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Routing Protocols for the Aircraft AD HOC Networks

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Abstract*: The communication between the aircraft-to-aircraft and aircraft-to-ground can be established with the support of Aircraft Ad hoc Networks (AANET). Routing in the aircraft ad hoc networks is a challenging task due to its unique attributes such as very high mobility of the aircraft nodes and dynamic topology. Few research works had developed routing environment and protocols for the dynamic topology based AANET. This paper analyses the developments of the routing protocols for the aircraft ad hoc networks. This paper extensively discusses the routing protocols and comparative analyses of the performance metrics namely throughput, packet delivery ratio, end to end delay, routing overhead, and number of handoffs. Further, this work deliberates the aircraft ad hoc networks simulation environment, aircraft's velocity, different radio propagation models of aircraft simulation model. Various challenges and issues of routing protocols are extensively analyzed and compared with existing methodologies in this paper.

Keywords: AANET, Routing Protocol, Aircraft, Two-ray ground reflection model, PDR, Delay.

I. INTRODUCTION

The Aeronautical Telecommunications Network (ATN) has difficulty in fulfilling free flight requirements and other restrictions. The aircraft can be identified as a pseudo-linear fast-moving mobile entity with no pause time during routing. ATN's shortcomings are the use of aircraft as only as end nodes. That is aircraft must transmit their data packets through ground stations through the direct communication between aircraft. It makes the free flight (situation awareness information) practically unachievable. But the dynamic nature of AANETs allows nodes to form both Intermediate and End Systems. It provides the aircraft to aircraft and high bandwidth connectivity with communication data links. It reduces and accommodating the transit to the free flight.

Using AANETs we truly expand the existing communication capabilities among aircraft and between aircraft and airports. The airspace is populated by airports, High Altitude Platforms (HAPs) or satellites and aircraft, which act as network nodes. HAPs are either airships or planes, which operate in the stratosphere, 17 to 22 km above the ground, well above any normal aircraft and the below orbiting satellites [1].

Typically, in AANETs the VHF Omni-directional Range (VOR) is utilized with the frequency of 108-118 MHZ. It uses the radio navigation system to get the aircraft position. VOR signal supports the predictable accuracy of 90m. It covers the radial distance range of 100 nautical miles (60,000 feet). Additionally, the Ka-band can be utilized for internet and VoIP communications. Its frequency is 26.5-40 GHz. Thus, it provides high bandwidth communication [1].

Airports, HAPs, and satellites are referred to as backbone nodes and act as gateways to the Internet while satisfying high demanding aeronautical and inflight entertainment applications. Air Traffic Management (ATM) applications in the routing protocol use the Automatic Dependent Surveillance-Broadcast (ADS-B) concept. ADS-B is a cornerstone for the implementation of the free-flight concept. It exploits the existing Global Positioning System (GPS) and the Galileo system in order to acquire the precise position of the aircraft.

The ADS-B maintains the aircraft's information such as state vector, mode status, and surveillance data. Traffic Information Services- Broadcast (TIS-B) provides traffic information obtained from surveillance radars or other ADS-B systems. The Flight Information Services-Broadcast (FIS-B) provides weather, airspace, urgent notices, and other flight information. Fig. 1 shows the typical Aircraft ad hoc network. In AANET, the direct aircraft to aircraft as well as aircraft to ground and aircraft to satellite communication are possible [2, 13].

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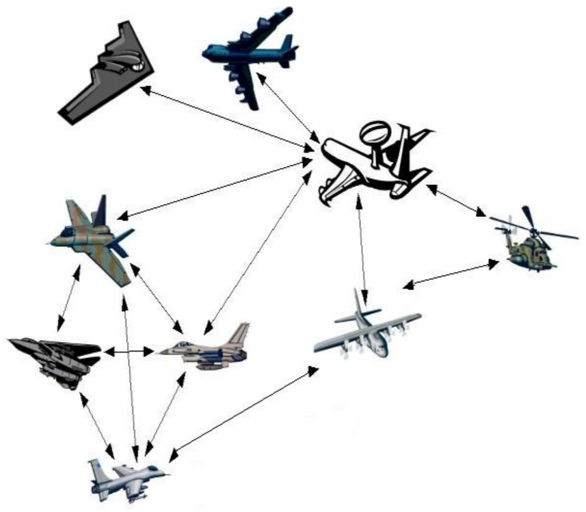

Fig. 1 AANET

This paper is organized as follows. Section 2 discusses the recent research works on routing in the Aeronautical Mobile Ad hoc Networks.

