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Advanced Radar Range Prediction and Performance Analysis in Aircraft Adhoc Networks (AANET)

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Abstract: Aircraft ad hoc networks simplify airplane-to-airplane or airplane-to-service station communication. It evolved from MANET and VANET ad-hoc networks. MANET connects mobile networks and VANET for cars. Adhoc networks are popular because they can be built without routers or access points when no network exists. Flights are self-organizing nodes in AANET. This dynamic network requires only two nodes and no specific infrastructure. This method is important for GPS navigation, aircraft–ship communications, and navy signaling. These Ad Hoc networks let aircraft interact with the grounds and service stations to decrease traffic between aircraft. It can also connect with a network radar aircraft to avoid collisions. Planes ad-hoc networks connect planes spontaneously. It is versatile and simple. The aircraft adapts to the situation to make connections; thus, routers or networks are unnecessary. Planes' fast mobility accelerates network evolution. No infrastructure is needed for aircraft to transmit and relay data. AANET optimizes performance despite restricted bandwidth, power, and processing. This paper describes the AANET network and the recommended solutions to improve airplane performance. It also covers existing methodologies, benefits and cons, and various scholars' work on the AANET.

Keywords: Cause-Related Marketing (CRM); Aircraft Ad-Hoc Network (AANET); Vehicular Ad-Hoc Network (VANET); Mobile Ad-Hoc Network (MANET); Wireless Connections; Networking System.

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1. Introduction

The AANET began at the beginning of the year 2021 when the communication between aircraft – aircraft and ground services began to become possible in a dynamic and ad hoc manner. The Ad hoc network began with a mobile ad hoc network (MANET), which facilitates connecting laptops and mobiles with a wireless connection. Later, MANET and VANET (vehicular ad hoc network) were developed to communicate. With the principles and design of both MANET and VANET, the development of AANET took place to facilitate communication between aircraft. With the introduction of AANET, communication between aircraft and aircraft on the ground has become a lot easier. The aircraft acts as a self-aware node that helps pass signals to various other nodes in a wireless communication fashion, thereby reducing traffic congestion, providing emergency

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communication, and providing immediate response to the signals sent. The mechanism of AANET is very simple: if one aircraft acts as one node, the aircraft receiving the signal will act as node two, and the signals will keep passing until they reach their destination node. Here, the working transmission of signals depends on client-server communication; the aircraft sending the signal will act as a server, and the aircraft receiving the signal will act as a client.

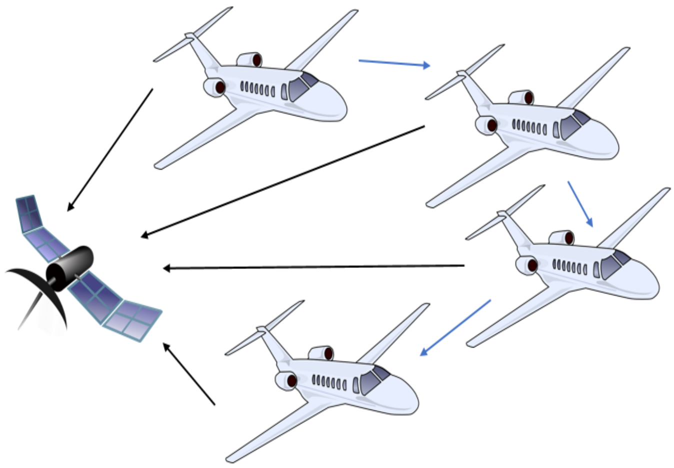

Figure 1: Communication between aircraft to aircraft, aircraft to ground

In Figure 1, the demonstration of aircraft communication is given where the three aircraft act as node 1, node 2, and node three, respectively, and there is a transmission of signal similarly node two and node three are sending signals to the ground services which is a clear depiction of AANET.

