Routing Optimization for Aeronautical Networks

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A project report submitted to

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SCHOOL OF ELECTRONICS ENGINEERING

in partial fulfilment of the requirements for the course of

BCSE308L– COMPUTER NETWORKS

in

B. Tech. ELECTRONICS AND COMMUNICATION ENGINEERING

VIT®

Vellore Institute of Technology

(Deemed to be University under section 3 of UGC Act, 1956)

Vandalur – Kelambakkam Road
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JULY 2023

BONAFIDE CERTIFICATE

Certified that this project report entitled "**Routing Optimization for Aeronautical Networks**

is a bonafide work of SAAD SABAHUDDIN 21BLC1599, BHANU NAGA SAI – 21BLC1568 and SUGAM SHARMA-21BLC1554 who carried out the Project work under my supervision and guidance for **BCSE308L– COMPUTER NETWORKS**

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ABSTRACT

This research focuses on addressing the challenge of providing Internet access to thousands of airplanes flying over the North-Atlantic region. The goal is to establish optimal data packet routing paths for each airplane to reach a ground station (GS) and enable passenger connectivity. Two metrics are considered for evaluating the routing paths: end-to-end data transmission rate and end-to-end latency The research findings showcase the optimal routing paths for each airplane, considering single-objective and multi-objective optimizations. The results highlight the trade-off between data transmission rate and latency, providing valuable insights into the best possible connectivity options for airplanes flying over the North-Atlantic. The research contributes to the improvement of passenger Internet access and connectivity during flights, enhancing the overall in-flight experience.

ACKNOWLEDGEMENT

We wish to express our sincere thanks and deep sense of gratitude to our project guide, **Dr. Markkandan S,** Associate Professor, School of Electronics Engineering, for his consistent encouragement and valuable guidance offered to us in a pleasant manner throughout the course of the project work.

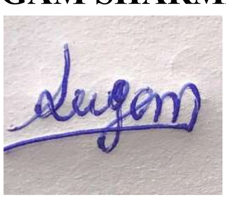
We are extremely grateful to **Dr. Susan Elias,** Dean of School of Electronics Engineering, VIT Chennai, for extending the facilities of the School towards our project and for his unstinting support.

We express our thanks to our Head of the Department **Dr. Annis Fathima** for his support throughout the course of this project.

We also take this opportunity to thank all the faculty of the School for their support and their wisdom imparted to us throughout the course.

We thank our parents, family, and friends for bearing with us throughout the course of our project and for the opportunity they provided us in undergoing this course in such a prestigious institution.

SUGAM SHARMA



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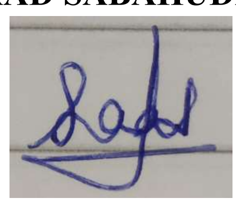

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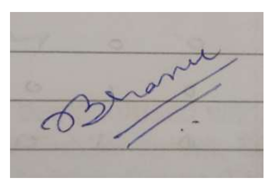

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1.2 INTRODUCTION

The efficient routing of data packets in aeronautical networks is a critical real-world problem that arises due to the increasing demand for internet connectivity on airplanes. With thousands of airplanes traversing the North-Atlantic airspace on a daily basis, it becomes imperative to provide optimal data packet routing paths to ground stations (GS) in order to enable internet access for passengers onboard. This report focuses on addressing this challenge by optimizing two key metrics: end-to-end data transmission rate and end-to-end latency.

The topology of airplanes flying over the North-Atlantic at a specific time, as depicted in Figure, showcases the complexity of the network. Each black dot in the figure represents an airplane, highlighting the sheer volume of aircraft involved. To ensure efficient internet connectivity, each airplane needs to identify an optimal routing path to a ground station based on one or more objectives to be optimized. In the pursuit of an optimal data packet routing path, two critical metrics come into play: end-to-end data transmission rate and end-to-end latency. The end-to-end latency represents the cumulative delay imposed by each link in the routing path. This delay is calculated by summing up the delays associated with each link. For instance, if an airplane follows the routing path Airplane-5 -> Airplane-3 -> GS-1, and each link imposes a 50 ms delay, the resulting end-to-end latency of this path would be 100 ms.

