitting clusters based on their similarity. Deterministic clustering can be sensitive to outliers and noise. It is generally faster and more efficient than probabilistic. This deterministic clustering has been further categorized as Weight Based, Fuzzy Based, Heuristic Based, and Compound.

3.4.2.1 Weight Based

3.4.2.1.1 Expectation-And-Likelihood-Based Clustering (EALC)

It uses a combination of distance-based and probabilistic-based approaches to partition data into clusters. This routing protocol is a type of model-based clustering that assumes that the data is generated from a mixture of Gaussian. This algorithm starts by initiating the mixture of parameters which includes the number of clusters i.e. covariances. Then it assigns data points to clusters based likelihood of belonging to each cluster and updates the mixture parameters based on the new assignments.

Advantages:

- It is a flexible algorithm that can handle all types of data which includes binary and categorical data
- It is able to scale large amounts of data sets efficiently.
- It is sensitive to the initial conditions, meaning, that different initialization can lead to different clustering.
- It also assumes that the data is generated from Gaussian distributions, which may not always be appropriate.

3.4.2.2 Fuzzy Based

3.4.2.2.1 Incremental Maximum Rule Learning (IMRL):

This algorithm is a hierarchical clustering algorithm that starts when each data point has its own cluster and iteratively merges clusters based on maximum rule creation.This rule is used by IMRL to measure the similarity between clusters, which is mostly based on maximum rule creation. After each iteration, the algorithm merges the two clusters with the highest similarities.

Advantages

- It is efficient and doesn't require a pre-specified number of clusters.

Disadvantages

- It may not be suitable for all data types, especially if the data contains outliers.

3.4.2.3 Heuristic Based

3.4.2.3.1 TDR (Threshold-Driven Resampling):

This aims to identify groups of data points based on similarities. In this method, data is divided into clusters based on the threshold value is determined by the

algorithm. It's a measure of similarities between data points.
This method works by randomly selecting a subset of data points, then calculating the pairwise similarities. Between each point in the subset. This threshold value is based on the distribution of pairwise similarities.
The process is repeated iteratively, with the threshold value updated after each iteration based on similarities. TDR is a clustering algorithm meaning that its output is always the same when the same input is given

Advantages

- It is highly scalable as it can handle large datasets.
- TDR is a flexible algorithm as it can be applied to various data types
- Limited to convex clusters: it may not be able to detect non-convex or irregularly shaped clusters in the data.
- Overfitting: TDR suffers from overfitting as it can create too many clusters in the data.

3.4.2.4 Compound

3.4.2.4.1 Gaussian Process Nearest Cluster - Spectral Projection:
It is a deterministic clustering algorithm that is based on a combination of Gaussian Process regression and spectral clustering. This protocol aims to identify clusters by modeling the underlying data distribution using Gaussian Process and then the data is onto a low-dimensional subspace using spectral clustering. It is used to estimate the distribution of the data in high-dimensional space. Whereas the spectral clustering approach allows the identification of clusters in the data based on the spectral properties of the data matrix.

Advantages

- It can handle both continuous and categorical data, also it can identify non-convex data.
- It can also handle datasets with missing values and can automatically determine the number of clusters.

Disadvantages

- It is quite expensive for large datasets and its performance maybe hampered.

3.5.0 Energy Aware Routing Protocols

UAV in an ad hoc network are powered by batteries which comes with the limitation of limited power along with the clause that the development of the technology is comparatively slower when compared to technical development of the latter part. Energy usage of a node may be divided into Consumption related to Interaction and Consumption related to Computation[24].
Conventional Routing Techniques tend to be focused on shortest path algorithm without taking energy pool into consideration leading to complete depletion of the energy resource available very rapidly without enough output. Energy Aware protocol take careful consideration of the UAV's short battery life and work to reduce energy consumption by choosing effective routes, managing the transmission power, and altering UAV speed also they optimize the UAV use of energy while idle during in-flight.
Energy Aware Routing Protocols (ERP) is an inquiry-based routing protocol intended to take into account network routing protocols over a network's power and separation between nodes. A node during operation has a radio transceiver which it engages to interact with other present nodes in its vicinity in an flying Ad hoc network and can be in one of the following four modes: Transmit, Receive, Idle and Sleep. When during sleep mode the ndoe used the least amount of energy, if in transmission mode, it used energy to maintain the signal-to-noise ratio which imperatively depends upon the distance between transmitter entity and receiver entity node. One of the major energy consumption takes place during transmission mode which can be optimized if the transmitter can dynamically alter the power regularly or surreptiously at low levels. We can categorize wide range of energy aware routing protocols as Activity-Based Protocols and Communication-Based Protocols as shown in fig. 3.5