2. Literature Survey

The increase in air transport in various fields has led to the development of aircraft communications. Many authors and researchers have come up with various perspectives to jot down the ideas and mention the technologies used for aircraft communications. Some of their contributed works are mentioned. A quick survey on the protocols for the communications required for the aircraft was done by Cassar and Ellul [1], where all the modes of communication for the aircraft were taken into account to get a detailed idea of the transfer of information between the aircraft or between the aircraft and the ground stations. Subsequently, the description of the hierarchal clustering algorithm was given by Bandyopadhyay & Coyle [2]. The new challenges for the FANET were described to provide a better understanding of how the aircraft's challenges can cause communication issues [3]. The survey on the AANET was developed even further by describing the properties of networking in unmanned aerial vehicles by taking a survey [4]. It is important to know about the lifetime of each AANET-containing aircraft's network, as Abdullah and Iqbal gave [5].

Delay-optimal routing and spectrum sharing in cognitive ad-hoc networks for understanding the routing properties of the aircraft [6]-[7]. The wireless sensors or wireless communications help in the easier transfer of messages as no prior connections need to be made. A detailed study of the FANET and its properties, challenges, and communication systems was made [8]. The aircraft and their communications can be done without havoc if no disasters occur. Still, if any mishaps occur, there needs to be a change in the communication or radar frequencies [9]. The routing strategies explain how information is shared between the routers of each transmitting entity [10]. These routing protocols require the accuracy of their performance, which is given in detail by Krishnan and Kumaresan [11] and Omar and El-Badawy [16]. Some of the aircraft will have integrated sensors, which was understood from the study of Akyildiz et al. [12].

AANET networks were developed using the basis of MANET and VANET to get a clear idea of the AANET. Even better MANET properties were also studied and used in mobile networks for communication [13]. CODA (Congestion detection and avoidance in sensor network) was an important feature in AANET for detecting congestions using a sensor mechanism [14]. A very detailed explanation of the scalability of the network in the AANET was provided, along with a description of the network's security [15]. Unmanned aerial vehicles are that one that doesn't require a human pilot to drive, which is very similar to the autopilot mode, so the study of the mechanism of the unmanned aircraft [17] for the understanding of how the ad-hoc networks work with the unmanned vehicles was done. The countermeasures are required when understanding the ad-hoc network properties [18]. The aircraft's speed is to be measured to understand the frequency of communication [19]. The blockchain analysis for optimizing the network properties was described [20]. A survey of the properties and networking types was analyzed [21]-[22]. These were the contributions made by different scholars to understand better the AANET properties and the required details for the proposed method of extension of the radar system [23].

3. Topology of Ad Hoc Network for Detecting the Range

The topology of a network is the demonstration of how the computers are connected; similarly, the topology of the AANET is the demonstration of how the aircraft are connected and how aircraft are connected to the service stations. These topologies are as follows:

- Distance-based ranging: As the name suggests, the distance between the aircraft is calculated to detect the range around which communication can be possible [24].
- Geometric topology: This topology determines the aircraft's positions and whether the aircraft is in the appropriate range [25].
- Collaborative ranging: This type of topology is used by aircraft to determine the range by transmitting and receiving signals. The time duration between sending and receiving signals determines the range [26].
- Dynamic range estimation: As the name suggests, the range is analyzed by looking at the signals' arrival time and the distance between the aircraft.
- Triangulation is a type of topology used to determine the angle between the aircraft and the range by the angle obtained [27].

