МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
Факультет аеронавігації, електроніки та телекомунікацій
Кафедра аеронавігаційних систем

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
д-р техн. наук, проф.
_______________Віталій ЛАРІН
«___»______________2023 р.

ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)
ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ
МАГІСТРА
ЗА ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ
«ОБСЛУГОВУВАННЯ ПОВІТРЯНОГО РУХУ»

Тема: «**Використання стільникового зв’язку в повітряних суднах**»

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Київ 2023

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аеронавігації, електроніки та телекомунікацій

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ЗАТВЕРДЖУЮ

Завідувач кафедри АНС

_______________Віталій ЛАРІН

«___»______________2023 р.

ЗАВДАННЯ

на виконання дипломної роботи

Боднара Олега Ігоровича

1. Тема дипломної роботи: «**Використання стільникового зв'язку в повітряних суднах**» затверджена наказом ректора №1443/ст від 22.08.2023 р.

2. Термін виконання: 23.10.2023. to 31.12.2023

3. Зміст пояснювальної записки: дослідити та проаналізувати впровадження технологій стільникового зв'язку в літаках, зосереджуючись на їх впливі на зв'язок, досвід пасажирів, ефективність експлуатації та безпеку. Робота спрямована на забезпечення всебічного розуміння переваг, проблем та потенційних рішень, пов'язаних з інтеграцією технологій стільникового зв'язку в авіаційній галузі.

4. Перелік обов'язкового графічного (ілюстративного) матеріалу: графіки, таблиці, формули.

5. Календарний план-графік

№ п/п	Завдання	Термін виконання	Відмітка про виконання
1.	Підготовка та написання 1 розділу «Стільниковий зв'язок як нова комунікаційна можливість»	23.10.2023-29.10.2023	виконано
2.	Підготовка та написання 2 розділу «Вивчення джерел літератури з авіаційних технологій стільникового зв'язку»	30.10.2023-05.11.2023	виконано
3.	Підготовка та написання 3 розділу «Стільникові технології в авіації та їх застосування в навігації»	06.11.2023-25.11.2023	виконано
4.	Підготовка та написання 4 розділу «Спец розділ»;	26.11.2023 - 03.12.2023	виконано
5.	Підготовка та написання 5 розділу «Охорона праці та навколишнього середовища ».	04.12.2023-10.12.2023	виконано
6.	Підготовка доповіді та графічних матеріалів	11.12.2023-31.12.2023	виконано

6. Дата видачі завдання: 10.09.2023.

Керівник дипломної роботи ________________ Богуненко Микола Миколайович

(підпис керівника) (П.І.Б.)

Завдання прийняв до виконання ______________________Боднар Олег Ігорович

(підпис випускника) (П.І.Б.)

РЕФЕРАТ

Пояснювальна записка до дипломної роботи «Використання стільникового зв’язку в повітряних суднах»: 104 сторінка, 29 рисунків, 5 таблиць, 27 використаних джерел.

Об’єкт дослідження – технології стільникового зв'язку в авіації.

Предмет дослідження – впровадження та використання технологій стільникого зв'язку на борту літака.

Мета роботи – визначити способи впровадження стільникового зв'язку для використання на літаках та надати рекомендації.

Метод дослідження – для досягнення цілей дослідження були використані такі методи:

Огляд літератури - було проведено комплексний огляд відповідної літератури, включаючи наукові статті, дослідження, галузеві звіти та нормативні документи, щоб зібрати інформацію про поточний стан технологій стільникового зв’язку літаків.

Аналіз випадків: було використано для аналізу прикладу реального життя авіакомпанії або оператора літака, що впроваджує стільникову технологію. Ці тематичні дослідження дають уявлення про практичне впровадження, переваги, проблеми та уроки, отримані за допомогою стільникового зв’язку в літаках.

Опитування та інтерв’ю: опитування та інтерв’ю проводились з пасажирами, членами екіпажу, професіоналами авіаційної промисловості та регуляторами, щоб зібрати дані та думки щодо використання технологій стільникового зв’язку на літаках.

Це дослідження спрямоване на розуміння потенційних переваги та проблем впровадження стільникових технологій на літаках і має за ціль зробити внесок у розробку рекомендацій, практик і стандартів для сприяння ефективному та безпечному використанню цих технологій в авіаційній промисловості.

Ключова слова: СТІЛЬНИКОВІ ТЕХНОЛОГІЇ, LTE, 5G, ЗВ'ЯЗОК, НАВІГАЦІЯ, ЕФЕКТИВНІСТЬ ПОЛЬОТІВ, БЕЗПЕКА ПОЛЬОТІВ, СТІЛЬНИКОВІ АНТЕНИ, ADS-B, ШТУЧНИЙ ІНТЕЛЕКТ, ІНТЕРНЕТ РЕЧЕЙ.

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
Faculty of air navigation, electronics and telecommunications
Air navigation systems department

PERMISSION TO DEFEND
Head of the Department
Doctor of Sciences (Engineering), prof
______________ Vitalii LARIN
«____» _____________2023

MASTER'S DEGREE THESIS

(EXPLANATORY NOTE)

GRADUATE OF EDUCATIONAL QUALIFICATION LEVEL
MASTER
EDUCATIONAL AND PROFESSIONAL PROGRAM
«AIR TFAFFIC SERVICE»

Theme: "**Cellular communication usage in aircraft**"

Completed by: Bodnar O. I.
Supervisor: Bogunenko M.M.
Supervisors of special chapter Ostrumov I.V.

Standards Inspector: Arhunov H.F.

Kyiv 2023

NATIONAL AVIATION UNIVERSITY

Faculty of Air navigation, Electronics and Telecommunications

Department: Air navigation Systems Department

Educational degree: Master

Specialty: 272 «Aviation Transport»

EPP: «Air Traffic Services»

PERMISSION TO DEFEND

Head of the Department

_____________ Vitalii LARIN

«____»_________2023

ASSIGNMENT

Of master's thesis

Bodnar Oleh Ihorovich

1. The thesis theme: "Cellular communication usage in aircraft" approved by the Rector's order of №1443/ст from 22.08.2023 р.

2. The Thesis to be completed between 23.10.2023 to 31.12.2023.

3. The content of the explanatory note: to investigate and analyze the implementation of cellular technologies in aircraft, focusing on their impact on communications, passenger experience, operational efficiency and safety. The work is aimed at providing a comprehensive understanding of the advantages, problems and potential solutions associated with the integration of cellular technologies in the aviation industry.

4. The list of mandatory graphic (illustrated) materials: graphs, tables, formulas.

5. Calendar timetable

№	Completion stages of Degree Thesis	Stage completion dates	Remarks
1	Preparation of chapter 1: « Cellular communication as a new communication opportunity »	23.10.2023-29.10.2023	completed
2	Preparation of chapter 2: « Studying of literature sources on aviation cellular communication technologies »	30.10.2023-05.11.2023	completed
3	Preparation of chapter 3: «Cellular technologies in aviation and their application in navigation»	06.11.2023-25.11.2023	completed
4	Preparation of chapter 4: « Special chapter»;	26.11.2023 - 03.12.2023	completed
5	Preparation of chapter 5: «Labor precaution and environment safety»	04.12.2023-10.12.2023	completed
6	Preparation of report and graphic materials	11.12.2023-31.12.2023	completed

6. Assignment accepted for completion: 10.12.2023.

Supervisor ________________Bohunenko M.M.

(signature)

Assignment accepted for completion ________________ Bodnar O.I.

(signature)

ABSTRACT

Explanatory note to the thesis "Cellular communication usage in aircraft": 104 pages, 29 figures, 5 tables, 27 used sources.

The object of research - cellular technology in aviation.

The subject of research - introduction and use of cellular communication technologies on board the aircraft.

The aim – identify ways to introduce cellular communication for use on aircraft and give recommendatios.

Method of investigation - the following methods were used to achieve the objectives of the investigation:

Literature Review - A comprehensive review of relevant literature, including scientific articles, studies, industry reports, and regulations, was conducted to gather information on the current state of aircraft cellular communications technologies.

Case analysis**:** was used to analyze a real-life example of an airline or aircraft operator implementing cellular technology. These case studies provide insight into the practical implementation, benefits, challenges and lessons learned through cellular communication in aircraft.

Surveys and interviews: Surveys and interviews were conducted with passengers, crew members, aviation industry professionals, and regulators to gather data and opinions on the use of cellular technology on aircraft.

This research aims to understand the potential benefits and challenges of introducing cellular technologies on aircraft and aims to contribute to the development of recommendations, practices and standards to promote the effective and safe use of these technologies in the aviation industry.

Keywords: CELLULAR TECHNOLOGIES, LTE, 5G, COMMUNICATION, NAVIGATION, FLIGHT EFFICIENCY, FLIGHT SAFETY, CELLULAR ANTENNAS, ADS-B, ARTIFICIAL INTELLIGENCE, INTERNET OF THINGS.

PAGE OF REMARKS

CONTENT

LIST OF ABBREVIATIONS AND EXPLANATION OF TERMS

4G - Fourth Generation

5G - Fifth Generation

5G NR - Fifth Generation New Radio

ACARS - Aircraft Communications Addressing and Reporting System

ACT – Aviation Cellular Tehnology

ADS-B - Automatic Dependent Surveillance-Broadcast

AI - Artificial Intelligence

AMQP- Advanced Message Queuing Protocol, is an open-standard application layer protocol used for asynchronous messaging between applications or organizations.

ANSP - Air Navigation Service Provider

AOC - Airline Operations Center

ARINC - Aeronautical Radio, Incorporated

ATC - Air Traffic Control

CAGR - Compound Annual Growth Rate, is a statistic used to measure the average annual growth rate of an investment over a specific period of time, longer than one year.

CPDLC - Controller Pilot Data Link Communications

DME - Distance Measuring Equipment

EC - The European Commission

FAA - Federal Aviation Administration

FCC - Communications Commission

FDD - Frequency-Division Duplexing

GEO - Geostationary orbit

GSM - Global System for Mobile Communications

IATA - Air Transport Association

IC - integrated circuit.

IFE - In-Flight Entertainment

IoT - Internet of Things

LEO - Low-Earth Orbit

LTE - Long-Term Evolution

LTE-A - Long Term Evolution Advanced

M2M - Machine-to-Machine

MEO - Medium-Earth orbit

MIMO - Multiple Input Multiple Output)

MQTT - Message Queuing Telemetry Transport, publish-subscribe messaging protocol designed for resource-constrained devices and unreliable networks.

NTN - Non-Terrestrial Networks, encompass various wireless communication systems operating above the Earth's surface

RF - Radio Frequency

SATCOM - Satellite Communication

SSR - Secondary Surveillance Radar

TDD - Time-Division Duplexing

UMTS - Universal Mobile Telecommunications System, third-generation (3G) mobile network standard that revolutionized mobile communications by providing significantly faster data speeds than its predecessor, GSM.

VHF - Very High Frequency

VOR - VHF Omnidirectional Range

Wi-Fi - Wireless Fidelity

INTRODUCTION

Rapid progress in communication technologies has revolutionized various industries, including the aviation sector. In recent years, cellular communication technologies have emerged as a potential solution to improve aircraft connectivity, offering numerous benefits such as increased safety, operational efficiency and passenger experience. The thesis "Implementation of cellular communication technology in aircraft" seeks to explore the feasibility and potential advantages of integrating cellular communication with aviation systems.

The aviation industry relies heavily on effective communication for seamless coordination between pilots, air traffic controllers and ground staff. Traditional communication systems such as radio and satellite networks have served this purpose for decades. However, with the increasing demand for faster and more reliable data transmission, cellular communication technologies present an intriguing opportunity to enhance the communication capabilities of aircraft.

This tesis aims to explore the practicality of implementing cellular communication technology in aircraft, taking into account aspects such as technical feasibility, regulatory requirements and cost-effectiveness. By delving into existing literature, analyzing relevant research, and examining the experiences of industry experts, this study aims to provide insight into the potential benefits, challenges and implications of integrating cellular connectivity into aircraft systems.

The objectives of this work include evaluating the impact of mobile communications technology on safety, efficiency and passenger service in aviation, as well as exploring potential solutions to address identified challenges. By comprehensively examining the existing body of knowledge and conducting systematic analyses, this research is expected to contribute to the understanding of the potential of mobile communication technology in aviation.

The significance of this study lies in its potential to shape the future of air communication systems to improve connectivity, improve operational efficiency and ensure a seamless passenger experience. The findings and recommendations of this work will be valuable to aviation stakeholders, including airlines, regulators and technology providers, as they consider integrating cellular communication technology into aircraft.

To achieve the goal of the thesis, it is necessary to solve the following tasks:

- Cellular communication as a new communication opportunity
- Studying of literature sources on aviation cellular communication technologies.
- Cellular technologies in aviation and their aplocation in navigation.

CHAPTER 1

CELLULAR COMMUNICATION AS A NEW COMMUNICATION OPPORTUNITY

1.1 Cellular Technology Overview

Cellular technology is a crucial component of modern communication systems, providing mobility, access to information and global data exchange. Below is extensive information, including figures characterizing this technology.

1. Users:

World Coverage: According to data for 2023, the number of mobile subscribers exceeded 8.5 billion, which significantly exceeds the population of the Earth.

2. Infrastructure and Frequencies:

Frequency Range: Cellular technology uses a wide range of frequencies. For example, 2G uses the 850/900 MHz and 1800/1900 MHz bands, while 4G and 5G use high-frequency bands from 600 MHz to 100 GHz.

Base Stations: The global number of base stations exceeds 10 million, providing reliable coverage in urban areas, rural areas and in places of high concentration of people

3.Technologies and Generations:

• 2G (GSM): Introduced in 1991, provides voice communication and SMS. Over 3.5 billion subscribers of 2G global network.

• 3G (UMTS): Launched in 2001, allows data transmission, including the Internet. More than 4 billion 3G users.

• 4G (LTE): Launched in 2009, provides high-speed Internet. More than 5 billion 4G users.

• 5G: Implemented worldwide. Data rates from 1 Gbps and a lower delay up to 1 ms.

Characterists of different generations of cellular communication are listed in the Table 1.1.

Table 1.1. – Characterists of different generations of cellular communication

Feature	2G	3G	4G	5G
Standard	GSM	UMTS	LTE	NR
Frequencies, MHz	900, 1800	900, 1800, 2100	800, 1800, 2100, 2600	600, 2100, 2600, 3500, 4200, 4500, 6000
Range	900-1800	900-2100	800-2600	600-6000
Bandwidth	256-14400 kbps	1,44-14400 kbps	1,44-100000 kbps	100-1000000 kbps
Reliability	Medium	High	High	High
Interference Resistance	Medium	High	High	High
Applications	Voice, data	Voice, data, video	Voice, data, video, content	Voice, data, video, content, AI, autonomous driving
Latency, ms	20-100	10-50	5-20	1-5

4. Innovations and Perspectives:

Internet of Things (IoT): The number of connected devices is projected to reach 25 billion by 2030, including vehicles, home appliances and medical devices.