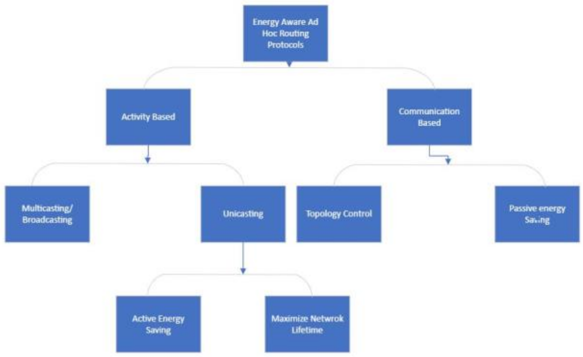

Fig 3.5

These protocols are centred on intelligent, power-conscious routing selections that control the data transmission process. We further categorise activity-based protocols into Unicasting and Multicasting/Broadcasting groups based on various routing duties. Topology control and Passive Energy Conservation are the two categories into which we divide connectivity-based protocols. The transmission power required by nodes is adjusted using topology control protocols to conserve energy while preserving reliable network connectivity. Since energy usage when a node's radio is idle is not insignificant, inactive energy saving protocols conserve electricity by simply turning off some idle nodes.

3.5.1 Activity Based Energy Aware Routing Protocol

A style of energy-efficient routing protocol called Activity Based Energy Aware Routing Protocol (ABEAR) was created for wireless sensor networks (WSNs) being modified for usage in unmanned aerial vehicles (UAVs). In order to effectively route data packets and conserve energy while extending the network's overall lifespan, ABEAR takes into account the amount of activity of each sensor node in a network. The frequency at which a sensor node observes and sends data to other nodes in the network is referred to as the node's activity level. Nodes with a high degree of activity use more energy than nodes with a low level of activity. By routing data through nodes with low activity levels, ABEAR seeks to balance the energy usage of each node in the network and so lower the overall energy consumption of the network. Data is moved through the network by ABEAR using nodes arranged in a hierarchical fashion. Cluster heads and common nodes make up the two groups of nodes. The data from the common nodes must be combined by the cluster heads before being sent to the base station or the sink node. As mentioned in the fig. 5.1 Activity based Energy Aware Routing Protocols have been classified into two types as follows

1. Unicasting : Unicasting Routing Techniques are used to find the most efficient route for data packets to take between nodes. These protocols aim to reduce network congestion and boost overall network performance by determining the quickest and most effective path between source and destination nodes. RIP (Routing Information Protocol), OSPF (Open Shortest Path First), and BGP (Border Gateway Protocol) are a few examples of unicasting routing protocols. These protocols analyse the network topology, bandwidth, and delay to choose the optimum routing for each packet using a variety of algorithms and metrics. In conclusion, unicasting routing protocols play a crucial role in providing efficient and dependable data transfer in contemporary computer networks. Direct paths between two network nodes are created using unicast routing techniques.

    a. Routing Information Protocol: is a dynamic protocol designed use the values of jumps as a metric route to find the most efficient path between source node and destination node for energy saving. It is a distance vector sub type protocol that has vale of 120 for AD and OSI as working networking layer. This protocol uses the merit features of RIP and its different versions as RIP can act as a measure which ca be used in all Unicasting, Multicasting

(RIP v2 224.0.0.9) and Broadcasting (RIP v1 255.255.255.255) along with its Classful Routing and Classless Routing giving additional support to save energy on transmission of information of masked subnet in its routing update. Its limitation however is it is not much scalable when its comes to large network are of UAV[25].

b. Open Shortest Path First Protocol (OSPF): is a state – linking protocol based on shortest path first algorithm. It is an Interior Gateway Protocol unlike Border Gateway Protocol. In the network where this protocol is implementesd the nodes present in same area maintains same linking state and describes the area's topological data. LSA (Link State Advertisement) packets help all the nodes and managing unit to develop a state linked database for UAV deployed in the area. An LSA can also be defined as a packet containing data about the nearby UAV nodes, distance and all the energy costs that will be spent if a transmission goes through on command. Based on the database formed, each node calculates the shortest path for transmission of data to intended node for Air-to Air transmission with least amount of energy spent in the whole process. OSPF works on Hello protocol for Link State having different phases as EXSTART phase in which nodes mutually negotiate which is the transmitter and receiver, EXCHANGE phase in this the two nodes exchange the Data-Base Description packets so as to find which LSA Database is to be sent, LOADING phase is a stage in which each node send a Link State Request(LSR) to entirety of LSA Transmission List during the previous phase and last FULL phase when the entire process completes with the exchange[26].