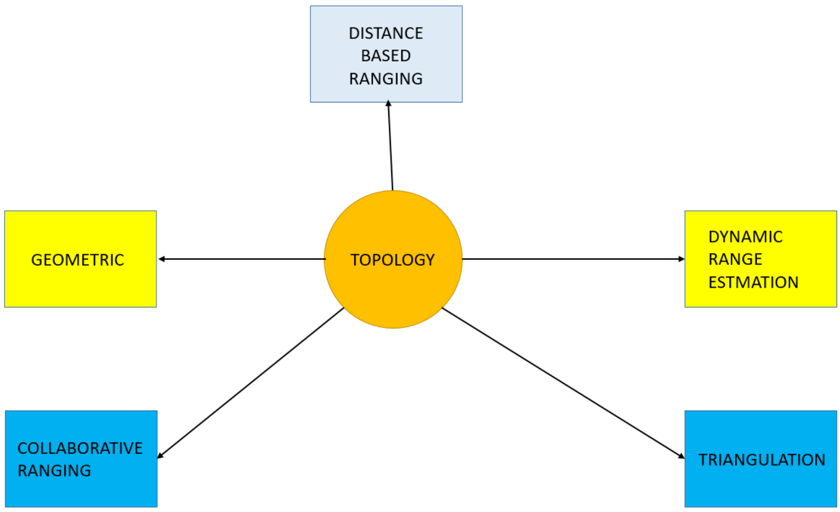

Figure 2: Different topologies for the AANET network

Figure 2 shows the topologies that can be used to make the AANET network.

3.1. Topology of AANET for Structure and Communication of Aircraft

The ranges or communication systems must be established for communication between the aircraft or ground stations, and the infrastructure must be made carefully [28]. A set of topologies is used to design the communications structures carefully. Some of the topologies are :

- Point–Point Topology: this topology is used when the communication between the aircraft or ground stations is more direct and easy information with little complication. As the name suggests, communication is just between one node and another [29].
- Multi-Hop Topology: The information is passed in packets between the aircraft or the ground stations by extending the range of the signals to pass the information [30].

- Mesh Topology: Many direct communications form an interconnected network, which looks like a mesh from the mesh topology. The communication can be bidirectional.
- Centralized topology: This is similar to star topology, where the aircraft or the ground station can act as a main hub from which other communications occur. The other aircraft can communicate with the hub and pass the signals [31].
- Dynamic Topology: Aircraft are not stationary, so detecting the range and passing the information to other aircraft or ground stations is difficult. A topology to detect the mobility of the aircraft was determined so that the range could be matched accordingly [32].

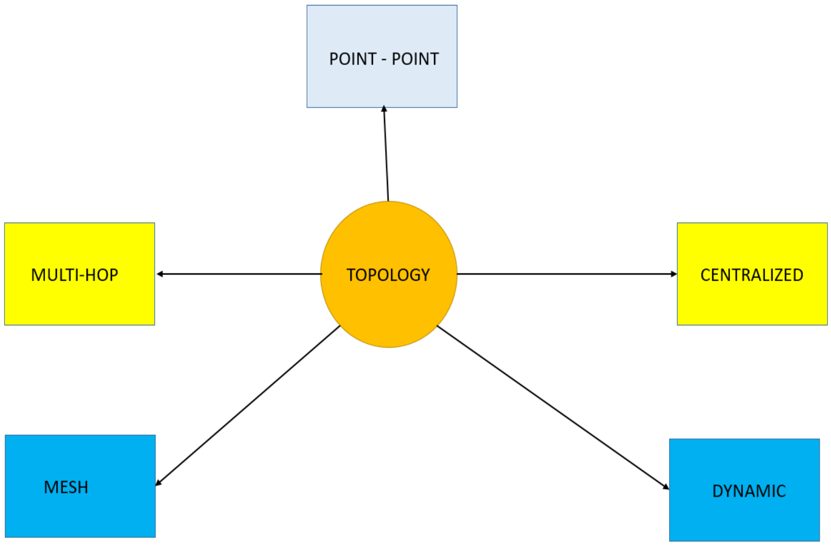

Figure 3: Structure and communication topologies

Figure 3 depicts how the structure must be established so that the network can produce an optimal performance.

3.2. Routing Protocols of AANET

The routing protocol is a protocol where communication between two entities is enabled by selecting the routes to pass information [33]. Some of the routing protocols used in AANET to provide communication are AODV, OLSR, DSR, MANET-CBRP, VBF, GRAB, and many more, as described in Figure 4. AODV is abbreviated as Ad Hoc On-Demand Distance Vector, where it establishes routes only when needed, i.e., the routes will only be initiated when there is a piece of information to be traveled, reducing the change in topology [34].