Artificial Intelligence (AI): Applying artificial intelligence to network optimization, load prediction, and performance enhancement.

Cellular technology is developing rapidly, providing incredible opportunities for communication and exchange of information. With the continuous improvement and introduction of new technologies, this type of communication remains a key element of the global information society.

1.2 Importance of Cellular Technologies in Aviation

Cellular technologies in aviation play an important role in ensuring the efficient and safe operation of aircraft. The key aspects that determine the importance of these technologies in the aviation sector are discussed below.

1.Provision of Communication in Flight:

Reliability of Data Transfer: Cellular communication technologies provide constant and reliable communication between aircraft and the ground during flight.

Voice and Data Communication: Designed to transfer not only voice communication but also important data between the crew and ground control centers via cellular network (Fig. 1.1)

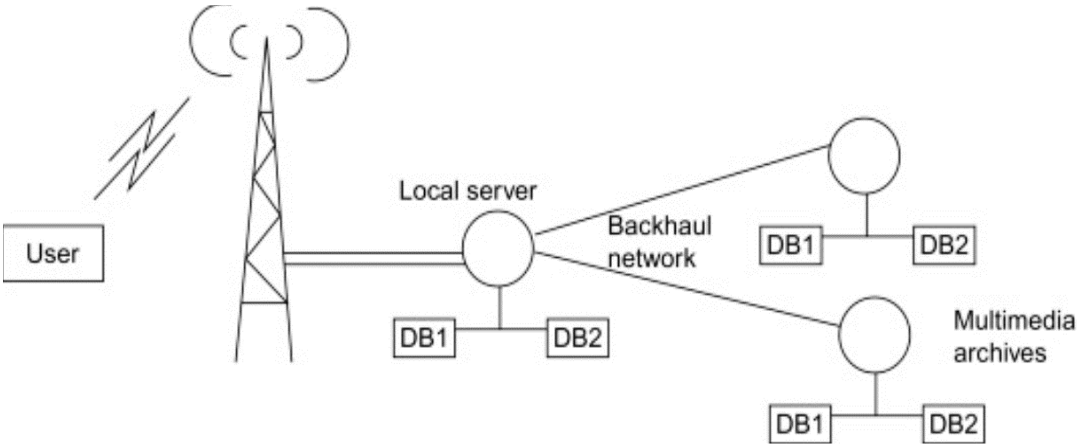

Figure 1.1 – Cellular network [26]

2. Enhancing Security and Situational Awareness:

Electronic Communication Systems: The integration of cellular communications into electronic systems allows airlines and dispatch services to quickly exchange information on flight status and situational awareness.

Emergency Notification: The possibility of immediate notification of emergency situations and accidents via cellular communication promotes rapid response and coordination of actions.

3. Traffic and Navigation Management:

4D-Navigation technologies: The use of cellular communication to transmit accurate data on the position of the aircraft in time (4D navigation) with 4D trajectory (Fig.1.2) which contributes to effective traffic management and rational use of airspace.

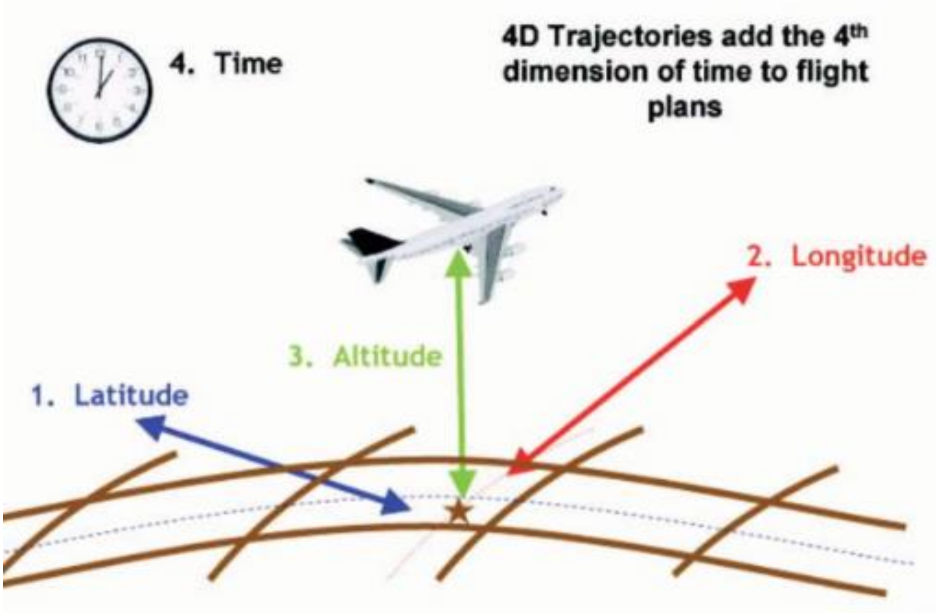

Figure 1.2 – 4D trajectory [26]

4. Improvement of Passenger Experience:

Internet on Board (Wi-Fi): Enabling passengers to access the Internet and communicate during the flight, which increases comfort and entertainment.

Mobile Communications: Using passengers' mobile devices to make calls and exchange messages, which adds flexibility and convenience.

5. Monitoring and Maintenance:

Maintenance: The use of cellular communication to monitor the condition of aircraft technical equipment, which contributes to the rapid detection and correction of faults.

Fuel Requirements: Remote fuel consumption monitoring and route optimization to save fuel.

The importance of cellular technologies in aviation is difficult to overestimate. They determine the efficiency and safety of aviation operations, and contribute to improving comfort and convenience for all airspace participants.

1.3 Problem: Meeting the Need for Efficient and Reliable Communications Systems on Aircraft

In today's aviation environment, where precision, efficiency and safety are key factors, the problem of providing effective and reliable communication systems on aircraft is becoming increasingly urgent. Detailed consideration of this issue includes the following aspects:

1. Dissatisfying Infrastructure and Modern Requirements:

Ensuring efficient and reliable communications in the modern aviation industry faces significant challenges, particularly those related to the use of outdated technology and limited infrastructure bandwidth. This jeopardizes not only passenger comfort but also the safety and efficiency of air transport.

Modern aviation communications needs are driven by the need for advanced technologies for fast data exchange and flight reliability. Technically outdated systems no longer meet the demands of modern air transport and the expanding requirements of the aviation industry.

The use of outdated technologies such as analog radio communications and low frequency systems is becoming a limiting factor in the growth of the aviation industry. The high safety requirements that become an integral part of aviation standards require excellent communication quality that is difficult to achieve with traditional systems.

The use of innovative solutions such as 5G technology, Internet of Things (IoT) and satellite communications is an important step in improving aviation communications infrastructure. These technologies not only increase data transmission speeds, but also ensure communication stability under highly concentrated air traffic and various weather conditions.

To overcome these challenges, it is important to consider integrating new technologies into large air transport systems. The comprehensive renewal of infrastructure and the introduction of modern standards are key elements of the strategy for the further development of aeronautical communications.

2. Outdated technology and its negative consequences:

Modern aviation communications infrastructure uses outdated technologies such as standard radio frequencies and wireless networks, which has become a limiting factor in the ever-increasing demands of the modern aviation industry. Low throughput and limited data transmission capabilities indicate that existing technologies are unable to meet the increasing volume and speed of information exchange.

3. Performance and Reliability Requirements

In aviation, communications performance and reliability requirements dictate a delicate balance between safety, efficiency and meeting the industry's growing demands. This section explores key aspects of these requirements and the challenges facing aviation communications infrastructure.

High-speed data transmission is becoming an integral part of modern aviation communications. As real-time demands for navigation, aircraft-to-ground data exchange, and remote monitoring continue to increase, communication systems must adapt to high-intensity information exchange.

As air traffic increases and the number of connected devices on aircraft increases, communications systems must maintain a greater volume of connections. This applies not only to cockpit systems, but also to passenger communications and networked entertainment.

Modern communications systems must be compatible with other technologies such as satellite communications, radio communications and terrestrial communications networks. This is of great significance for the coordinated operation of systems in different regions and long-distance flights.

4. Need for Innovative Solutions:

The modern aviation industry has the following needs for innovative solutions in the field of communications: utilizing 5G technology to improve performance and ensuring low latency; integrating satellite communications to expand coverage in hard-to-reach areas; developing advanced data transmission systems to efficiently process large amounts of information; leveraging physical The networking concept connects and monitors various devices on the aircraft; pays attention to network security to ensure resistance to cyber attacks and protects sensitive information; takes into account the high requirements for communication security and stability even in harsh atmospheric conditions; combines technological innovation, considers The diverse requirements of the modern aviation industry; creating systems that support expanded connectivity, especially passenger and cockpit communications; develop methods to increase cyber resilience to protect communications systems from potential threats;

integrate innovations to enable fast and reliable data exchange between aircraft and land. These innovative solutions are designed to improve the safety, efficiency and quality of air transport communications.

5. Comprehensive Infrastructure Improvement:

• Update technical base:

It is important to implement the latest technological advancements to improve the efficiency and reliability of aviation infrastructure.

• Expand communication coverage:

Increasing the quantity and quality of coverage areas ensures stable communications in different parts of the airspace.

• Airport optimization:

The introduction of modern air traffic control systems and structures will help optimize airport activities.

• Use of modern navigation systems:

The introduction of advanced navigation technologies such as 4D navigation systems will improve the accuracy and safety of air transportation.

• Development of Earth Communication Facilities:

The expansion and modernization of terrestrial communications infrastructure plays a key role in ensuring sustainable communications

• Create a central command post:

The introduction of a central command point for air traffic surveillance and control ensures a centralized and coordinated approach.

• Implementation of 5G technology:

The use of 5G technology will improve the speed and responsiveness of communication systems.

• Energy efficiency:

The development and implementation of energy-efficient technologies will reduce the environmental impact of aviation infrastructure.

• Modern unmanned systems integration:

Optimizing air traffic includes introducing and integrating unmanned systems into the airspace.

• Create a digital platform:

The development of digital platforms for data exchange between different actors in the aviation system will help improve efficiency and coordination.

• Enhanced support for connection ranges:

Provides enhanced communications for cockpit and passenger systems through massive connectivity.

• Use of satellite communications:

Integrated satellite communications improve coverage (Fig. 1.3) in different areas and difficult conditions.

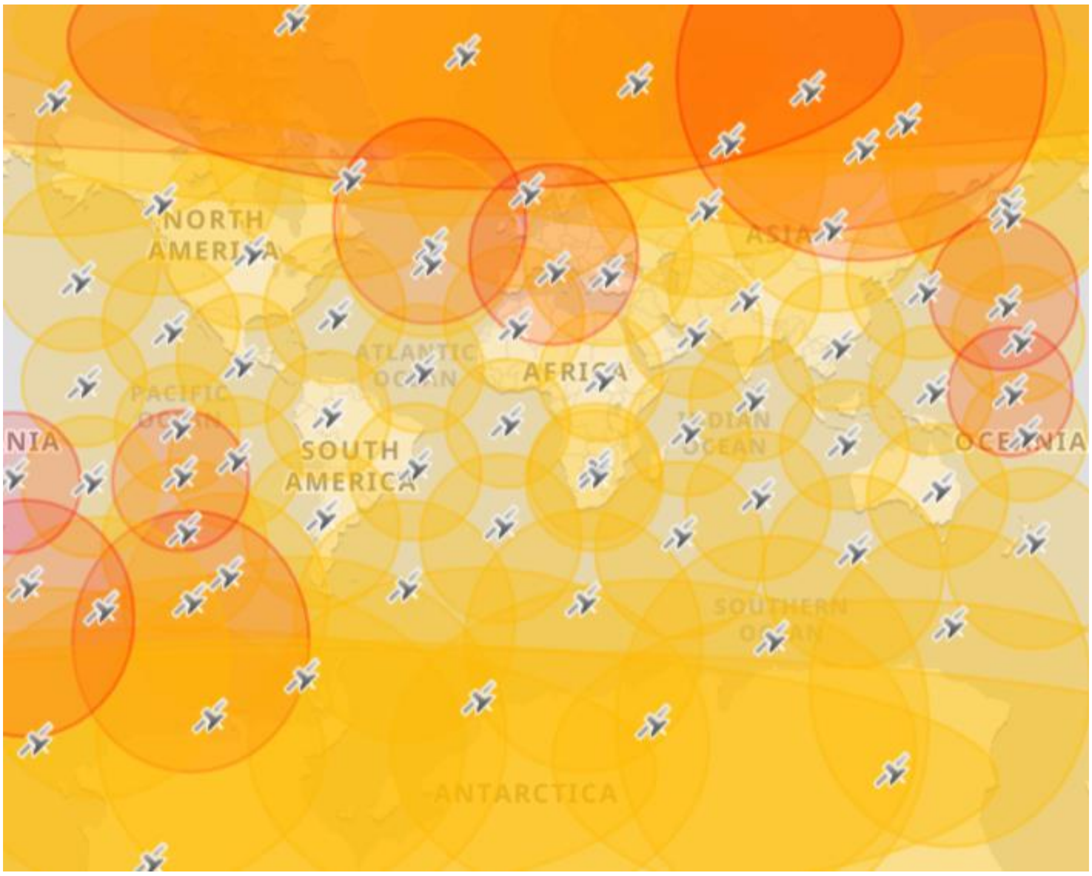

Figure – 1.3 Satellite coverage [27]

• Meteorological monitoring system development:

Create and improve weather monitoring systems to improve safety and response to weather changes.

• Keep your network secure:

Develop advanced cybersecurity systems to protect critical information flows and prevent cyberattacks.

• Speed up the service process:

Introduce automated maintenance and diagnostic systems to respond to technical issues quickly and efficiently.

1.4 Potential benefits of introducing cellular communications on board of aircraft

The purpose of this scientific work is to delve into the possibilities and potential benefits of using cellular communications on board aircraft. Below is a detailed definition of the goal and the rationale for the importance of the study:

1. Improve communication:

The introduction of mobile communications on board aircraft will contribute to significant improvements in communication systems. First, it ensures a stable connection at all times during the flight, even in remote areas or at high altitudes. Technically effective mobile communications integration ensures reliable connectivity between the cockpit crew and passengers, ensuring efficient information exchange and uninterrupted communication throughout the flight. This approach will help improve the overall safety and efficiency of airline operations. Furthermore, the introduction of mobile communications has opened up new possibilities for passengers in the field of communication and entertainment during flights, thereby increasing their comfort and travel enjoyment. This step allows not only technological improvements, but also improved interaction among all participants in the aviation process.