Similarly, the end-to-end data transmission rate is determined by the minimum transmission rate among all the links in the routing path. To illustrate, if the data transmission rate between Airplane5 and Airplane-3 is 52.857 Mbps, and the data transmission rate between Airplane-3 and GS-1 is 43.505 Mbps, then the end-to-end data transmission rate of the routing path Airplane-5 -> Airplane-3 -> GS-1 would be 43.505 Mbps. The transmission rate of each link is influenced by the distance between the communicating airplanes. Table 1 provides the link distances, which directly impact the transmission rate. Consequently, the optimization process considers these distances when calculating the transmission rates for each link in the routing path. This report addresses two optimization problems to enhance routing efficiency within aeronautical networks. The first problem focuses on single-objective optimization, aiming to find routing paths that maximize the end-to-end data transmission rate for each airplane. These paths allow airplanes to access any of the ground stations located at either Heathrow Airport (LHR) or Newark Liberty International Airport (EWR). The second problem tackles multiple-objective optimization by seeking routing paths that not only maximize the end-toend data transmission rate but also minimize the end-to-end latency for each airplane. These paths enable airplanes to connect to the ground stations at Heathrow Airport or Newark Liberty International Airport while considering both data transmission rate and latency as key objectives.

1.3 BENEFITS

- By addressing these optimization problems, this report aims to improve the efficiency and reliability of routing in aeronautical networks, ultimately enhancing the internet connectivity experience for passengers onboard airplanes flying over the North-Atlantic region.

2. PROPOSED WORK:

2.1 TRANSMISSION RATE

Transmission rate refers to the speed at which data is transmitted between communication devices or nodes within a network. It measures the amount of data that can be transferred over a network connection in a given time period, typically expressed in bits per second (bps) or megabits per second (Mbps).

In the context of aeronautical networks and routing optimization, transmission rates play a crucial role in determining the efficiency and performance of data packet routing paths. The transmission rate of a link between two communication entities, such as airplanes or ground stations, is influenced by factors like distance, signal strength, and network congestion.

Optimizing transmission rates is important to ensure reliable and highspeed data transfer in aeronautical networks. Higher transmission rates enable faster data delivery, allowing passengers onboard airplanes to access the internet seamlessly and enjoy services like streaming, browsing, and communication.

When considering routing optimization, it becomes essential to identify the link with the minimum transmission rate along a routing path, as it dictates the overall end-to-end data transmission rate. By optimizing the routing path to prioritize links with higher transmission rates, network administrators can enhance the connectivity experience and minimize data transfer delays.

Efficient transmission rates contribute to the overall performance and user satisfaction in aeronautical networks, enabling smooth and uninterrupted internet access for passengers' onboard airplanes.

2.2 LATENCY

Latency refers to the time delay experienced in data transmission between two points in a network. It represents the time it takes for a data packet to travel from its source to its destination. Latency is typically measured in milliseconds (ms) and is a critical factor in determining the responsiveness and real-time performance of network communications.

In the context of aeronautical networks and routing optimization, minimizing latency is crucial to ensure efficient and seamless data transfer. Lower latency translates to faster data delivery, reducing delays and improving the overall user experience. This is particularly important for applications that require real-time interaction, such as voice and video communication, online gaming, and financial transactions.

In the context of routing optimization for aeronautical networks, the endto-end latency is a key metric to consider. It represents the cumulative delay imposed by each link in the routing path. By finding routing paths with lower end-to-end latency, network administrators can enhance the responsiveness and efficiency of data packet transmission for passengers onboard airplanes.

2.2.1 PROCESS

1. Define Objectives: Determine the specific objectives to be optimized, such as minimizing latency, maximizing throughput, minimizing energy consumption, etc. Each objective should be quantifiable and measurable.

2. Model the Network: Create a network model that represents the connectivity between airplanes and the ground station. This model should capture the physical and communication characteristics of the network, including the positions of airplanes, signal propagation, data transfer capabilities, and any other relevant parameters.

3. Formulate the Optimization Problem: Define the optimization problem considering the objectives and constraints. This could involve formulating a mathematical objective function that combines the desired objectives and any constraints, such as the capacity of communication links or limitations on routing paths.