The OSLR is another protocol abbreviated as optimized link state routing, which keeps the information up-to-date for all nodes [35].

DSR dynamic source routing is much more similar to AODV, but it will use source routing to initiate the nodes where it carries the whole packet to its destination [36].

The MANET-CBRP is another protocol in which machine learning is merged with the networking systems to optimize the routing paths [37].

VBF is vector-based forwarding where each node already has a pre-defined position in the networking system from which the information is passed [38].

The IRP (improved routing protocol) is another set of protocols where the protocol helps in providing the perfect route for various network metrics [39].

Cross-layer Probabilistic Adaptive Multicasting (CPAM) is another protocol that is used to adjust the data packet as per requirement and pass the information from all the other kinds of nodes so that all the packets can transport information at the same time more efficiently [40].

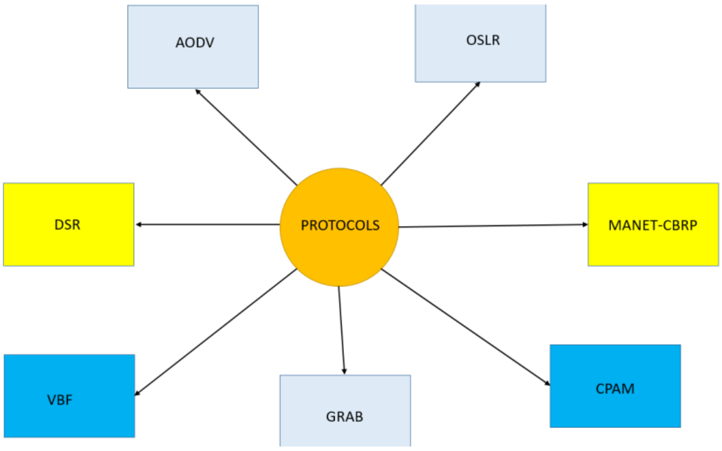

Figure 4: Protocols required for AANET

3.3. Communications and Connections of AANET

The communication in the AANET is very similar to the client server-based communications in a network so that the server will listen to the client, and the client will respond to the server; the same principle is used in the AANET to Communicate between aircraft to aircraft and between aircraft and service stations [41]. There are two ways of communication, namely, TCP and UDP. Both these protocols are used in the AANET to provide connections [42]. The differences are depicted in Table 1 as follows:

Table 1: Comparison of UDP and TCP

UDP	TCP
Lower latency – UDP being connectionless can provide faster communication as it does not need to wait for the connection to be made.	A connection must be made before the transfer of data to guarantee a transfer of data.
UDP can provide multicasting or broadcasting, which can be useful when multiple communications need to be exchanged.	TCP uses flow controls so the receiver is not overloaded with messages, as it sends messages only after receiving an acknowledgment.
As UDP does not need to wait for a connection and provides lower latency, it automatically transfers faster data.	More latency is expected as a connection needs to be made, and an acknowledgment is to be received by the sender to send the next data.
The transfer of information is guaranteed in the UDP, but it does not guarantee that the receiver receives it, so UDP is used when the main motive is to transfer the data.	TCP provides reliable data transfer where the receiver receiving the information is guaranteed.

In real-world scenarios, the UDP can be used when the data needs to be transferred sooner [43]. The receiving of the data need not be guaranteed, so in AANET, it can be used in voice communications when the communication between the two aircraft must be enabled, can be used for video streaming for exchanging videos during communications, can be used for exchange sensor readings, engine performance readings, flight control communications which are collectively termed as Telemetry Data. UDP can also be used to update each aircraft's position each time it moves [44]. It is also helpful in providing weather information and signaling during any emergency, as information needs to be transmitted immediately [45].