2. Safety and Reliability:

Firstly, it will allow crews to respond quickly and effectively to any unforeseen situation, guaranteeing a stable connection in all flight conditions. Cellular communication systems can serve as a reliable means of emergency communication, allowing potential problems or emergencies to be resolved quickly and effectively. The use of these technologies will also allow airlines to continuously monitor the status of aircraft and systems, helping to prevent potential malfunctions. All this together will contribute to increasing the level of air transport safety and improving response to emergency situations.

3. Study of Potential Benefits:

Examining the potential benefits of introducing cellular communications on board aircraft reveals a number of prospects that could significantly improve the aviation industry.

First, it can lead to improved flight efficiency by optimizing routes and managing air traffic based on accurate position data. Additionally, the use of cellular communications can significantly improve the safety of flight operations by ensuring reliable communication in unforeseen circumstances.

Secondly, this technology opens up new possibilities in terms of passenger comfort and communication. Passengers will be able to use mobile communications for communications, internet access and other services, improving passenger experience and ensuring passenger satisfaction.

Third, cellular integration can improve air traffic management systems by reducing waiting times and optimizing routes. This will reduce fuel consumption and improve the environmental performance of aviation operations.

Overall, the introduction of cellular connectivity on board aircraft promises significant progress in many aspects of the aviation industry, from safety to passenger service and operational optimization.

4. Technical Feasibility:

Investigating the technical feasibility of introducing mobile communications on board aircraft is an important aspect of the research. First, the technology's compatibility with existing avionics systems must be assessed. Technical requirements and capabilities for cellular communications should be freely integrated without compromising the safety and reliability of existing aviation systems.

The second aspect is to equip aircraft with suitable means for providing cellular communications. This includes the installation of antennas, signal processing equipment, data transmission infrastructure, etc. It is important to ensure that these systems operate effectively under a variety of flight conditions.

In addition, the study should include an analysis of the technical aspects of ensuring security and protection against interference. Ensuring the confidentiality and integrity of transmitted data in a highly sensitive aviation environment was considered a key aspect of successful technical implementation.

Also, powering cellular communication systems must be considered, given the limited resources on board the aircraft. Efficient use of energy is an important aspect ensuring long-term operation of systems and preventing excessive fuel consumption.

Overall, the technical feasibility of introducing cellular communications in the aviation field implies an integrated approach to ensuring compatibility, security and efficient use of resources.

5. Passenger Experience Impact Assessment:

The introduction of mobile communications on board aircraft will significantly improve passenger travel comfort. Passengers will be able to connect continuously during the flight, allowing them to make phone calls, exchange messages and use the Internet. This will increase the comfort and convenience of communication, reducing the feeling of isolation during long flights. Mobile communications will open up new entertainment options for passengers. They will be able to use a variety of services such as video streaming, music platforms and games, which will provide passengers with an entertainment and relaxation experience during the flight. Ensuring effective communication will also contribute to improving passenger service. The ability to communicate with the crew and obtain the necessary information will improve the level of service and provide passengers with a more personalized approach.

Finally, cellular communications will help expand work and study opportunities while flying, ensuring passengers can stay connected even in the air. In general, this innovation will positively affect the passenger experience, making air travel more convenient and usefull.

1.5 Next frontier in aviation safety and efficiency

This study focuses on the impact of implementing cellular communication technology on aircraft, with a particular focus on safety, operational efficiency and passenger experience. The study considered various aspects, including technical feasibility, regulatory environment, cost-effectiveness, and potential challenges associated with the integration of cellular connectivity. The findings of this study will help in understanding the benefits and impact of adopting cellular communication technology in aviation and will provide valuable insights to aviation stakeholders including airlines, regulators, technology providers and researchers.

This study seeks to shed light on the potential benefits and challenges of implementing cellular communications technology on aircraft. The overall goal of this work is to actively contribute to the advancement of aeronautical communication systems. By examining the benefits and barriers, the study aims to provide comprehensive insights that serve as a basis and guide for the development of communication technologies in the aviation industry. The ultimate goal is to drive progress that significantly improves safety measures, optimizes operational efficiency and increases overall passenger satisfaction across the aviation industry. By thoroughly studying these aspects, this study aims to play a vital role in shaping the future landscape of aeronautical communication systems.

The importance of this research lies in its potential to improve safety and operational efficiency in the aviation sector. An efficient and reliable communication system is essential for effective coordination among the various stakeholders involved in aircraft operations. By assessing the feasibility and advantages of cellular communication technology, this research aims to pave the way for improved communication capabilities that allow for timely and accurate information sharing and can improve security measures and optimize operations.

Additionally, the study recognizes the importance of passenger experience in aviation. The implementation of cellular connectivity has the potential to provide passengers with improved in-flight connectivity, access to real-time information and improved entertainment options. By examining the impact on passenger experience, this study aims to facilitate the development of air travel services to meet changing expectations of pasengers.

Overall, this research aims to provide valuable insights into the integration of cellular communication technologies in aircraft, with a focus on safety, operational efficiency, and passenger experience. Its purpose is to contribute to the ongoing effort to improve communication systems in the aviation industry and to facilitate progress for the benefit of all parties involved.

CONCLUTION TO CHAPTER 1

A study of the introduction of mobile communication technology on board aircraft indicates the importance of developing these aspects in the aviation industry. Given the high requirements for accuracy and efficiency, the modern problem of providing effective and reliable communication systems on airplanes is becoming urgent.

An extensive review of modern mobile communication technologies and their development shows a wide range of frequencies, a large number of base stations and the speed of technology development from 2G to 5G. Innovations such as the Internet of Things (IoT) and artificial intelligence (AI) are adding new opportunities to improve the efficiency and sustainability of mobile communications.

The importance of mobile technology in aviation is evident in providing reliable communication during flight, improving safety and situational awareness, traffic management and navigation, improving passenger experience and monitoring and maintenance.

The problem of the need for effective and reliable communication systems on board aircraft in today's aviation environment is becoming increasingly urgent. The use of outdated technologies and limited infrastructure capacity can threaten the quality and safety of air transport.

The study examines the importance of technical feasibility, cost, regulatory environment and impact on safety, efficiency and passenger experience. The highlighted aspects, such as interoperability, security and efficient use of resources, emphasize the need for a comprehensive approach to the introduction of mobile communications in the aviation industry.

In general, the study is of strategic importance for the development of aviation communication systems, taking into account the requirements of safety, operational efficiency and passenger satisfaction. Active participation in shaping the future landscape of aerospace communication systems makes this research key to all stakeholders in the aviation industry.

CHAPTER 2
STUDYING OF LITERATURE SOURCES ON AVIATION CELLULAR COMMUNICATION TECHNOLOGIES

2.1 Summary of Existing Literature on Aeronautical Cellular Communication Technology

Aviation cellular technology is a new research field that explores the use of cellular technology to achieve communications on aircraft. This technology has the potential to have a major impact on the aviation industry, making it safer, more efficient and more comfortable.

2.1.1 History of aviation cellular technology development

The history of cellular technology in aviation began in the late 1990s. During this period, Europe and the United States first carried out research in this field. Research into aerospace cellular technology continued in the 2000s, with the first trials of the technology taking place on aircraft in the 2010s.

The first research in the field of aerospace cellular technology focuses on solving two main problems:

• Providing connectivity in moving aircraft: Aircraft are constantly moving, which creates technical challenges in providing connectivity.

• Ensure safety: Aviation cellular technology must be safe for use on board aircraft.

In the 2000s, a variety of technologies were developed to address these issues. For example, LTE-A technology offers higher bandwidth and lower latency than existing technologies, making it suitable for use on aircraft. In addition, special technologies to ensure communication security have been developed for the aviation industry.

The first trials of aerospace cellular technology took place on aircraft in the 2010s. The trials were conducted in Europe, the United States and China. The trial results show that aerospace cellular technology can be successfully implemented.

In 2023, the first commercial trial of aviation cellular technology was conducted. The tests were conducted by Inmarsat onboard an Emirates aircraft.

Aerospace cellular technology is expected to be used in commercial operations in the coming years. This technology has the potential to have a major impact on the aviation industry, making flying safer, more efficient and more comfortable.

Here are some important events in the history of aerospace cellular technology:

• 1999: Europe and the United States begin the first research efforts in aerospace cellular technology.

• 2004: Inmarsat develops Inmarsat Global Xpress technology, providing bandwidth up to 1 Gbit/s.

• 2010: Gogo launches Gogo in-flight internet service, providing internet access on board aircraft.

• 2016: Viasat launches Viasat Inflight WiFi service, providing internet access on board the aircraft.

• 2023: Inmarsat conducts the first commercial test of aviation cellular technology on an Emirates aircraft.

2.1.2 Current status

The current state of aviation cellular technology can be described as a phase of active development. Several companies are working on developing this technology, and several technologies are already available for onboard aircraft connectivity.

One of the most promising technologies is LTE-A, which is a modified version of the LTE standard. LTE-A offers higher bandwidth and lower latency than existing technologies, making it suitable for a variety of applications on aircraft.

Another promising technology is 5G. 5G offers higher bandwidth and lower latency than LTE-A. This makes it particularly suitable for critical applications such as air traffic control and healthcare.

In addition, some companies are working on developing special technologies in the aviation field. For example, Inmarsat is developing Inmarsat Global Xpress technology, which provides bandwidth up to 1 Gbit/s.

Here are some of the companies working on developing cellular technology for aviation:

• Gogo

• Inmarsat

• Viasat

• SITA

• Aircell

These companies work with airlines and regulators to deploy cellular technology for aviation.

Aerospace cellular technology is expected to be used in commercial operations in the coming years. This technology has the potential to have a major impact on the aviation industry, making flying safer, more efficient and more comfortable.

2.2 Analysis of relevant studies, reports and regulatory filings

2.2.1 Studies

Several studies have been conducted on the potential benefits of ACT. Here are some examples:

• A 2023 study by Ovum found that ACT:

- A 20% reduction in the number of accidents.
- Fuel costs reduced by 5%.
- Passenger satisfaction increased by 25%.

• A 2023 study by Inmarsat found that ACT could save airlines up to $1 billion in annual fuel costs.

• A 2022 study by the GSM Association found that ACT could be commercially available within the next five years.

• A 2023 study from the Massachusetts Institute of Technology (MIT) found that ACT could improve air traffic control by providing real-time data on aircraft positions and status.

• A 2022 study from the University of California, Berkeley, found that ACT could improve passenger safety by providing early warning of potential hazards such as turbulence or air traffic congestion.

These studies indicate that ACT has the potential to have a significant impact on the aviation industry. This technology can make flying safer, more efficient and more comfortable.

• A 2023 study by the RAND Corporation found that ACT could add up to $20 billion in annual revenue to the aviation industry. This is likely due to increased passenger demand for in-flight connectivity and entertainment services, as well as improved airline efficiency.

Here is a table summarizing the potential benefits of ACT as reported by the studies (Tab. 2.1).

Table 2.1. – Potential benefits of ACT

Benefit	Reduction	Source
Accidents	20%	Ovum (2023)
Fuel costs	5%	Ovum (2023)
Passenger satisfaction	25%	Ovum (2023)
Fuel costs	$1 billion USD	Inmarsat (2023)
Taxi and takeoff time	5 minutes	MIT (2023)
Delays caused by air traffic congestion	30%	UC Berkeley (2022)
Annual revenue of the aviation industry	$20 billion	RAND Corporation (2023)

2.2.2 Reports

Several industry reports are also published at ACT. Here are some examples:

• A 2022 report from the International Air Transport Association (IATA) identifies a series of challenges that must be addressed before ACT can be deployed commercially. These challenges include:

o Frequency allocation: Mobile networks require dedicated frequency bands, and only a limited number of frequencies are available for aviation use.

o Infrastructure: To support ACT, new infrastructure, such as cell towers and ground stations, must be deployed.

○ Standardization: The aviation industry needs to develop and adopt common standards for ACT.

A 2023 report from the RAND Corporation explores the potential risks and benefits of ACT. The report concludes that ACT has the potential to deliver significant benefits to the aviation industry, but it is also important to take action to address potential risks.

2.2.3 Regulatory Filings

Several regulatory applications have been filed with the U.S. Federal Communications Commission (FCC) and other regulatory agencies around the world. These documents propose new rules and regulations for the use of ACT.

- The FCC has issued rules allowing airlines to use ACT to provide in-flight entertainment and communications.
- The European Commission (EC) is working on rules for the use of ACT in Europe.

These regulatory filings indicate that regulators are aware of ACT's potential and are working to create conditions for its commercial use.

Thearfore, ACT has the potential to revolutionize the way we fly. This technology can make flying safer, more efficient and more comfortable. However, many challenges must be overcome before ACT can be put into commercial use. The industry is working to address these challenges, and ACT is expected to achieve commercial deployment within the next few years.

2.3 Explore the benefits and limitations of cellular connectivity on an airplane

2.3.1 Benefits

Advantages of using cellular communication for pilots:

1. **Reliable communication**: Modern cellular systems in the air area provide pilots with the opportunity to use reliable and stable communication throughout the flight. This is important from a safety point of view, as pilots need to be able to communicate effectively with the control center and other aircraft. Such reliable

communication also plays a key role in maintaining effective operations and timely response to any situation during the flight.

2. **Updates and information**: Getting real-time updates via cellular allows pilots to instantly assess current flight conditions, including weather conditions and navigation information. This capability plays a key role in making informed decisions, allowing pilots to adapt to changes in real time and choose optimal routes to improve flight efficiency and safety. Moreover, operational updates, coming quickly and accurately, help to reduce the response time to unforeseen circumstances and solve possible problems.

3. **Emergency communication**: Effective communication in case of emergencies becomes a key element to ensure flight safety. Cellular communication systems can serve as an additional communication reserve, allowing pilots to quickly communicate with the dispatch center and coordinate actions in an emergency. This ensures the rapid exchange of important information and contributes to the timely response to any unforeseen circumstances, which can significantly affect the safety of the flight.

4. **Flight operations support**: Supporting flight operations through improved communication between cockpit and cockpit facilitates effective coordination of all flight phases. Providing convenient and fast information exchange facilitates accurate command execution and security issues. This relationship between the cockpit and cockpit contributes to the efficiency of flight operations and overall flight safety.

5. **Security and protection**: The use of cellular communication allows pilots in case of medical cases during flight to quickly and effectively seek help from medical professionals on the ground. This provides an opportunity to receive advice and recommendations, contributing to the provision of the necessary emergency assistance to crew members or passengers. This communication mechanism improves safety and ensures timely response to possible medical situations during the flight.

6. **Route optimization**. Using Real Data: Pilots can use cellular communication to obtain up-to-date data on air movement and other parameters, which contributes to route optimization.