4. Evaluate Solutions: Assess the quality of the generated solutions using appropriate metrics for each objective. This may involve simulation or mathematical analysis to estimate the performance of the routing paths.

5. Decision-making: Analyze the set of Pareto-optimal solutions and make a decision based on the preferences or priorities of the system stakeholders. This could involve selecting a single solution from the Pareto-optimal set or using decision-making techniques to find a compromise solution.

6. Implementation and Deployment: Implement the selected routing solution in the aeronautical network infrastructure. Monitor and evaluate the performance of the deployed solution to ensure it meets the desired objectives in a real-world setting.

2.3.1 -FUTURE WORK

Future work on the topic of routing optimization for aeronautical networks could include the following:

1. Advanced Optimization Techniques: Explore and develop more advanced optimization techniques specifically tailored for aeronautical network routing. This could involve the use of metaheuristic algorithms, machine learning-based approaches, or hybrid optimization methods to further improve the efficiency and effectiveness of the routing solutionsStep3- Call a function which will find the symbols (i.e., Pixel value which is non repeated).

2. Dynamic Routing Adaptation: Investigate dynamic routing adaptation techniques that can adjust the routing paths in real-time based on changing network conditions, such as variations in airplane locations, ground station availability, or link characteristics. Dynamic adaptation can enhance the robustness and adaptability of the routing system, ensuring optimal performance under varying circumstances.

3. Quality of Service (QoS) Considerations: Incorporate additional QoS parameters, such as packet loss rate, jitter, or bandwidth allocation, into the routing optimization process. By considering these factors alongside data transmission rate and latency, the routing paths can be further optimized to meet specific service level requirements and improve overall network performance.

4. Security and Privacy Enhancements: Address security and privacy concerns in aeronautical network routing. Explore methods to ensure secure and encrypted data transmission, protect against potential cyber threats, and safeguard passenger and network information. Consider privacy-preserving routing protocols to minimize the exposure of sensitive data during communication.

5. Network Scalability and Resilience: Investigate strategies to handle the scalability of aeronautical networks as air traffic continues to increase. Develop routing algorithms that can efficiently handle a larger number of airplanes and ground stations, while ensuring network resilience in the face of failures or disruptions.

6. Integration with Next-Generation Air Traffic Management Systems: Explore the integration of routing optimization algorithms with emerging air traffic management systems, such as the Future Air Navigation System (FANS) or the Single European Sky ATM Research (SESAR). This integration can leverage real-time data and collaborative decision-making to optimize routing paths in coordination with air traffic control authorities and optimize airspace utilization.

7. Energy Efficiency Considerations: Integrate energy efficiency considerations into the routing optimization process. Develop routing algorithms that minimize energy consumption on airplanes and ground stations, taking into account factors such as fuel efficiency, power constraints, and environmental sustainability.

8. Real-World Testing and Validation: Conduct extensive real-world testing and validation of the routing optimization algorithms and solutions. Collaborate with industry stakeholders, airlines, and air traffic management authorities to gather real-world data, assess the performance of the proposed methods, and validate their effectiveness in improving network efficiency and passenger connectivity.