UDP is essential in UAS (Unmanned Arial Systems), where low latency and connectionless communications are essential. Sometimes, in aircraft, live streaming of data is required to know the situation or the status of the other aircraft or for the ground stations to know the status of the aircraft flying; in such a situation, UDP is highly recommended [46]. At the same time, TCP can be used in many real-world scenarios like navigation and flight control, where the ground stations and the aircraft communicate for navigation [47]. A connection is needed here; hence, we use TCP. It is also used when the aircraft or the ground stations must get traffic alerts or emergency signals [48].

TCP is extremely useful in flight planning and coordination; that is, TCP plays a major role in connecting two fights or flights to ground stations for communications; here, TCP is used as a connection-oriented communication system, and Airspace management is used to tell the controls of the aircrafts such as the aircraft restrictions, route changes, and coordination with other aircraft. For the remote areas where aircraft fly or for the autonomous aircraft where the communication between the aircraft plays a vital role, it needs to ensure that the communication between the sender and the receiver is guaranteed and that the receiver receives the messages [49]. To ensure this, we use the TCP protocol [50]. Apart from these, TCP protocols can also play a major role in army aircraft, where there are constant communications between the aircraft, especially to guide the aircraft about the enemy aircraft or to know the coordinates of the enemy aircraft. This TCP protocol can help transmit information to the aircraft, which acts as a receiver or sender [51]. Similarly, the ground stations can act as the sender or the receiver [52].

Once the aircraft receives the message, they are requested to send an acknowledgment to the sender to indicate the receipt, and then the sender gets ready to send other messages [53]. This is a property of TCP protocol. Aircraft or Airspaces need to maintain a database to know the history of communication or to know about the stored information, so TCP helps maintain the consistency of the databases [54]. The TCP protocol can be used to meet the accuracy standards of the communications between the aircraft or the aircraft authorities.

3.4. Application of AANET

- Emergency communication and coordination: If the aircraft has to initiate an emergency landing due to unexpected weather or unfavorable conditions, the ad hoc network favors real-time communication between the aircraft.
- Air traffic management: Ad Hoc networks can manage air traffic by providing direct communication between aircraft and avoiding collisions and deconflictions [55].
- Remote areas connectivity: In areas where disasters occur frequently, and infrastructure availability is minimal, the ad hoc network helps provide temporary communication for data transfer [56].
- Data sharing and surveillance: The ad hoc networks can provide weather and important information required for aircraft or ground services [57].
- Search and rescue operations: These ad hoc networks help inform search teams and ground stations to prepare them for situations.
- Aerial surveillance and border control The ad hoc networks can provide proper surveillance through aircraft that can be useful for the army.

4. Existing Method

Many researchers have proposed innumerable concepts and mechanisms from which the working of Aircraft ad hoc networks can be understood. Some methods include the description of satellite communication, which can be used for communication between aircraft or ground stations, providing broader coverage of receiving signals. Later in the years, multi-hop communication was formulated where the aircraft act as relays, simultaneously facilitating multi-communication between the aircraft and the ground stations. Air ground integration is another method for merging aircraft and ground services.

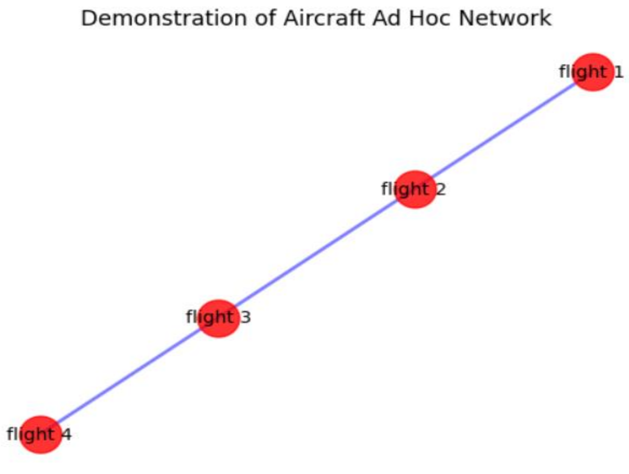

Figure 5: Demonstration of the working the AANET

Figure 5 explains how the aircraft act as nodes and how each aircraft is connected to the radar to pass information in the form of signals to other aircraft. Here, a depiction of 4 aircraft connected is given.