2. Multicasting/Broadcasting: Multicast Routing techniques, which have a common tree topology and disseminate messages to every node within their broadcast area, this is not the case. Hosts on the same network segment can communicate with one another directly using multicasting routing techniques instead of passing packets through a router. Each packet is broadcast over the data connection layer in order to accomplish this, ensuring that all nearby devices may receive it. When transmitting video broadcasts or live conferences over an IP network, multicasting methods are frequently employed. PIM (Protocol Independent Multicast) and DMM (Distance-Vector Multicast Routing Protocol) are two examples of multicasting routing protocols. Another term for a specific kind of network connection or transmission is unicast routing. This context uses the term to describe the transmission of data from a source node (the source) to a certain destination node (the destination). This is distinct from broadcasting, which sends data simultaneously in all directions. Wireless networks can also use unicasting routing algorithms to enhance overall network performance. For instance, the IEEE 802.11 standard mandates that every device must be in communication with a single access point at any given time. As more devices join the network, this requirement might eventually cause congestion and lower capacity.

   a. Protocol Independent Multicast (PIM): is a set of multicast routing protocols wherein each of the member protocol is revamped for a variety of environment. There are two principal protocol mode:

Sparse mode and Dense Mode. Another mode called as Bi-directional mode is also in existence but its implementation in real world cases is less widely used.[27]

3.5.2 Communication Based Energy Aware Routing Protocol

By reducing the amount of communication necessary for data transmission, communication-based energy-aware routing methods seek to minimise energy consumption in wireless sensor networks (WSNs) used by UAVs for communication. These protocols limit the quantity of data transferred and improve network energy efficiency by using methods including data aggregation, compression, and prediction. Compressive Data Gathering (CDG) is an illustration of a communication-based energy-aware routing protocol. Compressive sensing is a technique used by CDG to limit the quantity of data that sensor nodes send. Nodes transmit compressed data instead of raw data, which lowers energy usage and increases network longevity. Additionally, CDG employs a distributed approach to enhance compression ratio and reduce energy usage. Predictive Data Gathering (PDG) is another example of a communication-based energy-aware routing technology. Prediction algorithms are used by PDG to estimate sensor data and minimise data transmission. PDG lowers energy use and increases network longevity by foreseeing sensor data. A distributed approach is also used by PDG to enhance accuracy in prediction and minimization of energy consumption. To function at their best, communication-based energy-aware routing protocols need complex algorithms and ample computer power. These protocols are appropriate for WSNs with fast data rates and little available energy. The unique application needs and network parameters determine whether communication-based energy-aware routing methods should be used. In conclusion, communication-based energy-aware routing protocols employ methods like data aggregation, compression, and prediction to lower energy usage and improve the network's energy efficiency. These protocols are appropriate for WSNs with fast data rates and little available energy[24].

Communication Based Energy Aware Routing Protocols have been further divided into two principal branches which are: Topology Control and Passive Energy Saving.

1. Topology Control: To optimise the topology of the network and save energy, topology control routing protocols are a form of routing protocol used in wireless ad hoc networks. The management of the network topology, which includes the placement of nodes and their connections, is referred to as topology control. By managing transmission power and choosing the most efficient paths for data transmission, topology control routing protocols aim to reduce the power consumption of nodes. These protocols function by configuring each node's transmission range and restricting the number of neighbours with whom a node can connect. This lessens interference and enhances the performance of the entire network. Few of the Routing Protocols are

    a. Minimum Energy Routing (MER): a kind of topology control routing protocol that chooses the shortest route between nodes to reduce energy usage. The protocol employs a distributed method to determine the energy-efficient shortest path between nodes. It can further divided on the basis of link costs: Minimum Total Transmission Power (MTTP), Minimum Total TransCeiving Power (MTTCP) and Minimum Total Reliable Transmission Power (MTRTP). The transmission power is used by MTTP protocols as the link metric to find the path between the source and the destination that has the least overall transmission power. The connection cost in MTTCP protocols includes both the receiving power and the transmission power. To successfully send data packets from one node to its neighbouring node, the MTRTP protocol employs the entire transmission power as the connection cost[28].

b. Spanning Tree Based Routing (STBR): is a kind of topology control routing protocol that builds the network topology as a spanning tree. The root node chosen by the protocol is the lowest energy node, and the root node serves as the centre of a spanning tree that is built around it. Thus, energy use is reduced, and network performance is enhanced. It is a layer 2 level protocol created to avoid looping in an network topology of UAV so as to reduce the energy loss taking place due to data transmission due to presence of abundance of redundtant looped paths.

c. Power Aware Localized Routing (PALR): is a sort of topology control routing protocol that minimises energy use by using a localised strategy. The network is divided into clusters by the protocol, which also chooses a cluster head for each cluster. The optimal path for data transmission must be chosen by the cluster head, who is also in charge of overseeing communication inside the cluster. Goal of the protocol was to gain the following features while routing, Minimize Energy required per routing task, Loop Freedom, Maximize the number of routing tasks a node can perform, Minimize communication overheard, Avoid memorizing past traffic route, Localized algorithms, Single path routing algorithm and maximizing delivery rate[29].