The comparisons and discussions of the routing environment, simulation performances of the AANET are presented in section 3. Finally, section 4 concludes the paper with future enhancements.

II. RELATED WORKS

M. Iordanakis et al. (2006) presented an Ad-hoc Routing Protocol for Aeronautical Mobile Ad hoc Networks (ARPAM) based on AODV multi-purpose routing protocol [1]. The ARPAM protocol exploits the geo-localization information for the aeronautical applications. The RREQ messages contain geo-localization information such as position coordinates and velocity vectors. Global Positioning System (GPS) and the Galileo system used to acquire the precise position of the aircraft. The omnidirectional VHF antenna type utilized for the routing protocol. The proposed ARPAM routing protocol shows increased performance over the existing AODV, DSR and TORA routing protocols.

E. Sakhaee et al (2006) discussed an overview of Aeronautical Ad Hoc Networks addressing a suitable aeronautical mobility model and routing schemes to work effectively with the aeronautical ad hoc network [3]. The link and path duration are affected by two factors: relative velocity and relative position. This concept proposes the Doppler shift that changes in frequency to find and determine the link duration of the aircraft. It observes change to the frequencies of radio signals transmitted to and from planes. The presented Multipath Doppler Routing (MUDOR), considers mobility, relative velocity and relative position of nodes on a path. It selects the path with the longest path duration based Doppler Value of the path. Also, find a stable path with relative velocity instead of the shortest distance. The simulation results show MUDOR has QoS performances than DSR.

An Analysis of routing protocols in ad hoc network Airlines is discussed by D. Yang and Y. Yao (2017). The AODV and OLSR routing protocols are simulated in the aviation environment and the performances show that the stability of AODV is better than OLSR, the delay of AODV is longer than OLSR [4].

A Geographic Routing Protocol for Aircraft Ad Hoc Network (GRAA) proposed by Seung and Kim (2010) to cope with the dynamic topology changes [5]. It makes use of frequently updated mobility information from the base station on the ground. This work develops the GRAA routing protocol using the popular geographic routing protocol, Greedy Perimeter Stateless Routing (GPSR). The GRAA uses the updated information from the ground to get the up to date position information of the aircraft. A packet containing geographic position information of the destination is populated for the routing path discovery. The GRAA is compared with the GPSR and the performance results show the GRAA has a higher packet delivery ratio and lower end-to-end delay.

A novel method introduced to improvise the performance of Unmanned Aeronautical Ad-hoc Networks routing algorithms by M. Kardoust et al (2017). It works based on Geographic Greedy Forwarding (GGF) and maintains multiple loop-free paths [6]. For routing, The GGF uses the Modified-Reactive Greedy Reactive (RGR) for the discovery of the routing path that are stored in the node' routing table instead of using only one routing path. From the all discovered routing path, the best route is used as the first proposed route between the source and destination nodes. When this route fails than the immediate second route is utilized for routing. This method reduces the repeated broadcasting of route discovery packets and selects link with the disjoint path. in the network. The simulation results of this method are more efficient in packet delivery ratio, end to end delay, and throughput ratio than other methods.

Delay Aware Multipath Doppler Routing in Aeronautical Ad hoc Networks (DMDR) is presented by W. Gu et al (2011). The DMDR integrates the relative velocity and expected queueing delay to select the node for routing using the Doppler shift [7]. Using Doppler value, each node selects the stable neighbor node from all nodes in the networks. Thus, it avoids the queueing delay during the route discovery process. The DMDR protocol works based on the DSR routing protocol. By using the Doppler value, it selects the stale nodes and avoids the queueing delay, transmission buffer, link congestion, and packet dropping. DMDR shows efficient performance compared with the DSR and MUDOR protocol.