4.1. Proposed Method

The working of aircraft using Ad-hoc networks is only possible if they are within a limited range from the first radar, which reduces the communications between other aircraft flying, so if the range of the radar is increased to a larger distance, then the communication will be made better such that the information can be passed easily to the farther aircraft to avoid any kinds of mishappenings. For this to occur, four flights in the limited radar are considered, and then one of the flights is considered for at a farther distance. Since the radar has increased its distance, the signaling between the aircraft has also increased, and the information can be passed on to all the aircraft.

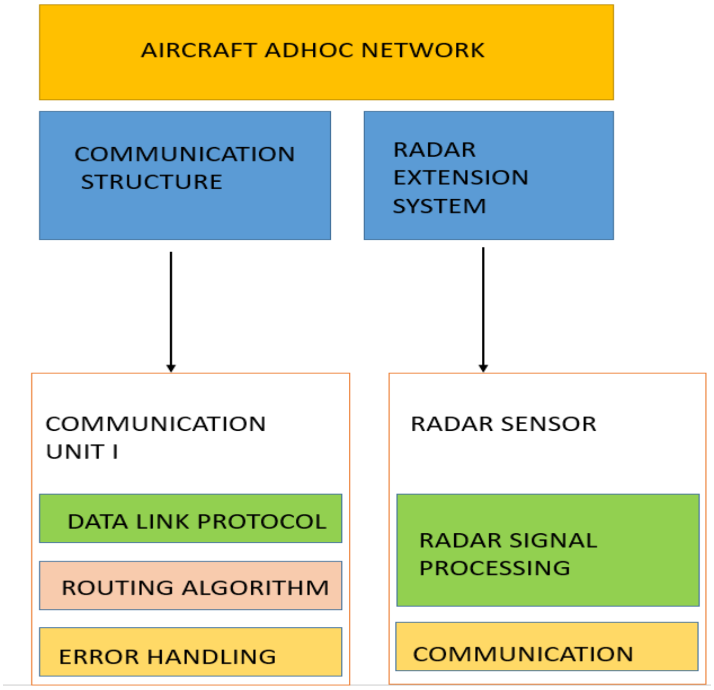

Figure 6: Architecture diagram for the proposed method

The above figure 6 depicts the following:

- The communication units are responsible for handling the communications of the ad-hoc networks.
- The radar extension system represents the radar extension capabilities of the aircraft in the AANET network.
- The radar signal processing senses the radar in the surroundings and captures them.
- Error handling is responsible for controlling the occurrence of errors in the system.

4.2. Program Code for Increase in Radar Coverage

```
import matplotlib.pyplot as plt
import networkx as nx
import numpy as np

 nodes = [‘flight 1’, ‘ flight 2’, ‘flight 3’, ‘flight 4’]
edges = [(‘flight 1’, ‘flight 2’), (‘flight 2’, ‘flight 3’), (‘flight 3’, ‘flight 4’)]

radar_coverage_radius = 0.6

G = nx.Graph()
G.add_nodes_from(nodes)
G.add_edges_from(edges)
```

```
pos = nx.spring_layout(G)  # Positioning of nodes
nx.draw_networkx_nodes(G, pos, node_color='r', node_size=500, alpha=0.8)
nx.draw_networkx_edges(G, pos, width=2, alpha=0.5, edge_color='b')
nx.draw_networkx_labels(G, pos, font_size=10, font_color='black')

for aircraft in nodes:
    x, y = pos[aircraft]
    radar_circle = plt.Circle((x, y), radar_coverage_radius, color='r', fill=False, alpha=0.5)
    plt.gca().add_artist(radar_circle)

plt.title('Aircraft Ad Hoc Network with Radar Coverage')
plt.axis('off')
plt.show()
```