2. Passive Energy Saving: By minimising the quantity of data transmission and processing, passive energy-saving routing methods seek to minimise energy usage in wireless sensor networks (WSNs). These protocols utilise topology management and cluster-based routing to minimise individual node energy usage and increase network longevity. For instance, an adaptive clustering strategy was suggested to lower node energy consumption and enhance network performance in a research on energy-efficient routing protocols for WSNs. Another study suggested energy-efficient Dynamic Source Routing (DSR) protocol combined with optimised passive clustering to increase network lifespan by identifying and resolving the significant energy leveraging behaviours of WSN.

3.6.0 Topology-Based Routing Protocol

The topology-based routing protocol is used in computer networks to determine the optimal path for data transmission from one deceive to another. This protocol makes decisions based on the network's structure, such as each device's location and connectivity. This protocol uses mathematical tools to design and optimize UAVs. Its designs have the potential to improve reliability and efficiency. It makes them a more powerful tool for a wide range of applications. However, it requires advanced mathematical tools and computational resources.

Topology-based UAV routing protocol has been further categorized into four parts. They are Reactive, Proactive, Hybrid, and Static routing protocols.[30,33]

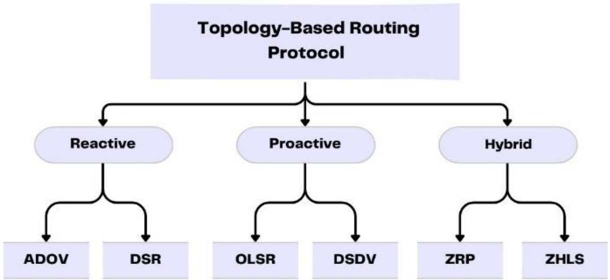

Fig 3.6 Classification of Topology-Based Routing Protocol

3.6.1 Reactive Routing Protocol

3.6.1.1 Ad-hoc On- Demand Distance Vector (ADOV)

This protocol is mostly used for mobile ad-hoc networks. It uses route discovery and route maintenance mechanisms to find out the shortest path. It helps us determine the routes on demand.

In this protocol, when two nodes want to communicate with each other, it sends a route request or RREQ. This RREQ is sent to all the neighboring nodes, it contains the address of the destination and also a sequence number. Whichever node receives the RREQ message, crosschecks with its routing table to see if it has a route to the destination node. If it doesn't then it reroutes the RREQ message.[30]

When the RREQ message arrives at the destination node, it sends a route reply or RREP to the source node. This RREP consists of the destination node. And source node uses the information in the RREP message to determine the optimal path to the destination node. AODV protocol supports route maintenance.

<u>Advantages:</u>

- Low Overhead: It only requires nodes to exchange information when a new route is needed. It reduces the amount of network traffic and conserves battery power.
- Scalability: It is highly scalable and can be used without sacrificing performance.

<u>Disadvantages:</u>

- Delay in Route Establishment: It may face delays in establishing a route when network congestion occurs. This delay results in data loss.
- Attack Vulnerabilities: It is susceptible to wormhole and blackhole attacks, among others. It could obstruct routing and stop data flow.

3.6.1.2 Dynamic Source Routing (DSR)

DSR is a reactive, on-demand, and topology-based protocol used in mobile ad hoc networks. It is a source routing protocol, which means that the entire route from source to destination is contained in the packet header. This helps to forward packets based on the exact route to the destination instead of relying on the routing table.

In this protocol, when a source node sends a packet to the destination node, it initiates a route discovery process. When it is the route discovery process, the source node floods the network with a route request packet (RREQ) which contains the destination node. When a node receives the RREQ message, crosschecks with its routing table to see if it has a route to the destination node. If it doesn't then it adds its address to the packet and forwards it to its neighbors.

This process continues until the RREQ reaches the destination node.[30,31]

<u>Advantages:</u>

- It is highly adaptive and it can quickly adjust to changes
- This protocol is highly scalable as each node maintains its own routing tables and can be used in large MANETs.