Routing algorithm NoDe-TBR (Node Density-Trajectory-Based Routing) proposed by Quentin Vey et al (2016) for Aeronautical Ad-hoc Networks [8]. The NoDe-TBR routing protocol discovers the geographical path for routing by considering the node density in the region. It utilizes the position centric concept. Because the position centric protocols have lower signalization traffic than the node centric protocols. The TBR utilizes the node position as well as the geographical path. It works by portioning of a plane into the regions based on the distance to points in a subset of the plane using the Voronoi diagram. The geographic trajectory (geopath) is computed and sanded it with the header.

It involves the two processes. Geopath computation and forwarding strategy. The Fast-Forwarding Method used for geopath computation and gradient descent algorithm for sensing. In NoDe-TBR, the aircrafts periodically broadcast its trajectory to every node for the next period. For the simulation, it takes the real-time node position for NAT (North Atlantic Tracks). It is the real traffic trajectory from the euro control historical traffic repository.

Vivek Kumar et al., (2014) had discussed the overview of Aircraft Ad-hoc Network (AANET) [9]. In AANET, aircraft node has the responsibility of communication with ground infrastructure and other aircraft. The aircraft node in the ad hoc networks should have self-aware, so that information becomes available through aircraft-to-aircraft, aircraft to ground communications. In AANET, the traffic between aircraft nodes should be distributed and which leads to have improved communication, reliability, security, as well as scalability.

These enhancements in the aircraft node will also improve the information delivery and availability in the AANET.

Asha et al., (2015) had presented the review of routing protocols in airborne networks for efficient routing [11]. They suggested that various parameters such as performance, routing model, network structure, methodology are should be considered to design an efficient routing protocol in an airborne network. It discusses the routing protocols such as OLSR, OSPF-MDR, MARP/MDP, ADS-B, AODV, MARP/MDP, Aero Routing Protocol, and DSR for the airborne network.

S. Mehta and Supriya had implemented traffic management in Geographic UAV and security attacks in MANETs [12]. It compares the packet delivery ratio between different types of protocol and then creates different nodes like in GPS then further implement unmanned aerial vehicle algorithms with the latest technologies. The optimized shortest path between source and destination calculated and location information exploited using GPS, GPSR, and LAR. Based on position information forwarding decision is taken for the destination and possible candidate nodes. The geographic UAV algorithms implement on the bases of its decisions on the locations of the nodes. Thus, a protocol knows about the current topology or the estimated future changes of such topology with its routing structure without increasing the maintenance overhead. It also implemented routing UDP attacks and smurf attacks based on DoS (Denial of Service) in MANETs.

A review of applications of Flying Ad-hoc Networks (FANET) is presented by M. Kumar et al [13]. It presents the use of FANET in various areas and provides a path to known about the various challenging tasks in FANET. The UAVs are an attractive technology for many civilian and military applications. Due to the high and frequent mobility of the nodes, maintaining a communication link between the UAVs is a challenging task. It presents the lights on the main tasks of FANET and their use in the modern era.

A reliable system to overcome the weakness of current the HF radio communication system for oceanic aeronautical flight routes is presented by the H. D. Tu and S. Shimamoto (2009). It uses the aeronautical VHF channel with an air-to-air radio relay system based on local mobile Ad-hoc networks [15]. For access to/from all aircraft in the system, a TDMA (Time Division Multiple Access) scheme are used. Algorithms for relaying packets, schemes to reduce the packet-loss-ratio and interference caused by surrounding aircraft are presented. It improves the system performance under real air-traffic scenarios, strengthens the reliability of oceanic aeronautical communication, and increases situational awareness of all oceanic flights as an effective solution to operate more flights on the ocean but in higher safety.