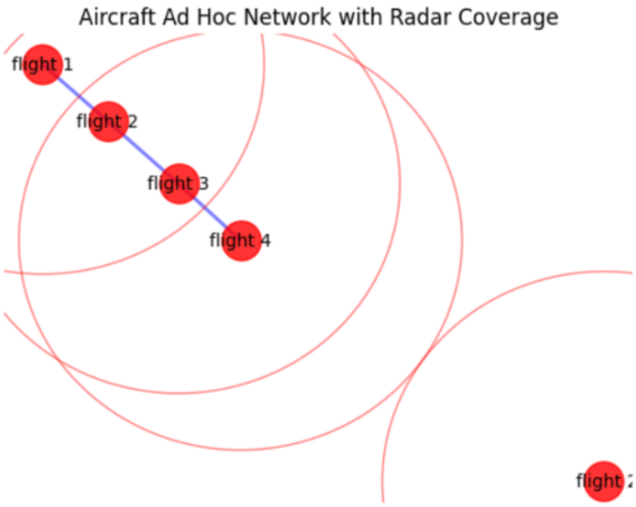

Figure 7: Output of the range extensions

Figure 7 depicts four flights on the radar for communication while another flight is away; since the system is performed for the extension of radar, the flight that is farther away will be able to communicate with the other flights so that communication will be possible.

4.3. MANET vs VANET vs AANET

AANET was developed with the ideas and base of MANET and VANET. MANET is used for communications among mobile phones or any communication devices, while the VANET network provides communication between vehicles. Table 2 describes the differences among the three types of networks.

Table 2: Comparison between 3 types of network

MANET	VANET	AANET
Network in which any mobile device acts as a node.	Network in which any vehicle acts as a node.	Network in which any aircraft acts as a node.
They exhibit diverse and unpredicted mobility patterns.	They exhibit complex and unpredictable mobility patterns.	They exhibit more predictable patterns.
Rapid and dynamic topology changes due to node mobility.	Frequent and rapid topology	Topology changes are generally predictable.
Communication range is generally limited due to radio transmissions.	Communication range Is limited due to the physical environment.	Communication range is influenced by altitude.

Stability depends on mobility patterns.	Less stable	Comparatively more stable than MANET or VANET
Challenges occur in routing due to dynamic routing	Considers adaptive and robust routing protocols	Uses more sophisticated routing protocols
Used in disaster response, military networks	Used in vehicular applications, road safety	Used in aviation communication, aircraft.

Figure 8: MANET

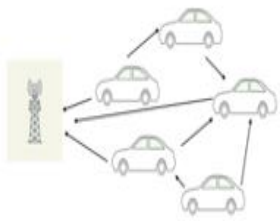

Figure 9: VANET

Figure 10: AANET

Figures 8, 9, and 10 provide a pictorial representation of the different kinds of networks and their connection with their sources. In the case of MANET, another mobile device or any communication device acts as a source. In contrast, in the case of VANET, a cell tower can act as a source that provides a signaling channel to the moving vehicle. With AANET, a satellite, a ground station, or an aircraft can provide signals and information.

5. Server Client Communication

The main requirement for implementing an aircraft ad hoc network (AANET) is to facilitate proper communication. Since multiple factors like range, position, angle, distance, and signals need to be looked into to formulate the mode of communication, network-based communication was used to facilitate the same. In a network-based communication system, a connection between the sender and receiver makes the signals pass to the receiver. This can be done in 2 ways, namely the (i)User datagram protocol(UDP), where a connection is not required to be made before the sending of information, and (ii) Transmission Control Protocol(TCP), where a communication is to be made to facilitate the passing of information. The AANET uses both kinds of protocols based on the requirement. Further, when designing the connections between aircraft or ground stations, factors like encryption, security, authentication, and routing protocols must be carefully considered to ensure the perfect communication design. The sender who sends the information is said to be on the server side, whereas the receiver who receives the information is on the client side.