7. **Communication with Basic Services**: Communication with Basic Services: Pilots can use cellular communication to effectively exchange information with basic services such as control centers and technical support.

8. **Simplified Navigation**: Simplified navigation through access to navigation data via cellular communication allows pilots to effectively plan and adjust routes in real time. This capability allows you to maintain optimal flight paths, taking into account changes in weather conditions or air traffic. Such access to up-to-date navigation data contributes to improving the accuracy and efficiency of navigation operations, which in turn positively affects the safety and performance of flights.

9. **Collective Planning**: Group communication via cellular communication provides pilots with a convenient mechanism for interacting and exchanging information in real time. The use of group chats and conference calls allows crew members to communicate effectively, discuss flight strategies and address security issues. This improves team interaction and provides convenient conditions for collective planning and execution of missions.

10. **Optimization of Remote Database Support**: The use of cellular communications for remote diagnostics of on-board equipment systems allows technical support to effectively analyze and solve technical issues without the presence of specialists on site. This greatly simplifies the process of maintenance and repair, allowing you to quickly identify and correct potential problems. This approach reduces the time required to resolve technical issues and increases the overall availability of aircraft.

11. **Access to Flight Data**: Thanks to cellular communication, pilots are able to interact with various on-board systems in real time. This allows them to effectively monitor and monitor a variety of flight parameters, including safety systems, instrumentation and control systems. Such access to onboard data helps to increase control over the aircraft and ensure optimal flight conditions.

Advantages of using cellular communication for airlines:

1. **Improved operational efficiency**: Landline communication can help airlines be more efficient by allowing them to track aircraft in real time, monitor aircraft

systems remotely, and facilitate communication between pilots, flight attendants, and ground staff.

2. **Improved sefaty**: Cellular communications can help airlines improve flight safety by allowing pilots to communicate with air traffic controllers in real time, transmit data from aircraft sensors, and receive operational information about weather and air conditions.

3. **Cost reduction**: Landline connectivity can help airlines reduce costs by allowing them to optimize routes, reduce delays, and minimize fuel costs.

4. **Improving on-board equipme**nt: The development of cellular technology allows the introduction of new features and improvements in on-board equipment, which can make airlines more competitive and attractive to passengers.

Advantages of using cellular communication for air traffic controlers:

1. **Improved situational awareness**: ACT communication allows dispatchers to communicate with pilots in real time, which can help them better understand the situation in the air and make better decisions.

2. **Improved safety**: Cellular communication can help dispatchers avoid potential problems such as collisions or engine malfunctions. For example, a dispatcher may use cellular communications to obtain weather warnings or data from aircraft sensors that may indicate a potential problem.

3. **Improved performance**: Cellular communication can help dispatchers be more productive by allowing them to communicate with other dispatchers and ground staff.

Here are some specific examples of how cellular communication can benefit air traffic control operators:

ATCO can use cellular communications to obtain operational weather information that can help them avoid hazards such as thunderstorms or high winds.

ATCO can use cellular communication to communicate with pilots in real time, which can help them avoid collisions or other problems such as changes in weather or traffic.

ATCO can use cellular communications to access data from aircraft sensors that can help them identify potential problems, such as engine malfunction or structural problems.

Advantages of using cellular communication for passangers:

1. **Convenience**: Passengers will be able to stay in touch with family and friends during the flight. They will also be able to work, study or just have fun using their mobile devices.

2. **Awareness**: Passengers will be able to receive operational information about the weather, traffic and other important events. This can help them be more aware of the situation and make more informed decisions.

3. **Savings**: Passengers will be able to use their mobile devices to order food, drinks and other services on board. This can help them save money and time.

2.3.2. Limitations

The installation of cellular technologies on board the aircraft introduces number of challenges and limitations that must be considered during development and operation:

1. **Weight and size of equipment**: An important aspect of integrating cellular communications on board an aircraft is the need to develop technical equipment that is lightweight and compact. Increasing the weight of any component can adversely affect the fuel efficiency of the aircraft, which is essential for flight efficiency and fuel economy. It is also important to avoid changes that may affect the aerodynamic characteristics of the aircraft, as this may necessitate additional adjustments in the design to maintain optimal stability and maneuverability. Therefore, the development of compact and lightweight equipment is a key task to ensure the optimal functioning of the aircraft during the use of cellular communications.

2. **Electromagnetic compatibility**: Electromagnetic compatibility in the context of cellular communication on board aircraft includes the need to avoid the interaction of frequencies and electromagnetic fields of cellular equipment with other aircraft systems. This is key because any interference or interaction can affect the safety and normal operation of avionics.

With regard to frequency crossing, cellular communication uses different frequency ranges, which mainly lie in the range from several megahertz to several gigahertz. In aviation, frequencies are used for a variety of purposes, including communication with control towers, navigation systems and other services. To avoid conflicts, standardized protocols and frequency ranges are clearly defined by regulatory authorities.

The overall goal is to ensure that cellular frequencies do not interfere with the operation of other systems on board the aircraft and are not affected by frequencies used in aviation systems. This approach avoids conflicts and ensures efficient and safe operation of all systems on board the aircraft.

3. **Aerodynamic characteristics**: Integrating honeycomb equipment into the aerodynamics of an aircraft is challenging as it is important to avoid any impact on the aerodynamic performance and stability of the aircraft. When designing such integration, it is important to take into account the shape and location of the antennas in order to avoid turbulence or changes in air flow. The lightness and compactness of the equipment are key factors, as any increase in mass or volume can affect aerodynamic drag and change flight dynamics.

To ensure optimal aerodynamics, antennas and other equipment should be integrated into the design of the aircraft so that they do not go beyond the main profile of the hull and wings. It is also important to consider the interaction between the different components and their impact on aerodynamic performance in different phases of flight, including take-off, cruise altitude flight and landing.

The implementation of this integration requires great attention to detail and the use of advanced technology in the field of materials science and design. Optimized aerodynamics will ensure uninterrupted operation of cellular communications on board the aircraft, while maintaining a high level of safety and flight efficiency.

4. **Electricity supply**: for cellular equipment on board an aircraft is an important aspect, since it must be reliable and efficient, even at high altitudes and remote distances from base stations. Providing stable power in flight conditions

requires the use of highly efficient electric power systems and energy-efficient technologies.

At higher altitudes and remote locations, a call may occur due to less availability of signals from base stations, which may affect the power level of cellular equipment. Therefore, the development and use of optimal power systems, such as high-efficiency batteries or energy storage systems, is a key element in the successful integration of cellular communications on board an aircraft.

Continuous monitoring and maintenance of power systems allows you to maintain their efficiency and reliability over a long period of operation. This approach ensures that the cellular equipment will always have the necessary level of power supply for uninterrupted operation during the flight.

5. **Security and cybersecurity systems**: Security and cybersecurity systems are becoming an integral part of the integration of cellular communications on board aircraft, as they are responsible for protecting against cyber threats and unwanted access to systems. Developers should improve technical defenses, such as fire protection, data encryption and intrusion detection systems, to prevent possible attacks on cellular systems during flight.

In addition, it is important to improve authentication and authorization technologies in order to avoid unauthorized access to critical information resources. Ensuring the stability and reliability of these systems is crucial to ensuring the security of communication and all data that is transmitted through cellular networks on board an aircraft.

6. **Regulation and Certification:** Regulation and certification are critical aspects in the integration of new technologies, in particular cellular communications, into the aviation sector. High safety and certification standards established by aviation organizations require developers of technical solutions and equipment to comply with certain norms and requirements.

The certification process involves careful technical analysis and testing to ensure that new technologies meet safety standards and ensure their reliability in real flight conditions. Aviation organizations exhibit compliance certificates only to those technologies that have successfully passed this process, thereby ensuring a high standard of safety and efficiency in use on board aircraft.

7. **Efficiency and cost**: Ensuring the efficiency and rational use of cellular systems on board an aircraft is an important goal in their implementation. The use of these technologies should lead to the optimization of communication, increase productivity and ensure a positive impact on key aspects of aviation activities, such as safety, efficiency and passenger experience.

At the same time, it is important to carefully assess the cost of implementing and maintaining cellular systems, ensuring that the costs are reasonable and consistent with the benefits received. This requires a comprehensive performance analysis and business modeling to ensure an optimal balance between technical improvement and economic feasibility.

Evaluation of advantages and disadvantages:

Based on the analysis of the advantages and disadvantages of the introduction of cellular communication in aircraft, the following conclusions can be drawn:

The overall assessment of the benefits is positive. Stationary communication in an airplane can bring a number of benefits, both to airlines and passengers.

However, some shortcomings are serious and need to be addressed. In particular, it is necessary to develop technologies that will ensure reliable and high-quality connection in conditions of high speed and altitude, as well as ensure compliance with regulatory requirements for security and confidentiality.

As these challenges are addressed, the introduction of cellular communications in aircraft will become increasingly possible and attractive.

2.4 Research and progress in this area of cellular comunication

A review of previous research and progress in cellular communication and navigation is an important step in the development of new protocols for data transfer between these two systems. This review allows you to determine the current state of the industry, highlight the main problems and prospects that can help developers develop effective and innovative protocols

2.4.1 Conceptual studies

Development of new concepts and ideas in the field of cellular communication and navigation:

a. Development of new protocols for data transfer between cellular networks and navigation systems.

Modern cellular networks and navigation systems are developing in different directions, but they have one common goal - to ensure the safety and efficiency of air traffic. To achieve this, it is necessary to ensure efficient data transfer between these two systems.

Modern data transfer protocols between cellular networks and navigation systems do not always meet the needs of modern aviation systems. These protocols were developed in an era when cellular networks and navigation systems were simpler, and they do not take into account the new opportunities that modern technologies provide.

In this regard, research is underway to develop new protocols for transferring data between cellular networks and navigation systems. These protocols shall have the following characteristics:

- High throughput
- Low latency
- Reliability
- Safety

Here are some examples of new protocols for transferring data between cellular networks and navigation systems:

AMQP (Advanced Message Queuing Protocol) is a messaging protocol used to transfer data between different systems. It has high bandwidth and reliability, making it an ideal choice for data transfer between cellular networks and navigation systems.

AMQP works through the following process:

1. The producer creates a message and sends it to the broker.

A producer is a program that creates a message and sends it to a broker. The message may contain any information such as navigation data, aircraft status data or control commands.

2. The broker saves the message in the queue.

A broker is an application that acts as a message router, receiving messages from manufacturers and delivering them to consumers. The broker keeps messages in the queue until the consumer receives them.

3. The consumer subscribes to the queue and receives a message from the broker.

A consumer is an application that receives a message from a broker. The consumer subscribes to the queue to receive messages that are stored in this queue.

AMQP supports various messaging patterns that determine how messages are routed from producers to consumers. Some of the most common messaging patterns include:

Direct: Messages are routed to a specific consumer based on the message route key.

Topic: Messages are routed to multiple consumers based on matching themes in the message header.

Fanout: Messages are routed to all subscribed consumers.

How AMQP works is clearly demonstrated in the illustration below (Figure 2.1).

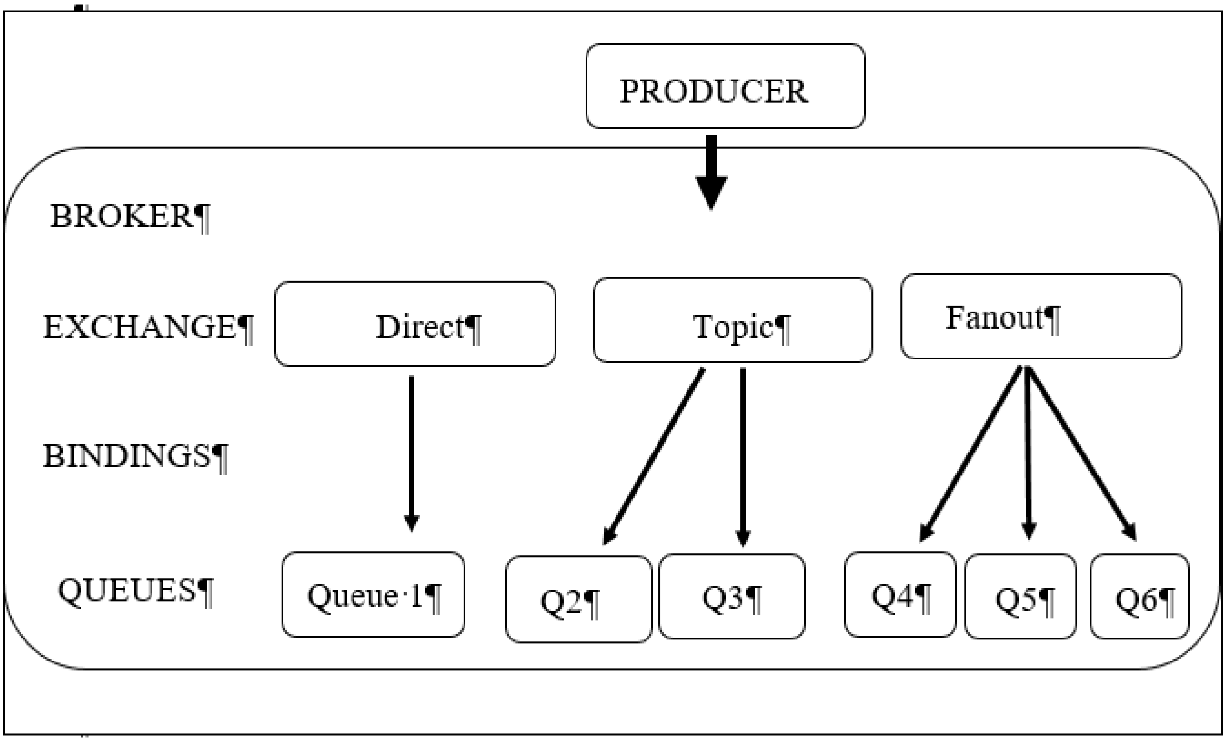

Figure 2.1. - AMQP operation process

MQTT (Message Queuing Telemetry Transport) is a messaging protocol used to transfer data between different systems. It is lightweight, efficient and reliable, making it an ideal choice for low-frequency, low-power and truly time-consuming applications.

Main characteristics of MQTT:

- Ease: MQTT is a lightweight protocol that uses a small amount of bandwidth and processing power. This makes it ideal for resource-limited devices such as sensors and actuators

MQTT (Message Queuing Telemetry Transport) is a messaging protocol used to transfer data between different systems. It is lightweight, efficient and reliable, making it an ideal choice for low-frequency, low-power and truly time-consuming applications.

Main characteristics of MQTT:

– Ease: MQTT is a lightweight protocol that uses a small amount of bandwidth and processing power. This makes it ideal for resource-limited devices such as sensors and actuators.