The wireless ad hoc networks based internet access for aeronautical communications is presented by the F. Besse et al (2010). Nowadays the civil airlines want to offer their customers the opportunity to access the Internet, to manage their mails, to watch video on demand, to access corporate VPNs, etc. All these services represent a new type of air-ground communications called APC (Aeronautical Passenger Communications) in the ATN (Aeronautical Telecommunication Network) context [16]. It implements an aeronautical ad hoc access network and satellite links can be used simultaneously for these communications.

Link availability estimation-based routing (LEBR) protocol for AANET is proposed by L. Lei et al (2016). LEBR uses the semi-Markov smooth mobility model to construct a reliable routing path with higher link availability and to reduce the frequent link breakages in AANET. It estimates the link lifetime by analyzing the probability density function of the relative speed of two nodes. The availability factor and path selection metric are considered for the routing. The results of LEBR show better performance gains in comparison with the AODV routing protocol [17].

A geographical routing protocol for heterogeneous aircraft ad-hoc networks (GRHAA) was developed in [18] to cope with the highly dynamic behaviors of airborne networks. The GHRAA works by two phases. One is primary path estimation by known route information using ADS-B. In the next phase, nodes in the primary detect neighboring nodes for path optimization. Then forwards the data by intelligent data packet forwarding scheme. GHRAA uses, GHRAA flooding based and GHRAA time based on the route discovery process. Simulation results show GHRAA predicts node for routing by accurate position scheme in heterogeneous environments. Also, outperforms than LAR and GPSR protocol in terms of delay and packet delivery ratio.

The aeronautical routing protocol (AeroRP) was presented in [20] for highly dynamic aircraft environments. AeroRP uses the current and predicted geolocation information for the route discovery process. Neighbor node discovery is carried by the velocity-based heuristics. It makes the one-hop routing decision. Because nodes at very high velocity lead to breakage of links after the end to end path determination. It has a neighbor discovery process and data forwarding process. In the first process, it gathers the location information on the network topology by active snooping, which extracts location information. In the later process uses the topology information to determine the next hop to send the packet.

Performance comparison of GRHAA and AeroRP routing protocol are discussed in [20]. The metrics, packet delivery ratio and end-to-end delay are evaluated and compared using two mac protocols that are IEEE 802.11 and IEEE 802.11

Table 2. Mobility Parameters for AANET

Parameter	Value
Area	2000 x 2000
Propagation model	Two Ray ground
Antenna type	Omni-directional
Number of nodes	15
Maximum Speed	1000 Kilometer
Minimum Speed	800 Kilometer
Pause time	2.0 seconds
Simulation Time	200 seconds

DCF CSMA/CA (carrier sense multiple access protocols with collision avoidance) and two mobility models that are Mission plan based (MPB) and Semi-Random Circular Movement (SRCM) model. The performance results show that GRHAA with CSMA has better results than AeroRP in the SRCM mobility model. The GRHAA produces higher results with the help of hierarchical architecture.

III. CONFIGURATION AND SIMULATION OF AANET IN NS2

The following parameters are computed and updated for the simulation suitability of the AANET environment in the NS2 propagation files. The NS2 simulator is a suitable network simulation tool to simulate the properties of the ad hoc networks [10, 19].

The AODV protocol modified and the position values are frequently updated to configure the AANET parameters. The propagation parameters are calculated and configured in the file named threshold.cc from the propagation folder of the ns 2.25 directory. The transmission range parameters such as capture threshold (CPThresh_), carrier sense threshold (CSThresh_), receiver sensitivity threshold (RXThresh_), bandwidth (Rb_), transmission power (Pt_) values are computed for the AANET environment are they updated in the corresponding files of the NS2 [14, 21].

The following equation is used for the calculation of transmission range values using the two-ray ground reflection model.

$$Pr = \frac{Pt * Gt * Gr * (ht^2 * hr^2)}{d^4 * L}$$

Where, the Pr represents the receiving threshold; Pt gives transmit power; Gt is transmit antenna gain, receive antenna gain is given by Gr, L is depicted as system loss for two-ray model; ht is the transmit antenna height, the receive antenna height is represented by hr; the distance is represented by parameter'd'. Table.1 summarizes the transmission range parameter values for the AANET. The values for the transmit antenna gain and the receive antenna gain are given as 1.5. The height of the both transmit antenna and receive antenna are set as 1.5. The system loss is unchanged with the default value of 1.0.