Algorithm for Server Side

1. Import socket, threading
2. Create a class FlightServer and define functions
3. Define a constructor with parameters self, host, port
4. Define another user-defined function and specify the socket family and type of socket used
5. Bind the port and host
6. Let the socket listen for 5 seconds
7. Give a print statement that says server listening with " and specify the port and host number.
8. Now create a client socket and initialize the socket
9. Use a try block to check the receiving of the data; if the information is received, print the received data
10. Once the data is received, the server needs to be stopped. To create another function, use def to print "server stopped."
11. Use the main function to give the port and the host numbers to which the connection needs to be made.

5.1. Discussion on Server-Side Communication

Figure 11 above shows how the socket is established. The socket is established so that the two aircraft or the aircraft can communicate with the service station using socket programming. Here, the socket is ready to take the messages from the client. The port and host numbers will be synced with the client, and communication will begin.

```
Server is on..... Listening......
```

Figure 11: Output for server communication

Generally, the socket will be able to communicate with the client in multiple ways here; the socket and client are used in the aircraft so that necessary information can be passed to the other aircraft in range and the traffic in the air or the major accidents can be prevented. The server will listen to the client and wait for its message once the server accepts it. A response will be generated. A gap of seconds is given so there is no message overlap.

Client Algorithm

1. Import socket
2. Create a client class and define a constructor, specifying the self, port, and host.
3. Define another user-defined class to connect the host and the port, specifying the socket family and type.
4. Create another function to send a message to the server and specify the message's path.
5. Create another function to specify the message: "Message from client: Hello from the aircraft; a flight is seen close to yours; wait for further command!"
6. Once the message is sent to the server, the connection must be closed, so create another function to close the connection.
7. Use the main function to give the port number and the host number.
8. The port and the host number are supposed to be the same as the host and port number given on the server.
9. This is done so the client can connect to the proper server to pass the information.
10. Else, the information will not be passed.

5.2. Discussion on Client-Side Communication

```
Message from client: Hello from the aircraft , A flight is seen in the close
proximity of yours , Wait for further command!
```

Figure 12: Output for client communication

Figure 12 shows that the connection is made between the server and the client, and they are ready to communicate. The client can send messages to the server; the connection is closed once the message is sent. The number of messages can be sent based on the requirement. This socket communication can be used between the aircraft for a faster communication rate. The client will act as both a receiver and a sender; it will receive the messages and respond to the client. In AANET, aircraft act as both server and client.

The client side of the socket programming ends with connections once the message or the information is sent to the server. The server contains a typical flow of data and waits for requests from the client. Here in AANET, the server waits for the information from the client, where the client can be either an aircraft or a service station. The service stations can send coordinates, weather, proximity, and emergency details to the aircraft, whereas the other aircraft can communicate with each other for specific required information.

6. Conclusion

Aircraft ad-hoc network, or AANET as it is abbreviated, is a communication system established in early 2021 in all the air transport entities for better communication between them. The AANET uses socket programming for communication, which has two components: a client and a server. The client sends requests to the server, and the server responds with a message. In

AANET, the aircraft or the ground stations act as clients and servers. The ground stations can send messages to the aircraft about all the necessary information. The AANETs can facilitate communication between aircraft within a prescribed range to avoid any air traffic or accidents between aircraft. The aircraft will easily be able to communicate with the other aircraft, know their coordinates, and avoid mis-happenings. This mechanism only applies to those in the prescribed range, whereas those outside will not be able to get any warning about the upcoming disaster. Hence, this paper deals with the extension of the radar system so that flights farther away can get a piece of prior information about the traffic in the air and take the necessary actions. Considering the existing methods, a proposed method of the radar system extension is given. Further developments in extending the radar can be made to improve proficiency in the AANET system. Overall, this paper briefly describes the client-server communication, existing radar properties, UDP vs. TCP comparison, comparison between different ad-hoc networks, proposed methods for extension radar, topologies, and routing protocols used in AANET.

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Ethics and Consent Statement: This research adheres to ethical guidelines, obtaining informed consent from all participants.

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