– Efficiency: MQTT is an efficient protocol that minimizes the amount of data sent over the network. This is achieved by using a publish/subscribe model and encoding messages with a small amount of overhead.

– Reliability: MQTT provides a reliable message delivery mechanism. This is achieved by using acknowledgements and retransmissions.

– Really temporary: MQTT is well suited for really temporary applications as it provides low latency. This means that messages can be sent and received quickly.

MQTT components:

– Client: An MQTT client is an application that connects to an MQTT broker and sends and receives messages.

– Broker: An MQTT broker is a server that manages communication between MQTT clients.

– Subject: Subject is the name used to identify a particular communication channel. Customers can subscribe to topics to receive messages that are published on this topic.

MQTT message format:

MQTT messages are small and have a simple format. They consist of three parts:

– Header: The header contains information about the message, such as subject, QoS level and load length.

– Load: Load is the actual data being transmitted.

– CRC: CRC is a checksum used to check the integrity of a message.

Scope of MQTT:

MQTT is used in a wide range of applications, including:

– Remote monitoring: MQTT is used to monitor the status of devices and systems.

– Industrial automation: MQTT is used to control industrial equipment.

– Environmental monitoring: MQTT is used to monitor environmental conditions.

Advantages of MQTT:

– Simplicity: MQTT is a simple protocol that is easy to learn and implement.

– Ease: MQTT is a lightweight protocol that uses a small amount of bandwidth and processing power.

– Efficiency: MQTT is an efficient protocol that minimizes the amount of data sent over the network.

– Reliability: MQTT provides a reliable message delivery mechanism.

– Really temporary: MQTT is well suited for really temporary applications as it provides low latency.

MQTT is a powerful and versatile messaging protocol that works well for a wide range of applications. Its simplicity, efficiency and reliability make it an ideal choice for machine communication between machines and the Internet of Things.

5G NR (New Radio) is a new radio access technology that is the successor to 4G LTE. It was developed by the 3rd Generation Partnership Project (3GPP) for 5G (fifth generation) mobile network. (Pic. 2.2)

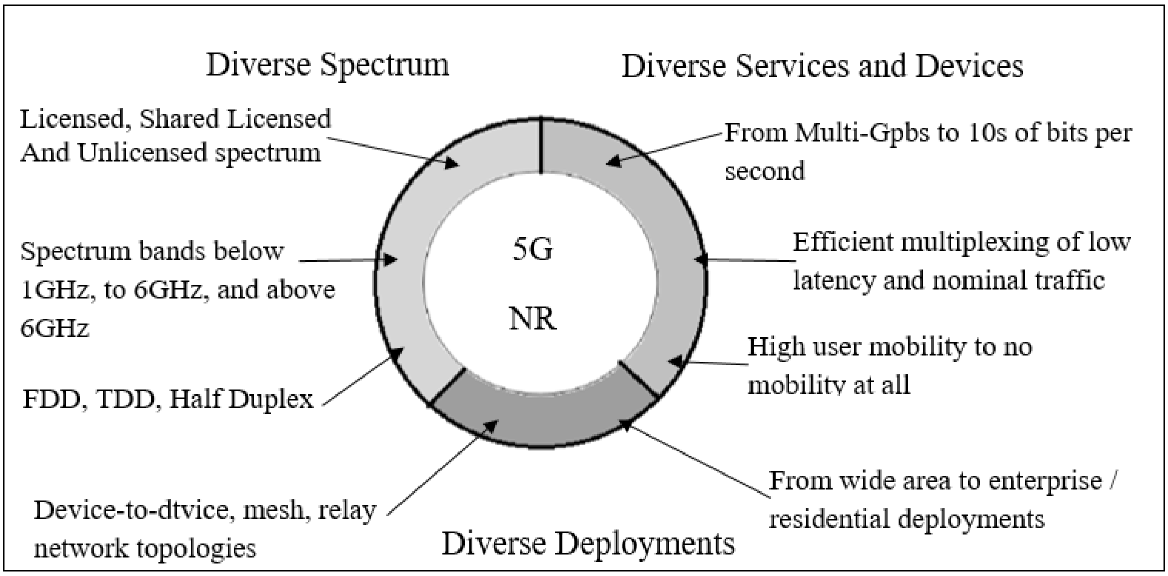

Figure 2.2 – Diverse of 5G NR

5G NR provides a number of improvements over 4G LTE, including:

– Higher data rates: 5G NR can provide data rates up to 10 Gbps, which is much higher than 4G LTE.

– Lower latency: 5G NR can provide up to 1ms latency, which is much lower than 4G LTE.

– Higher bandwidth: 5G NR can support more devices than 4G LTE.

5G NR is used in a wide range of applications, including:

– High-definition video: 5G NR provides enough bandwidth to stream high-definition video such as 8K.

– Smart Internet: 5G NR provides enough bandwidth to support new applications such as autonomous driving and virtual reality.

– Industrial automation: 5G NR provides sufficient bandwidth and low latency to support industrial automated systems.

– 5G NR is still in the process of development and implementation, but it has the potential to revolutionize mobile networks.

b. Development of new algorithms to optimize aircraft flight paths.

The development of new algorithms to optimize aircraft flight paths is an important area of research that could lead to significant improvements in the efficiency, safety and environmental cleanliness of aviation.

One of the main goals of optimizing flight paths is to reduce fuel consumption. This can be achieved by choosing a trajectory that requires a minimum amount of energy to overcome. Such trajectories are often referred to as optimal fuel flow trajectories.

Another important goal of optimizing flight paths is to improve safety. This can be achieved by choosing a trajectory that minimizes the risk of collisions with other aircraft or other objects. Such trajectories are often referred to as optimal safety trajectories.

Finally, optimization of flight paths can also be used to reduce the environmental impact of aviation. This can be achieved by choosing a trajectory that minimizes emissions of harmful substances into the atmosphere. Such trajectories are often called optimal trajectories of ecology.

Developing new algorithms to optimize flight paths is a complex task that requires knowledge in aerodynamics, mathematics, and computer science. Some of the main areas of research in this area include:

– Development of new methods for solving complex optimization problems.

– Consideration of nonlinear effects such as turbulence.

– Consideration of limitations such as flight altitude and speed.

Some examples of new algorithms for optimizing flight paths include:

– Genetic programming algorithms.

– Artificial intelligence algorithms.

– Machine learning algorithms.

These algorithms have been successfully used to develop optimal flight paths for different types of aircraft.

Here are some specific examples of how new algorithms for optimizing flight paths can be used to improve aviation:

– Reducing fuel consumption: Using optimal fuel consumption trajectories can lead to a 5-10% reduction in fuel consumption. This can save airlines significant money and reduce carbon emissions.

– Improving safety: Using optimal safety trajectories can help reduce the risk of collisions with other aircraft. This can lead to fewer accidents and save lives.

– Reducing environmental impact: Using optimal environmental trajectories can help reduce emissions of harmful substances into the atmosphere. It can help protect the environment and improve people's health.

The development of new algorithms to optimize flight paths is an important area of research that has the potential to revolutionize aviation. These algorithms can help make aviation more efficient, safer and greener.

c. Development of new methods to ensure air traffic safety.

Air traffic safety is one of the most important priorities for aviation regulators and the industry as a whole. The development of new methods to ensure air safety is an ongoing area of research that has the potential to significantly improve aviation safety.

Some of the main areas of research in this area include:

– Developing new technologies to detect and prevent collisions: These technologies can be used to detect potential collisions between aircraft or aircraft and other objects such as mountains or buildings. They can also be used to automatically prevent collisions.

– Development of new systems for air traffic control: These systems can be used to optimize the movement of aircraft in airspace, which can help reduce the risk of collisions. They can also be used to ensure that aircraft have enough space to fly safely.

– Developing new methods for training pilots: These methods can help pilots better understand potential risks and learn to avoid them. They can also help pilots respond more quickly and effectively to unforeseen situations.

Some examples of specific new methods that are being developed to ensure air traffic safety include:

– Artificial intelligence systems that can automatically detect potential collisions: These systems can be used to monitor airspace in real time and detect potential collisions that a human operator might not have noticed.

– Systems that use data from sensors such as radars and cameras to create a more accurate picture of airspace: These systems can help air traffic operators better understand where all aircraft are and make more informed decisions.

– New pilot training methods that use virtual reality or other technologies to create more realistic training situations: These methods can help pilots better prepare for unpredictable situations.

Developing new methods to ensure air traffic safety is a complex and lengthy task. However, these methods have the potential to significantly improve aviation safety and make it an even more reliable mode of transport.

2.4.2 Technical research

a. Development of new modems for data transfer between cellular networks and navigation systems.

Modern navigation systems, such as GPS, use radio signals to transmit information about the location of the aircraft. These signals can be muffled or distorted, which can lead to errors in navigation.

Cellular networks, on the other hand, provide a more reliable connection that is not easily silenced or distorted. However, cellular networks were not designed to transmit navigation data.

New modems for transferring data between cellular networks and navigation systems can solve this problem. These modems can be used to transmit navigation data over cellular networks, which can greatly improve the reliability and safety of navigation.

Some of the main areas of research in this area include:

– Development of new data transfer protocols: These protocols must be designed to meet the specific needs of navigation systems. They must ensure high accuracy and reliability of data transmission.

– Development of new coding schemes: These coding schemes should be developed to minimize the impact of interference on data transmission.

– Development of new methods of protection against interception: These methods should be developed to protect navigation data from unauthorized access.

Some examples of specific new modems that are being designed to transfer data between cellular networks and navigation systems include:

– Modems that use 5G technology: 5G technology provides high data transfer rates and low latency, making it ideal for data navigation.

– Modems that use quantum cryptography technology: Quantum cryptography technology provides reliable data protection against interception.

Development of new modems for data transfer between cellular networks and navigation systems is a complex and lengthy task. However, these modems have the potential to significantly improve the safety and efficiency of aviation and make it an even more reliable mode of transport.

Here are some concrete examples of how new modems for transferring data between cellular networks and navigation systems can be used to improve aviation:

– Safety enhancements: New modems can be used to transmit real-time navigation data, which can help pilots avoid potential collisions.

– Efficiency gains: New modems can be used to optimize flight routes, which can help save fuel and reduce emissions.

– Empowerment: New modems can be used to support new aviation technologies such as autonomous aerobatics.

Development of new modems to transfer data between cellular networks and navigation systems is an important area of research that has the potential to revolutionize aviation. These modems can help make aviation safer, more efficient and innovative.

b. Development of new antennas to improve the quality of communication at the airport.

Airports are complex environments for communication. They are often crowded with people, planes and other objects that can prevent the spread of radio signals. This can lead to loss of communication, which can have serious security implications.

New antennas for airports should be designed to meet the specific needs of this environment. They must be able to transmit signals efficiently under interference conditions.

Some of the main areas of research in this area include:

– Developing new forms of antenna factors: New forms of antenna factors can help them better fit into the limited space of the airport and reduce their sensitivity to interference.

– Development of new antenna materials: New materials can help improve antenna performance under interference conditions.

– Developing new antenna analysis techniques: New antenna analysis techniques can help developers better understand how antennas will perform in an airport environment.

Some examples of specific new antennas being developed for airports include:

– **Phase array antennas:** These antennas use a series of small antennas that work together to create a directional beam. They can be used to focus the signal on a specific target, which can help reduce the impact of interference.

Phased arrays follow the definition of beamforming. This is accomplished by taking the radiation patterns of each of the antenna in the array and combining them into a narrow beam or lobe of energy. The individual antenna signals are said to be competing with one another in a positive or negative manner. Some signals are stronger when combined, while others partially cancel one each other.

The radio signal that is intended to be transmitted is a sine wave. When you add two sine waves of the same frequency but with different phases, you will get a third wave of the same frequency but with a different amplitude and phase. By adjusting the phase and amplitude of the signal at each antenna, the combined beam can be altered in both dimensions (power level). Additionally, the beam can be directed in a specific direction.

Several methods are available to execute the phased array. The older analog approach is demonstrated in figure 2.4.2.1. The RF signal from the power amplifier for the transmitter (PA) is sent to a power divider that uniformly allocates the RF to the various paths to the antenna, this creates multiple paths to the antenna. The signals are attenuated and shifted in phase so that each antenna element can individually alter the level and phase of the signal to accommodate.

Figure 2.3 illustrates the way the phase shifters affect the total signal. The red line represents the front of the wave at each antenna. With no additional delay on the top antenna and identical incremental delays on the lower components, you can observe that the late waves occur further out in time to the right. After that, they add up to create a composite wave front that is shifted upward by an angle.

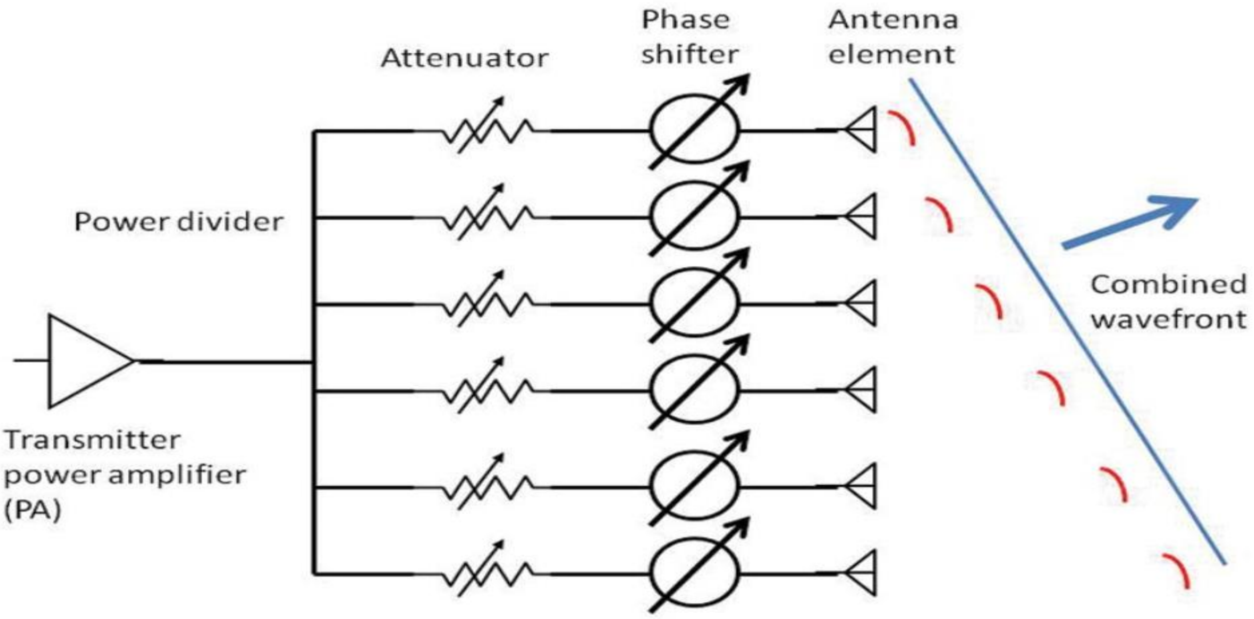

Figure 2.3-Original approach to implementing an array with separate circuits [13]

This older style employed separate attenuators, phase shifters, and other components. A more recent method is modular. That is, the antenna element and associated transmit and receive amplifiers, shifters, attenuators, and switches are all combined as a single module (Figure 2.4). In transmit mode, the signal from the transceiver traverses the attenuator, phase shifter, and T/R switch to reach the power amplifier and then the antenna

In transmit mode, the signal from the transceiver traverses the attenuator, phase shifter, and T/R switch to reach the power amplifier and then the antenna.