Table 1. Transmission Range Par005Aameters for AANET

Parameter	Value
Carrier Sense Threshold	1.55E-21
Capture Threshold	50
Receiver Sensitivity Threshold	7.05E-22
Transmission Power	1.1272
Frequency	3.90E+08
System Loss	1
Bandwidth	2*1e6
Transmit antenna gain	1
Receive antenna gain	1

The movement to the aircraft nodes is generated with the

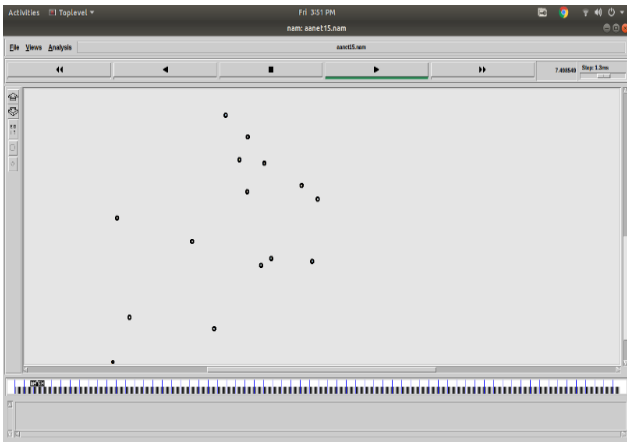

Fig.2 Simulation of movements of the Aircraft node

following parameters illustrated in Table.2. The random movements are generated using the random waypoint mobility model to imitate the movements of the aircraft in the NS2 environment.

Fig.2 Illustrates the 15 number of nodes in the AANET simulation area with the random minimum and maximum speed is between 800 to 1000 Km/s. The simulation time is set as 200 seconds. The pause time is set as 2.0 seconds.

The C++ script developed to show the node's current position values. Fig.3 shows the position values of the various node at a particular time. The position is represented in both X-axis and Y-axis values as illustrated in the Fig.3

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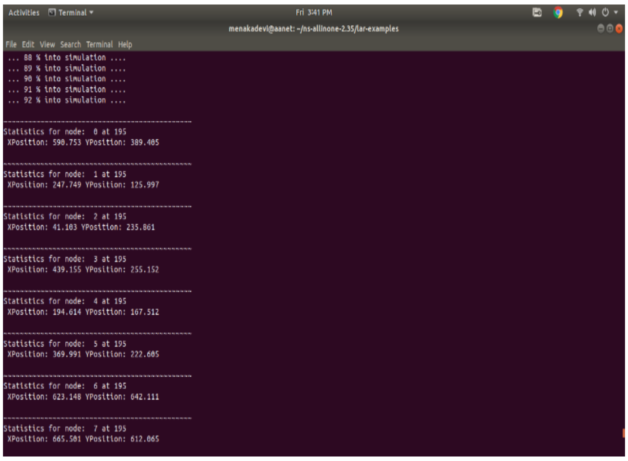

Fig.3 Position values of various node

IV. DISCUSSIONS AND COMPARISONS

This section compares the performance results of the existing works for the AANET such as throughput, packet delivery ratio, average end to end delay, routing overhead, velocity, and number of handoffs.

The ARPAM is an AODV based routing protocol and it is simulated work using the OPNET Modeler simulation tool. The aircraft environment is 1000 x 1000 km^2 with a density of 12 nodes and each aircraft moves with a velocity between 400-800 kmph. It adopts the Ka-band for the VoIP application data and VHF omnidirectional antenna. ARPAM analyses the routing overhead for the generated network traffic. ARPAM compares its results with the AODV, DSR, TORA. It shows the less routing overhead the other protocols.

However, throughput, packet delivery ratio, end to end delay between the server and client are not addressed in this work.