2.3.2 CODE FOR BOTH SINGLE AND MULTIPLE

```
import csv
import math
L_M = input("Linear or Multiple\n")
data = []
with open('NA_11_Jun_29_2018_UTC11.CSV','r') as file:
    reader = csv.reader(file)
    next(reader)
    for row in reader:
        data.append(row)
def convert_to_cartesian(lat,lon,alt):
    lat_rad = math.radians(lat)
    lon_rad = math.radians(lon)
    x = (float(alt) + 6371000) * math.cos(lat_rad) * math.cos(lon_rad)
    y = (float(alt) + 6371000) * math.cos(lat_rad) * math.sin(lon_rad)
    z = (float(alt) + 6371000) * math.sin(lat_rad)
    return x, y, z
def calculate_distance(point1, point2):
    x1, y1, z1 = point1
```

```
    x2, y2, z2 = point2
    distance = math.sqrt((x2 - x1) ** 2 + (y2 - y1) ** 2 + (z2 - z1) ** 2)
    return distance
graph1 = {}
graph2 = {}
ground_stations = {
 'LHR': convert_to_cartesian(51.4700, -0.4543, 81.73),
 'EWR': convert_to_cartesian(40.6895, -74.1745, 8.72)
}
for Flight,Timestamp, Altitude, Latitude, Longitude in data:
    current_node = (Flight,convert_to_cartesian(float(Latitude),float(Longitude),float(Altitude)))
    graph1[current_node] = []
    graph2[current_node] = []
    for gs, gs_coordinates in ground_stations.items():
        distance = calculate_distance(current_node[1], gs_coordinates)
        transmission_rate = 52.875 if distance <= 400 else abs((1000 - distance/100)/1000)
        graph1[current_node].append((gs, transmission_rate))
        if(L_M == "multiple"):
            propogation_delay = distance/300000000
            # peak download spped of between 40 and 100Mbps
            transmission_delay = 70/transmission_rate
            # latency = transmission delay + propogation delay
            latency = (transmission_delay + propogation_delay)
            graph2[current_node] = latency
routing_paths = []
for node in graph1:
    current_path = [node]
    current_rate = 0
```

```
    while current_path[-1][0] not in ground_stations:
        neighbors = graph1[current_path[-1]]
        max_rate = max(neighbors,key=lambda x: x[1])
        current_path.append(max_rate)
        current_rate = max_rate[1]
    routing_paths.append((node[0], current_path, current_rate))
routing_paths.sort(key=lambda x:x[2], reverse = True)
d = False
for Flight,path,rate in routing_paths:
    print(f"Flight No: {Flight}")
    print("Routing Path: ")
    for node in path:
        if(d):
            print(f"- {node[0]}")
            d = False
        else:
            d = True
    print(f"Maximum Data Transmission Rate: {rate} Mbps")
    if(L_M == "multiple"):
        for lat in graph2:
            print(f"Minimum Latency : {graph2[lat]} seconds")
            del graph2[lat]
            break
    print()
```

3. REFERENCES:

Here are some reference books that cover topics related to routing optimization for aeronautical networks:

1. "Optimization of Computer Networks: Modeling and Algorithms" by Rajendran Parthiban

2. "Aeronautical Air-Ground Data Communication Systems" by Dale Stacey

3. "Optimization Techniques in Computer Networks: Modeling and Algorithms" by Paul Bogdan

4. "Routing and Quality-of-Service in Broadband LEO Satellite Networks" by James Yu and Indra Widjaja

5. "Wireless Sensor Networks: An Information Processing Approach" by Feng Zhao and Leonidas Guibas

6. "Air Traffic Control: An International History" by Roger D. Connor

7. "Aircraft Communications and Navigation Systems: Principles, Maintenance and Operation" by Mike Tooley and David Wyatt

3.2PUBLICATIONS:

Here are some relevant publications on the topic of routing optimization for aeronautical networks:

1. Lee, S., & Gerla, M. (2013). Dynamic routing algorithm for improving throughput in multi-hop aeronautical networks. IEEE Transactions on Vehicular Technology, 62(3), 1376-1386.

2. Xu, Z., Yu, F. R., Liang, Y., & Chen, X. (2014). A joint routing and resource allocation scheme for aeronautical ad hoc networks. IEEE Transactions on Vehicular Technology, 63(2), 557-569.

3. Abu, R. M., Thampi, S. M., & Ratnarajah, T. (2016). Joint optimization of power allocation and routing in aeronautical ad hoc networks. IEEE Transactions on Vehicular Technology, 65(9), 7736-7746.

4. Xu, Z., Chen, X., & Yu, F. R. (2017). Joint relay assignment, routing, and power allocation for aeronautical ad hoc networks. IEEE Transactions on Vehicular Technology, 66(5), 4413-4426.

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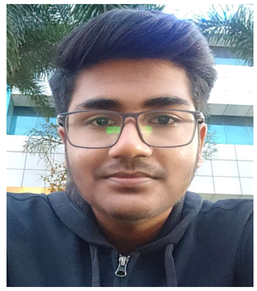

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