An example of a commercial product that can implement phased arrays is the Anokiwave family of millimeter wave phased array front-ends. The AWMF-0139 is a frequency hopper that switches between 24-26 GHz, which is the band that is expected to be used by the upcoming 5G cellular networks. It encompasses four components per IC.

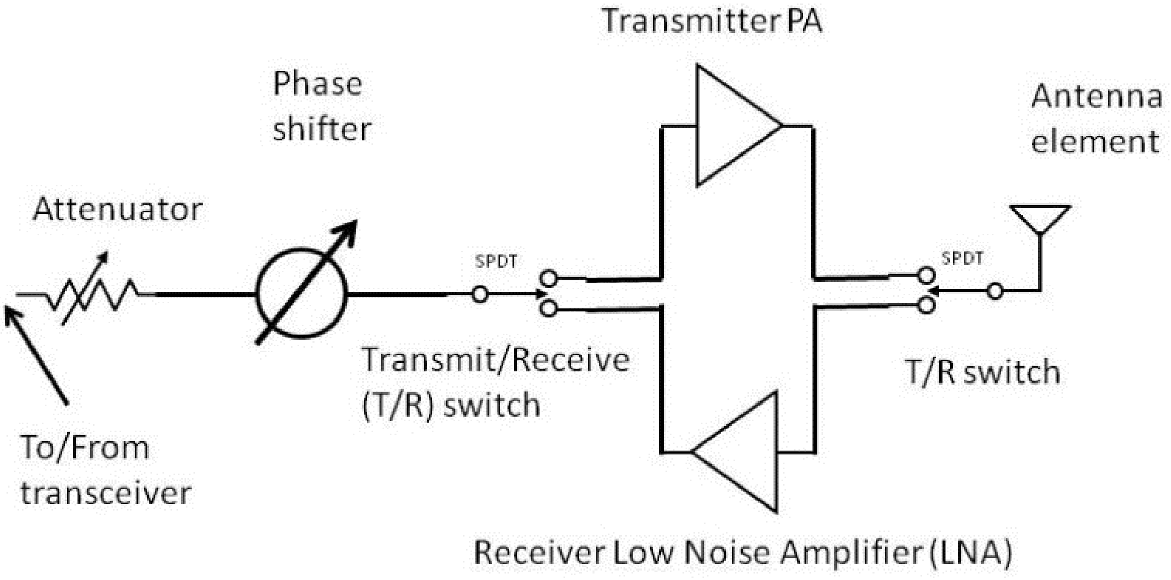

Figure 2.4 - Modular building phased array package with all components on one chip [13]

Figure 2.5 illustrates how 64 of these chips can be employed to create a 4 x 64 = 256 element vector. Another similar device is ADAR1000, which is an analog IC (integrated circuit).

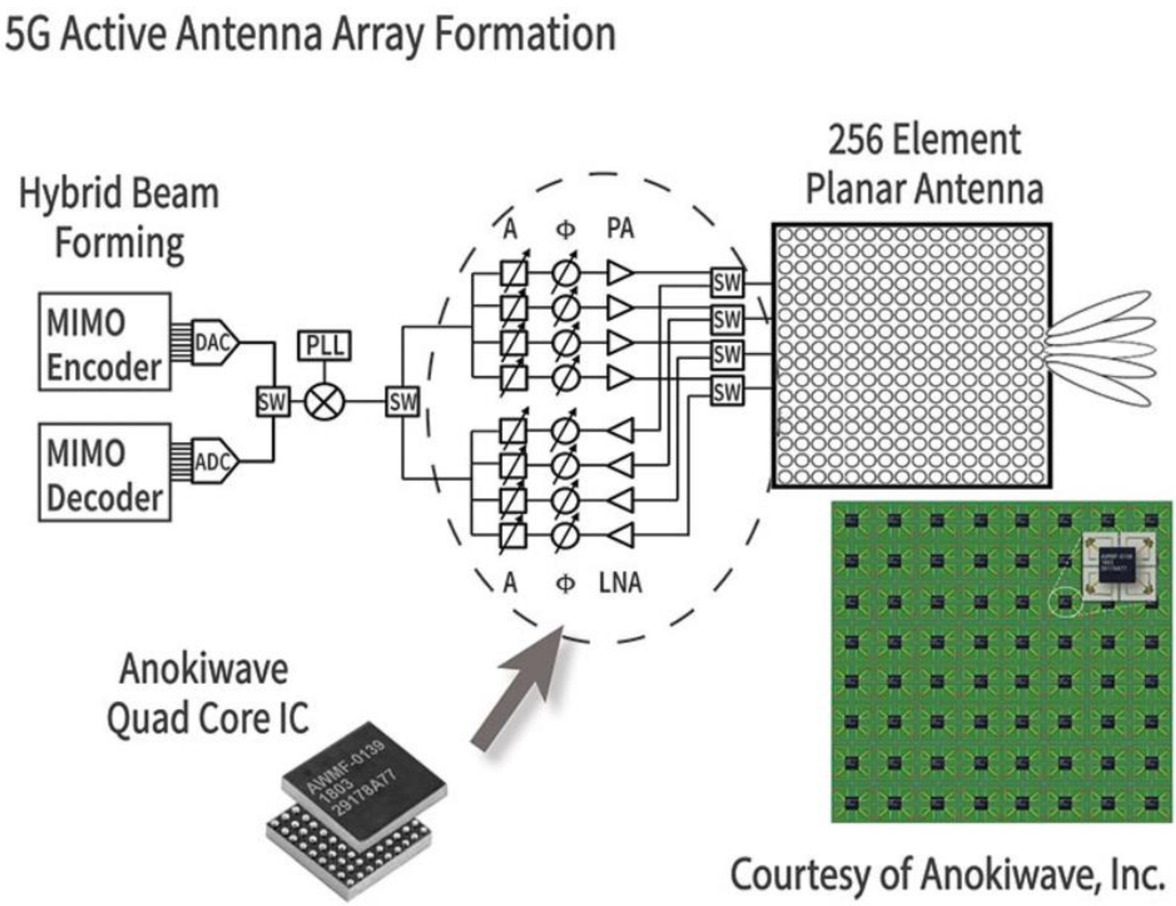

Figure 2.5 -The Anokiwave AWMF-0139 IC with 4 antenna modules [13]

Phased-array antennas can also be employed for multiple input and multiple output (MIMO). MIMO is a method of data transmission with multiple antennae over a single path in a single bandwidth. This has both effects.

First, each signal takes a slightly different path to the receiving antenna. The outcome is less of a fading and more dependable data. Second, MIMO increases the data rate by a factor that is derived from the number of transmit and receive antennae. Common configurations are 2 x 2, 4 x 2, 4 x 4, and 8 x 8, the first number is the number of transmit antennae, and the second number is the number of receive antennae.

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A multi-element phase array can be divided into components that are suitable for MIMO applications. For instance, the 256-element array could be organized to provide four 64-element arrays or 16 16-element arrays. With the ability to steer the beam, the signal path can be altered to have the greatest possible performance.

Additionally, 5G cellular radio operating in the millimeter wave bands will utilize MIMO to achieve gigabit data rates. The significant obstacle is placing a phased array in a smartphone's hand. Initially, two antennae will be employed, and later on, four will be used. MIMO is also popular in Wi-Fi wireless network controllers.

– **Adaptive Phased Array Antennas**: These antennas can change the phase of the signal at each antenna depending on environmental conditions. This can help improve the quality of communication under interference conditions.

Two primary types of intelligent antenna exist. As illustrated in Fig. 2.6, the first type is a phased array or single-beam antenna that is comprised of several different directionsal components. One component is always on, and it directs the signal toward the desired destination. Another type is the adaptive antenna array, as illustrated in Fig. 2.7, which is composed of multiple antenna elements that are weighted and then combined to maximize the desired signal to interference plus noise ratio. This essentially directs the main beam in the direction of the desired signal and nulls in the direction of the interference.

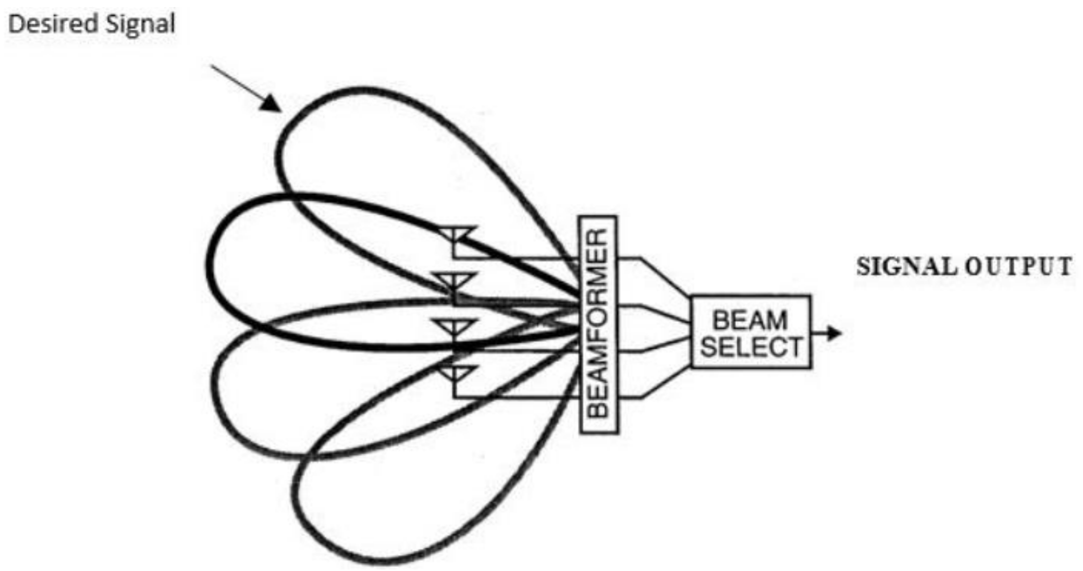

Figure 2.6 – Phased array [11]

As a result, a smart antenna is a phase or array of electronic components that adapt to the environment. That is, for the adaptive array, the pattern of beam change is dependent on the desired user and the interference, for the phased array, the beam is altered or different beams are selected as the desired user moves.

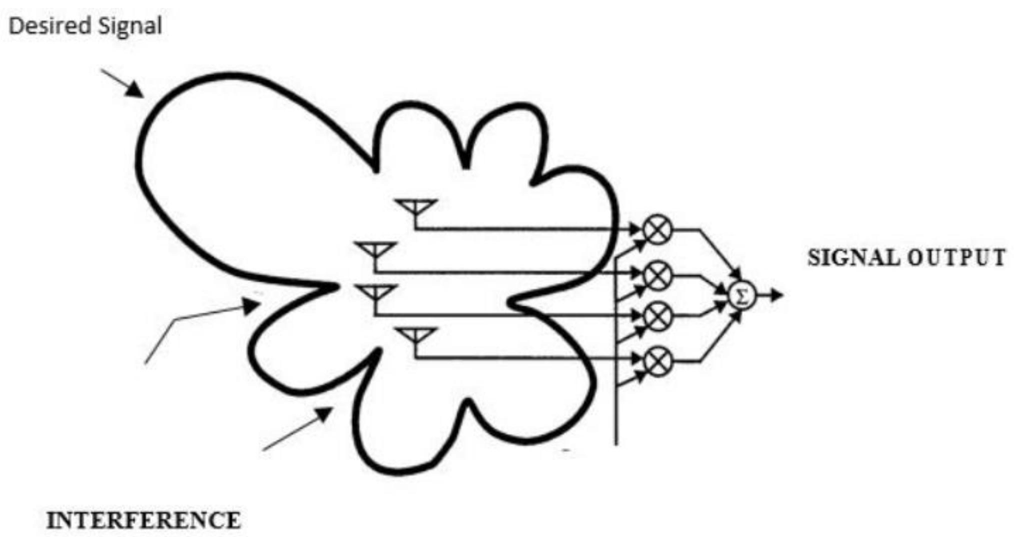

Figure 2.7 – Phased array [11]

Antennas with metamaterials: These antennas use metamaterials that have unique electromagnetic properties. They can be used to neutralize or reduce the impact of interference.

Matamaterial antenna design:

Designing a metamaterial antenna is similar to the design of an antenna with a conventional material, the two components can be combined to create a metamaterial that is both smaller in size and more efficient.

Typically, an antenna's design is printed on a PCB (printed circuit board). For use in the microwave region, the substrate is comprised of FR-4, and copper is employed as the metal component. The design of the antenna is comprised of strips of copper that are printed on a FR-4 substrate. The floor of copper is also utilized to reflect waves and increase the directness of the antenna. Many different designs of antennas exist as the design and operating frequency change in response to changes in the design, length, or area of the copper wire.

The procedure of creating a metamaterial is similar to the process of creating an antenna. Depending on the design, the metamaterials can be implemented as a series of multiple- component elements, or they can be part of the design of an antenna. By altering the wire dimensions, the index of refraction of the antenna as a whole is altered, and by extracting the S-parameters of the antenna, a specific frequency can be achieved where the return loss (the coefficient of reflection with a negative sign) is maximum. The process of calculating the refractive index and resistance from the S-parameters is possible shown below:

Calculation of normalized impedance formula (2.1):

$$z = \sqrt{\frac{(1 + S_1) - S_2^2}{(1 - S_1) - S_2^2}} \tag{2.1}$$

Where z is the normalized impedance. S1 and S2 are the reflection and transmission coefficients.

Calculation of revlective index by formula (2.2):

$$n = \frac{1}{kd} cos^{-1}\left[\frac{1 - S_1^2 + S_2^2}{2S_2}\right] \tag{2.2}$$

Where n is refractive index, k is the wave number, and d is the length of antenna.