The MUDOR uses the Doppler values for the computation of the longest path duration for the routing. It discovers the stable path using relative velocity and position. Its route discovery and maintenance process are based on the Dynamic Source Routing. It simulates this work in the area of 9 million km^2 with 6 number of hops and node density of 5000 for 230 minutes. The aircraft speed is 840 kmph. MUDOR was compared with the DSR and the number of handoffs for the path distance was calculated. The parameters number of handoffs, hops, average path distance and range in km are analyzed with the DSR protocol and it shows better performance than DSR. Although, this work does not compare with other on-demand and novel existing routing protocols.

The DMDR uses the Doppler shift to avoid queueing delay and to select the stable nodes. The DMDR is implemented using the QualNet discrete-event network simulator with the network size 10 km×10 km, node density of 200, and antenna coverage distance 0.5 km. Every aircraft moves according to a random group mobility model with the constant speed. The performance results of DMDR are compared with the Dynamic Source Routing Protocol (DSR) and Multipath Doppler Routing (MUDOR). DMDR has the lowest number of handoffs and end to end delay over MUDOR routing for the node density of 200. However, this work does not discuss the routing overhead for the transmission/reception of the packet. Fig.4 illustrates the average end to end delay of different routing in AANET.

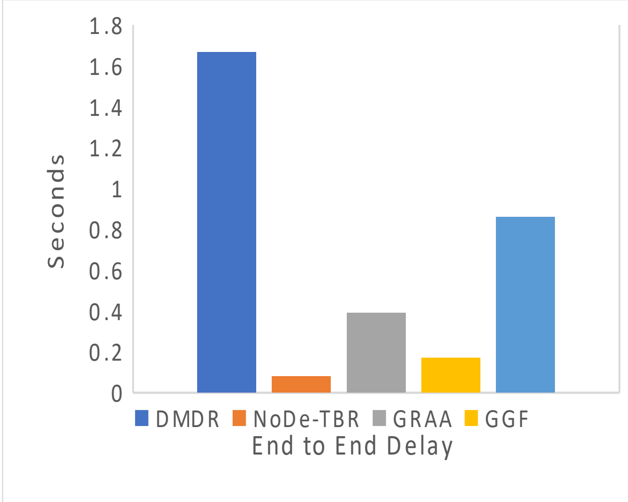

Fig. 4 Delay of routing protocols

The NoDe-TBR routing is a geographic routing with geopath computation and forwarding strategy using a fast marching method. It partitions the geographic region based on the node density using the Voronoi diagram and computes the geographic trajectory of the aircraft. The performances of NoDe-TBR were simulated and assessed with the OMNeT++ simulator using North Atlantic Tracks (NAT), which consists of structured air traffic. It considers the spatial and temporal diversity of node density and the aircraft trajectories. It takes the aircraft trajectories of 8h to 9h time slot from the euro control traffic repository for the simulation for the node density of 600 with each aircraft's radio range as 350 km and a velocity of 900kmph.

This work compares the AODV, DYMO and BATMAN routing algorithms. It has higher normalized reachability, lower network signalization traffic and average end to end delay for different routing algorithms. Fig.5 depicts the packet delivery ratio for AANET routing protocols.

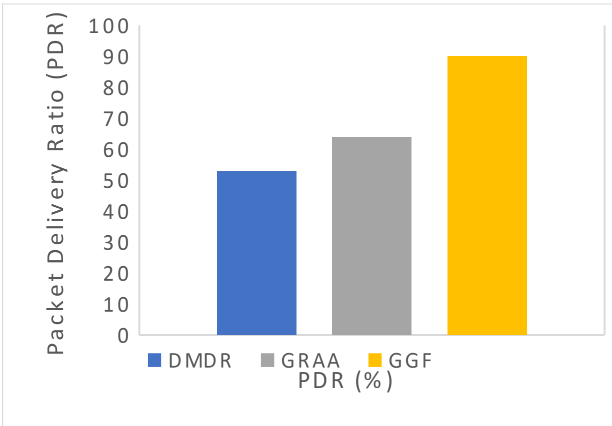

Fig. 5 PDR of routing protocols in AANET

The GRAA is based on the geographic GPSR with greedy forwarding routing. It is designed to adapt to the dynamic changes of the AANET.