<u>Disadvantages:</u>

- It can suffer from high overhead due to the inclusion of the entire route in the packet header.
- The performance is affected by the packets that require large packet sizes.

3.6.2 Proactive Routing Protocol

3.6.2.1 Optimized Link State Routing (OLSR)

OLSR is a proactive, topology-based routing protocol used in MANET. It is used designed to minimize the overhead associated with the link state routing protocol.
In this protocol, nodes broadcast their link state information to their neighbors. This contains the source or the node's address, the neighbor's address, and the quality of the links. The information is collected by each node to construct a topology map of the network. Once it's completed, it uses the shortest path algorithm to calculate the best routes, then it's shared among the nodes in the network.

Advantages-

- This protocol is highly scalable and can be used in large MANETs
- As the nodes broadcast their link state information to their neighbors, it has a low overhead compared to others.

Disadvantages-

- It suffers from high control message overhead in highly mobile networks since the nodes need to be updated constantly to their link state information.
- It has a high consumption of power and reduced battery life.

3.6.2.2 Destination-Sequenced Distance Vector (DSDV)

DSDV is a proactive, topology-based routing protocol used in MANET. It is a distance vector protocol, which means that each node maintains a routing table that consists of the distance and the next hop information.
In this protocol, the routing table is broadcasted by each node to its neighbor at regular intervals. This table includes the distance to each node and the next hop with the shortest distance. DSDV uses sequence numbers to prevent loops to make sure that nodes have updated information.
When a node receives a routing table from one of its neighbors, it compares the sequence numbers to check the recent table. If it is, then new information is updated.

Advantages-

- This routing protocol provides loop-free routing, making it reliable.
- The protocol is up to date and quickly adapts to changes in its network topology.

Disadvantages-

- It suffers from high control message overhead due to the periodic broadcast of routing tables.
- Since the nodes must wait for their neighbors to update, which can cause slow convergence in the large tables.

3.6.3 Hybrid Routing Protocol

3.6.3.1 Zone Routing Protocol (ZRP)

ZRP is a hybrid, zone-based, and topology-based routing protocol used in MANET. It provides efficient and scalable routing in both dense and sparse networks. ZRP is divided into a set of non-overlapping zones, containing a set of nodes. And further, the node uses a proactive, distance vector protocol to maintain a routing table consisting of information regarding distance and the next hop. The nodes also maintain a global routing table containing information about nodes outside their zone.
When a packet is sent to a destination node, first it checks if the destination node is within its own zone. If it is, then the node uses the local routing table to forward the packets to the destination.

Advantages-

- It combines both reactive and proactive routing protocols. Making t more efficient and fast routing protocols.
- ZRP is highly scalable and can be used in both dense and sparse networks.

Disadvantages-

- It suffers from high control message overhead due to the use of both proactive and reactive protocols.
- It is not highly feasible in dynamic networks.

3.6.3.2 Zone-based Hierarchical Link State routing protocol(ZHLS)

“ZHLS" stands for Zone-based Hierarchical Link State routing protocol [33].
It is used in wireless mesh networks to determine the optimal path for data transmission.
It continuously updates the routing protocol in the network even without any updates in the network topology. It is accomplished by the exchange of control messages between nodes. This protocol divides it into several zones, each having a zone leader responsible for collecting and maintaining routing information.

This zone leader exchanges information with each other to build a complete network map, that is used to calculate the optimal path. ZHLS uses link state routing, where each node maintains a database of topology and calculator shortest path. This helps to select the most efficient path for data transmission.

Advantages-

- It is an incredibly efficient and scalable routing method for wireless mesh networks.
- It provides a reliable and fast transmission.

Disadvantages-

- It requires a significant amount of network resources and processing power.
- It is not suitable for networks with dynamic topologies.

4.0 Conclusion

This thesis has explored the topic of Routing Protocols of UAVnet through an in-depth analysis of literature review and research analysis. The findings of this study have revealed that there are already installed routing protocols in MANET and VANET but new routing protocols are being introdused for FANET because of its high mobility and efficiency for the same .
Overall, this thesis has contributed to the existing literature. However, it is important to note that this study is not without limitations, such as lack of robustness, limited processing, Lack of Standardization, Limited Communication range, Limited Bandwidth etc. Future research could build upon this work by working on possible improvements discussed above.

In conclusion, this thesis provides a valuable contribution to the understanding of Routing Protocols of UAV and provides insights that can be used to inform Aerial photography and videography, Surveillance and security, Search and rescue, Agriculture, Delivery, Mapping and surveying, Environmental monitoring, Inspection and maintenance.

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