Calculation permeability of the antenna design by formula (2.3):

$$\mu = nz \tag{2.3}$$

Where μ is permeability of the antenna design.

Calculation of revlective index by formula (2.4):

$$\epsilon = \frac{n}{z} \tag{2.4}$$

Where ϵ is the permittivity of the antenna design.

Example:

Let's look at an example of a simple dipole antenna that operates at 2.4 GHz. The dipole antenna is one of the basic antennas for wireless communication, and it can be easily adapted to operate at specific frequencies. The overall design of the dipole antenna looks like a T-shape straight metal wired antenna (Figure 2.4).

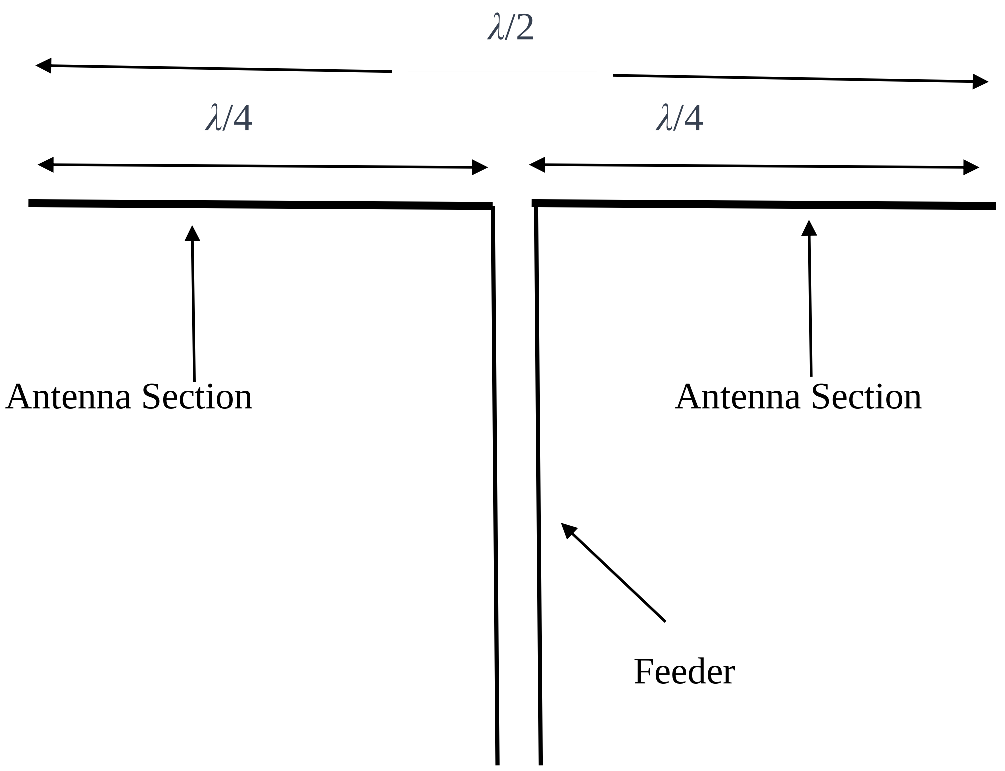

Figure 2.7 - Dipole antenna

The length of the dipole antenna can be calculated by the formula (2.5):

$$d = \frac{\lambda}{2} \qquad (2.5)$$

Where d – length of antenna and λ – wave length which can be counted by formula (2.6):

$$\lambda = \frac{c}{f} \qquad (2.6)$$

Where c- speed of light (approximately $3 * 10^8 m/s$ and f- frequency. Thus, the length of the antenna d is about half the wavelength.

Let the frequency of the antenna $f = 2.4GHz$ Then the wavelength by formula (2.4.2.6) will be approximately $\lambda = 0{,}125m$, and lengh of dipol antenna by formula (2.4.2.5) $d = 0.0625$.

Wave number k can be calculated using the formula (2.7):

$$k = \frac{2\pi}{\lambda} \qquad (2.7)$$

Where k is wave number.

In our case $k = 2\pi/0.25m$

Now let's assume some conditional values for reflection and transmission coefficients:

Reflection Coefficient $S_1 = -0.2$

Transmission Coefficient $S_1 = 0.7$

So, by using these data and formula (2.1) we can determine normalized impedance:

$$z = \sqrt{\frac{(1+0.2) - 0.7^2}{(1-S_1) - 0.7^2}} = 0.66$$

Calculation of revlective index by formula (2.2):

$$n = \frac{1}{\left(\frac{2\pi}{0.125}\right) \times 0.0625} cos^{-1}\left[\frac{1 - ((-0.2)^2 + (0.7)^2)}{2 \times 0.7}\right] = 7.82 \times 10^{-9}$$

Now using these data and formula (2.3) we can determine permeability:

$$\mu = nz = (7.82 \times 10^{-9}) \times 0.66 = 5.16 \ \times 10^{-9}$$

Revlective index by formula (2.4):

$$\epsilon = \frac{n}{z} = \frac{7.82 \times 10^{-9}}{0.66} = 1.8 \times 10^{-8}$$

A metamaterial antenna without Fig.2.8 and with Fig. 2.9 a metamaterial is demonstrated bellow. This antenna is said to be effective in the microwave domain with a targeted frequency of 2.4 GHz (which is the current frequency of wifi that delivers internet to our electronics).

It's apparent from Fig. 2.9 that the addition of metamaterial not only diminishes the size of the antenna, but also increases its loss of return in decibels. Additionally, metamaterial also has the effect of increasing the gain and beam of the antenna, as demonstrated in the patterns of radiation.

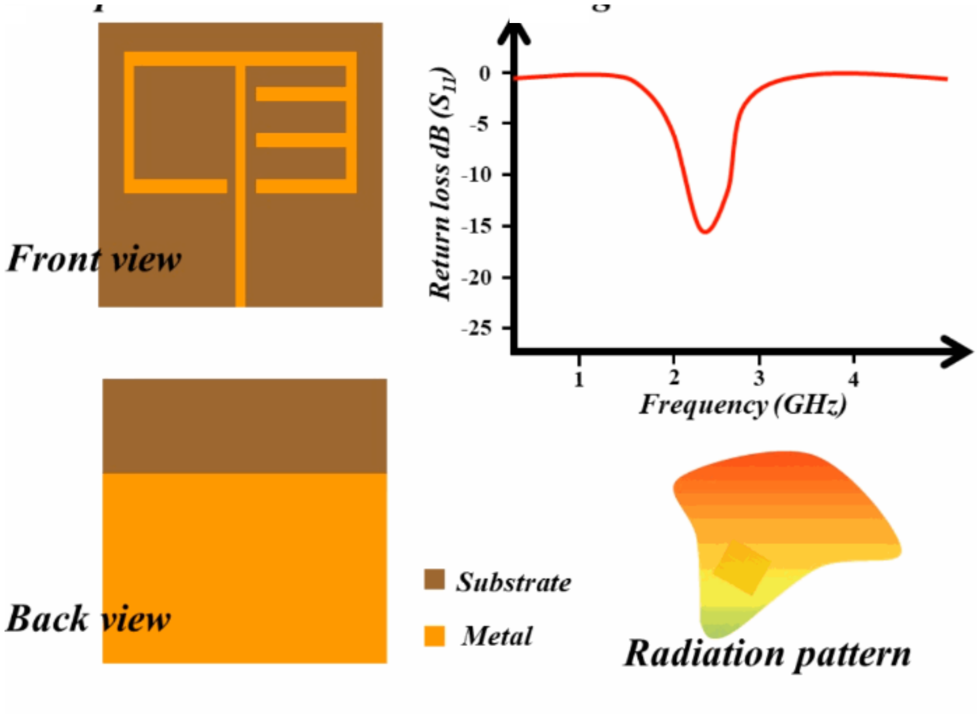

Figure 2.8 – Simple antenna without matematerial[2]

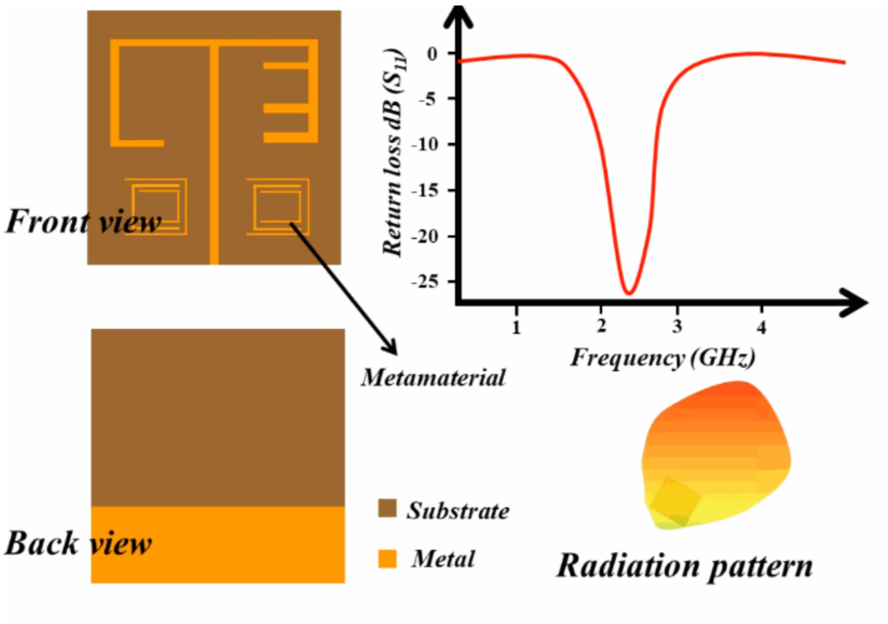

Figure 2.9 – Simple antenna with matematerial[2]

2.4.3 - Cost-effectiveness research

The cost-effectiveness of cellular communication in aviation is as follows:

Reducing air traffic control costs: This type of communication can help reduce air traffic control costs by improving air traffic control efficiency.

Modern air traffic control systems use radio signals to communicate between aircraft and ground controllers. These signals can be muffled or distorted, which can lead to loss of communication. This can have serious security implications, as pilots may not receive important information from controllers.

Cellular communication is more reliable than traditional radio signals because it is less sensitive to interference. This means that cellular communication can help reduce the number of cases of loss of communication between aircraft and dispatchers.

Reducing the number of cases of loss of communication can lead to lower costs for air traffic control. This is due to the fact that dispatchers should spend more time and resources on solving problems associated with loss of communication.

Increase airspace capacity: Cellular communication can help increase airspace capacity by optimizing flight routes.

Cellular communication can be used to transmit navigation data such as aircraft location, speed and altitude. These data can be used to optimize flight routes, which can help reduce air traffic density.

Reduced air traffic density can lead to increased airspace capacity. This means that more aircraft can simultaneously be in the same airspace.

Increased airspace capacity can lead to lower air transportation costs. This is due to the fact that airlines will be able to carry more passengers per flight.

Improved passenger service: cellulaer communication can help improve passenger service by providing them with additional services.

Cellular communication can be used to provide passengers with services such as communication with loved ones, Internet access and entertainment. These services can help make plane travel more comfortable and enjoyable.

Improved passenger service may lead to increased demand for air travel. This can lead to an increase in airline revenues.

The overall economic effect of the use of cellular communication in aviation is positive. Tape communication can help reduce air traffic control costs, increase airspace capacity, and improve passenger service. This can lead to lower air travel costs and higher airline revenues.

However, in order for cellular communication to be effectively used in aviation, it is necessary to solve a number of technical problems. One of the main problems is the need to provide a reliable connection in conditions of interference that can occur at airports and other places with a high density of radio signals. Another problem is the need to provide the high throughput required to transmit navigation data and other data.

Despite these challenges, cellular communication has significant potential to improve aviation efficiency and safety. This technology is already used in some countries, and its implementation in other countries is only a matter of time.

The cost of equipment and cellular services for aviation depends on factors such as:

Type of equipment: The cost of cellular equipment in aviation may vary depending on the type of equipment. For example, the cost of a cellular base station can range from several million to tens of millions of dollars.

Network size: The cost of building a cellular network for aviation also depends on the size of the network. For example, the cost of building a cellular network for one airport can range from several million to tens of millions of dollars.

Services: The cost of services for cellular communication in aviation also depends on factors such as the amount of data transmitted and the type of data transmitted. For example, the cost of services for the transmission of navigation data can range from several thousand to tens of thousands of dollars per month.

Example:

Consider an example of building a cellular network for one airport. The cost of equipment for the construction of this network can be about $100 million. The cost of building base stations will be about $70 million, and the cost of equipment for aircraft and other aircraft will be about $30 million.

The cost of services for this network can be about $1 million per month. This cost will include network usage fees, data fees, and technical support fees.

Thus, the total cost of building and operating a cellular network for one airport can be about $110 million per year.

2.4.4 Law Studies

The main legal aspects of the use of cellular communications in aviation include:

International law: particular the Chicago Convention on International Civil Aviation, regulates the use of radio frequencies in aviation. Cellular communication is also subject to this international law.

Domestic law: The domestic law of each country also regulates the use of radio frequencies. In many countries, there are special rules that apply to the use of cellular communications in aviation.

Safety regulations: Safety regulations that apply to aviation may also affect the use of cellular communications.

International Law:

The UN Charter regulates the use of radio frequencies in aviation. According to this treaty, each country has sovereignty over radio frequencies in its airspace.

Cellular communications are also subject to the Chicago Convention. According to this convention, countries must coordinate among themselves the use of radio frequencies in aviation.

Domestic Law:

The domestic law of each country also regulates the use of radio frequencies. In many countries, there are special rules that apply to the use of cellular communications in aviation.

These rules may contain the following requirements:

- Cellular equipment must be certified for aviation use.
- Cellular communications should only be used for security-related purposes.
- Cellular communication should be used in such a way as not to interfere with other radio frequency systems.

Safety rules:

The safety rules that apply to aviation may also affect the use of cellular communications. For example, safety regulations may require cellular equipment to be certified for aviation use.

This means that cellular equipment must be tested and certified for use in aviation. This certification process ensures that the equipment meets the required safety standards.

CONCLUTION TO CHAPTER 2

Summarizing the collected data, it can be determined that aviation cell technology opens up new opportunities for the transformation of the aviation industry. From the history of the development of this technology, it can be seen that its implementation was made possible by the development of special technologies such as LTE-A and 5G, which provide high bandwidth and low latency.

Analysis of various studies and reports indicates the potential benefits of using cell technology in aviation. Reducing accidents, saving on fuel costs, improving passenger satisfaction and other advantages make this technology attractive to the industry.

In addition, conceptual research aimed at developing new data transfer protocols and using new technologies, such as phase-massive antennas, suggests that there is great potential for further development of this technology.