The GRAA finds the shortest path using node position information. This work was simulated using the Qualnet network simulator with a two-ray ground radio propagation model. GRAA protocol analysis and compares the packet delivery ratio and average end-to-end delay with the GPSR routing protocol and shows better performance than GPSR. However, this work does not analyze the routing overhead, throughput, number of handoffs.

The geographic greedy forwarding works based on the modified RGR for the unmanned aeronautical ad-hoc networks. It discovers multiple routing paths and selects the best stable route for routing. If it fails then it selects the second-best route for the routing. The multiple routing paths are loop-free paths. It simulates the proposed method using OPNET Modeler with the simulation area 5 Km^2, radio range radius of the node as 1 km and channel capacity of nodes are 11 Mbit/s. This work compared with the modified RGR and shows better performance for the routing overhead, throughput, end to end delay, packet delivery ratio. However, it does not compare this work with the recent routing protocols.

Table.3 gives the performance analyses of various routing protocols. From the table, the GGF protocol gives the lowest routing overhead, MUDOR protocol gives the reduced handoffs as 3 for 950 nodes, LEBR protocol has the highest throughput as 3.4 bits per second, GGF gives 94 % of PDR and only 0.08 sec of end to end for NoDe-TBR protocol.

Table.3 AANET performance comparison

Authors	Method/ Protocol	Velocity	Routing Overhead	Handoffs	Throughput	Packet Delivery Ratio	End to End Delay
M.Iordanakis et al [1]	ARPAM	400-800 Km/h	100-300 bps	-	-	-	-
E.Sakhaee et al [3]	MUDOR	840 Km/h	-	3 for 950 nodes	-	-	-
W.Gu et al [7]	DMDR	constant	-	7 for 200 nodes	3.2 @ traffic 7 kb/s	53% @ traffic 7 kb/s	7.667 sec
Q. Vey et al [8]	NoDe-TBR	900 Km/h	-	-	-	-	0.08 sec
S. Hyeon et al [5]	GRAA	-	-	-	-	64 %	0.390 sec
M.Kardoust et al [6]	GGF	50 - 60 m/s	130 bps	-	2.52 bps	90 %	0.17 sec
L.Lei et al [17]	LEBR	800 Km/h	-	-	3.4 bps	-	0.86 sec
Saifullah K, at al [18]	GRHAA	100 Km/h				53 %	3.4 sec

A. Routing issues of the AANET

For instance, their simulation model is based on the random waypoint model is used as the radio propagation for the simulation of the AANET. Since the random waypoint model is not suitable for modeling the movements of the aircraft in the sky. Besides, there are different types of aircraft flies in the sky, therefore the homogeneous deployment is also an improper hypothesis for the real-time aircraft environments [22].

Furthermore, the aircraft nodes should be sparsely distributed in the sky in order to avoid collision between the flying aircraft. On the other side, the wireless standard protocol is IEEE 802.11 used for the maximal utilization of bandwidth. But, the suitability of this protocol in the AANET environment also questionable.

Also, still there is no standard simulation tool for the study and development of the routing protocol in the AANET. Even though, most of the research works adopt the ns2 for the analysis of AANET simulation studies and results. But the reliability and credibility of their simulation results are debatable.

V. CONCLUSION

The direct communication between the aircraft is the most crucial task in the aircraft ad hoc networks. This paper discusses the recent improvements of the routing protocols in the AANET. It analyses the air transportation systems, the impact of routing in airplane operation, airplane maintenance and air traffic control. It examines AANET design considerations such as adaptability, channel availability, scalability, latency, and bandwidth. Further, this paper analyses the performance metrics of different AANET routing protocols. Also, it analyses the aircraft ad hoc network parameters such as mobility, radio propagation model, topology change, node density, localization, and handoffs. The GGF method has the highest PDR and NoDe-TBR protocol gives a reduced delay over other protocols. For further works, a new routing protocol developed with the realistic mobility model for the AANET.

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AUTHORS PROFILE

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