However, despite the powerful potential, it is important to solve technical challenges, such as ensuring reliable connection under interference conditions and ensuring sufficient bandwidth. In addition, addressing the cost of equipment and services for aviation is key to successful implementation

In general, aviation cell technology defines a new stage in the development of the aviation industry, promising improvements in efficiency, safety and comfort. The introduction of this technology in the coming years could lead to a significant improvement in all aspects of the aviation experience for passengers and the industry as a whole.

CHAPTER 3
CELLULAR TECHNOLOGIES IN AVIATION AND THEIR APPLICATION IN NAVIGATION

3.1 The latest cellular technologies with application in aviation

Cellular communication is an important technology that has significant potential to improve the safety and efficiency of aviation. The latest cellular technologies such as 5G and Massive MIMO have a number of advantages for aviation applications such as:

• Higher bandwidth: This advantage allows you to transfer more data, which is necessary for applications such as navigation, video transmission and data transmission from sensors.

• Lower latency: This advantage allows real-time data transmission, which is important for applications such as navigation and aircraft control.

• Greater immunity to interference: This advantage allows for reliability of data transmission, which is important for applications such as navigation and aircraft control.

3.1.1 5G technology

5G technology has a number of potential applications in aviation. These applications include:

• Navigation: 5G technology can be used to improve the accuracy of aircraft location using GPS. This can be achieved by transferring additional data from on-board sensors, such as inertial sensors and magnetic field sensors, to ground servers. Ground servers can use this data to clarify the coordinates of the aircraft.

• Data transfer: 5G technology can be used to transfer data from aircraft to ground. This can be useful for purposes such as:

- Aircraft condition monitoring
- Assisting passengers in case of emergency
- Ensuring communication of passengers with their loved ones

• Flight control: 5G technology can be used to control aircraft flight. For example, 5G technology can be used to transmit data from on-board sensors to ground controllers. Ground controllers can use this data to control the aircraft in real time.

• Developing new safety systems: 5G technology can be used to develop new safety systems in aviation. For example, 5G technology can be used to transmit data from cameras installed on board an aircraft to the ground. This will allow dispatchers to monitor the condition of the aircraft in real time and assist the crew if necessary.

• Providing additional services to passengers: 5G technology can be used to provide additional services to passengers. For example, 5G technology can be used to transmit video from an aircraft to passengers.

The impact of 5G on the aviation lifecycle is a significant topic with far-reaching implications and goal. From the inception of aviation to its ultimate decommissioning, the introduction of 5G technology has the potential to revolutionize all stages of the cycle. The precise nature of this impact is still being explored, but it is clear that 5G will have a transformative effect on the aviation industry for years to come.

When utilized to its fullest extent, 5G implementation has the potential to revolutionize every aspect of aviation. The most significant areas of transformation include manufacturing, airports, airlines, and the passenger experience (Figure 3.1).

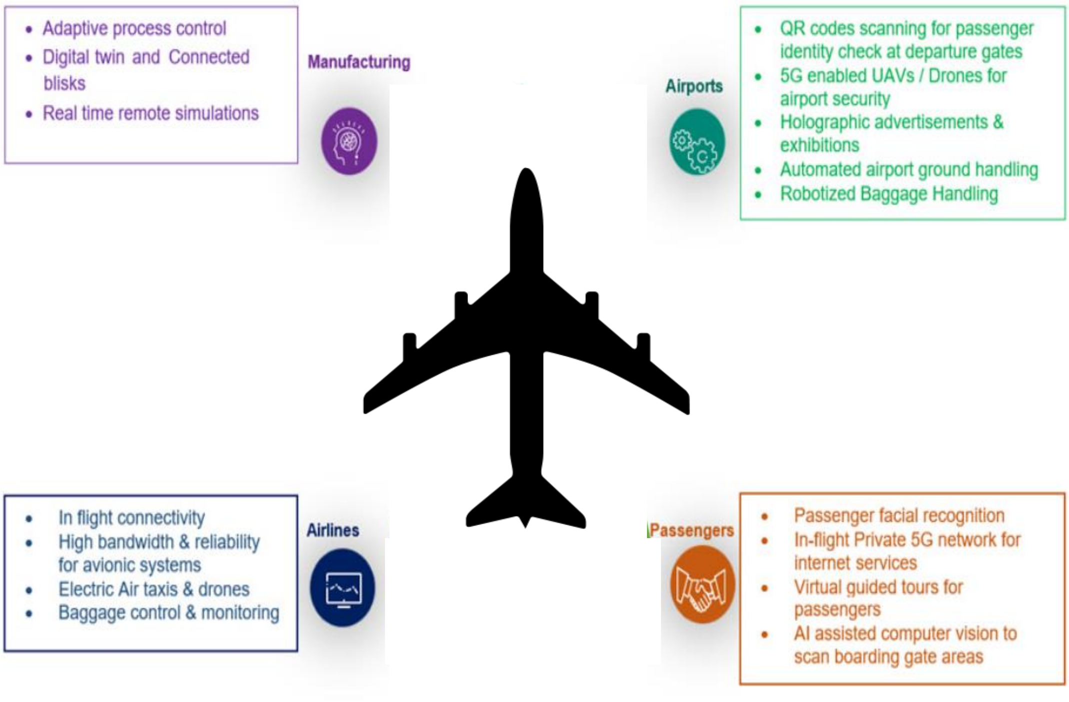

Figure 3.1 - Impact of 5G on the aviation lifecycle [1]

Manufacturing:

Before manufacturing begins, it's crucial to use remote simulation technology to calculate multiple parameters and calculate the time required. For instance, IoT sensors acquire virtual data about aircraft blades, which is then relayed to the machine control to gain important information. 5G promotes this acceleration, which enables manufacturers to perform more advanced analytics and predictions earlier on and thus identify and correct problems.

Similarly, 5G can help manufacturers understand all of the manufacturing scenarios and processes more comprehensively by allowing digital copies of aircraft blisks to be created. Blisks are complex products that necessitate high communication rates, high dependability, and high data rates to create. By deploying a 5G network on the manufacturing floor, manufacturers can guarantee highly precise manufacturing of the blisk and have real-time tracking capabilities as the blisk traverses the manufacturing line.

Airports:

Two general areas of operational concern are weather and security-related tasks. One possible way 5G can enhance security at the airport is through the use of network-connected 8K cameras and augmented-reality glasses. Different from the typical security perspective, 5G could also facilitate the use of Automated Guided Vehicles (AGVs) to complete full decontamination in real space, or allow airports to utilize real-time thermal imaging to detect fever.

Other problems with the weather, while uncommon, can lead to additional significant costs in addition to flight delays. With a 5G network that provides high speed connectivity, airports can observe the runways from the tower's control and send autonomous snowploughs to clear the runways, this diminishes the need for on-call drivers.

Even the sharing of flight information, seat assignments and terminal data can be enhanced by 5G, whether through advertisements that are holographic or other methods that involve bandwidth-intensive information divulging in real time.

Airlines:

It's simple to envision the effect of 5G on a facility like an airport, but the airlines themselves can utilize 5G technology as well. The avionic systems in airlines, for example, can have increased communication with control towers during landing via a highly dependable 5G connection. Additionally, the monitoring of real-time equipment using 5G networks can facilitate predictions of maintenance, this will allow airlines to observe the process of aircraft rotation.

Airlines also have the potential to enhance their cargo and passenger movement, with 5G providing the infrastructure to deploy vertical take-off drones (e.g. The electric air taxi will be able to reach the closest destination using a smartphone-based application.

Experience of the Passenger:

The possibilities are enormous in regards to utilizing 5G to enhance the passenger experience. From a logistics perspective, the process of verifying the identity of passengers via QR codes can greatly reduce the length of queues and wait periods. 5G-powered cameras and glasses could recognize faces and identify suspicious travelers. These devices would also allow customs officers to observe travelers as they cross borders. Real-time video streaming via 5G would allow for improved control of baggage during loading and unloading as well as during the flight itself. And 5G-connected computer vision could allow for personalized services that would allow for instantaneous analysis of passports with minimal waiting periods and no human intervention.

5G Market in Aviation**:**

The estimated size of the market is US$ 14.63 billion. by 2029 with a starting price of US$ 0.80 billion. In 2022, the online advertising market will have a CAGR of 51.4 % over the next five years. The worldwide 5G market in Aviation report is a comprehensive description of the industry, the market, and the leading players. The report has discussed the market from a demand and a supply perspective, respectively. The worldwide 5G market in aviation industry also has growth trends by segment, technology, and investment (Table 3.1).

Table 3.1. - 5G Market in Aviation [25]

5G Market in Aviation			
Report Coverage	Details		
Base Year:	2022	**Forecast Period:**	2023-2029
Historical Data:	2018 to 2022	**Market Size in 2022:**	US $ 0.80 Bn.
Forecast Period 2023 to 2029 CAGR:	51.4%	**Market Size in 2029:**	US $ 14.63 Bn.
Segments Covered:	by Platform	5G airport 5G aircraft	
	by Technology	FWA URLLC/ MMTC Embb	
	by Communication Infrastructure	Small Cell RAN DAS	
	by 5G Services	Airport Operations Aircraft Operations	

3.1.2 Massive MIMO Technology

Massive Multiple Input Multiple Output (MIMO) technology is a cellular communication technology that allows you to increase network bandwidth by using a large number of antennas (Fig. 3.2).

Figure 3.2- Massive MIMO antenna [25]

Principle of operation:

Massive MIMO technology is based on the use of spatial coding. The base station uses a large number of antennas that emit signals in different directions. The subscriber unit also uses a large number of antennas that receive signals from the base station.

Due to the use of a large number of antennas, the base station can transmit much more data than using traditional cellular technologies. This allows you to simultaneously serve a large number of subscriber devices, as well as provide a higher data transfer rate. (Fig.3.3).

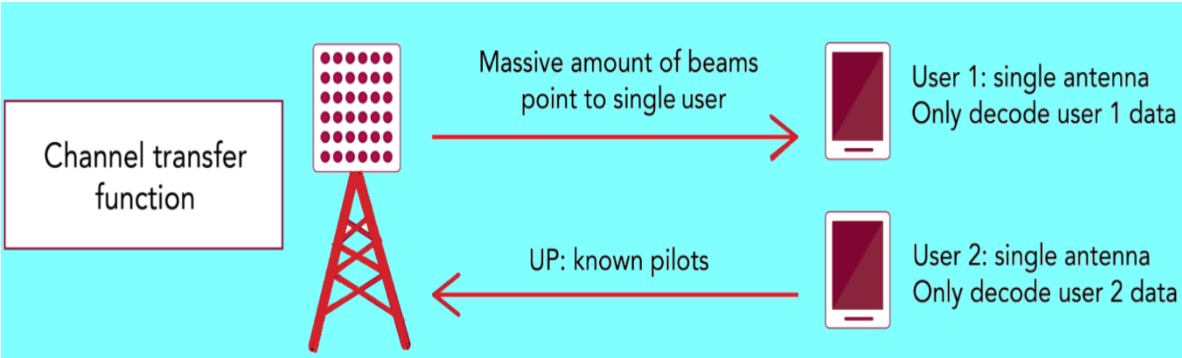

Figure 3.3 - Massive MIMO uses multiple antennas, shifting the beam's location by changing amplitude and phase [25]

Advantages:

• Massive MIMO technology has several advantages, such as:

• High bandwidth: Massive MIMO technology allows for high network bandwidth, which is necessary for applications such as navigation, data transfer and flight control.

• Low latency: Massive MIMO technology allows for low data latency, which is important for applications such as flight control.

• Greater immunity to interference: Massive MIMO technology provides greater immunity to interference, which is important for applications such as navigation and flight control.

Disadvantages:

• Massive MIMO technology has a number of drawbacks, such as:

• High cost: Massive MIMO technology requires the use of a large number of antennas, which increases the cost of equipment.

Implementation complexity: Massive MIMO technology is complex to implement, requiring the use of advanced technology.

Conclusion:

Massive MIMO technology has significant potential to improve aviation safety and efficiency. Massive MIMO technology is expected to be widely used in aviation in the future.

3.2 Navigation and cellular communication

Cellular communication technology can be used in navigation to improve the accuracy of aircraft location. This can be achieved by transferring additional data from onboard sensors to ground servers. Ground servers can use this data to clarify the coordinates of the aircraft.

The main advantages of using cellular technology in navigation:

- Improving the accuracy of aircraft location: Additional data from onboard sensors, such as inertial sensors and magnetic field sensors, can be used to refine the coordinates of the aircraft. This can help improve flight safety, as pilots will have a more accurate idea of the position of the aircraft.
- Reducing the cost of navigation: Cellular technology can help reduce the cost of navigation, as it can be used to transmit data from onboard sensors without the need to install additional ground systems.

3.2.1 Non-Terrestrial Networks

Another cellular technology that can be used in navigation is Non-Terrestrial Networks (NTN) technology. NTN technology uses satellites to provide cellular services.

Non-terrestrial networks are satellite-based communication systems that operate over the Earth’s surface, these networks involve satellites in a low-Earth orbit (LEO), a medium-Earth orbit (MEO), and a geostationary orbit (GEO), all of which are high in the atmosphere. These components are crucial to achieving complete coverage, providing coverage to areas that would not have access to traditional terrestrial networks.

Today, devices are categorized by whether they are connected to the cellular network or the satellite network. Ultimately, users who want satellite access must have another device associated with their current smartphone. With NTN, all devices will have the ability to connect to both terrestrial and satellite networks as part of the system. As the technology continues to evolve, the satellites will become the stations.

How NTN technology works:

NTN technology works on the same principle as traditional terrestrial cellular networks. Base stations that emit radio signals are installed on satellites. NTN devices such as smartphones, tablets or laptops can receive these radio signals and use them to connect to the network.

The main differences between NTN technology and traditional terrestrial cellular networks are:

• Base station location point: NTN base stations are located on satellites that are in orbit around the Earth. The base stations of terrestrial cellular networks are located on the ground.

• Range: The range of NTN base stations can be very large, since satellites can receive and transmit signals over long distances. The range of the terrestrial cellular network base stations is limited by the distance to the nearest base station.

• Reliability: NTN technology can be more reliable than traditional terrestrial cellular networks because it does not depend on terrestrial infrastructure.

Connectivity overview of non-terrestial networks shown in figure 3.4.

Some specific examples of how NTN technology can be used in navigation:

• NTN technology can be used to transmit data from onboard sensors, such as inertial sensors and magnetic field sensors, to ground servers. Ground servers can use this data to specify aircraft coordinates in areas where there is no access to ground cellular networks.

• NTN technology can also be used to transmit real-time video from an aircraft to the ground in areas where there is no access to terrestrial cellular networks. This may be useful for purposes such as monitoring the condition of the aircraft and assisting passengers in the event of an emergency.

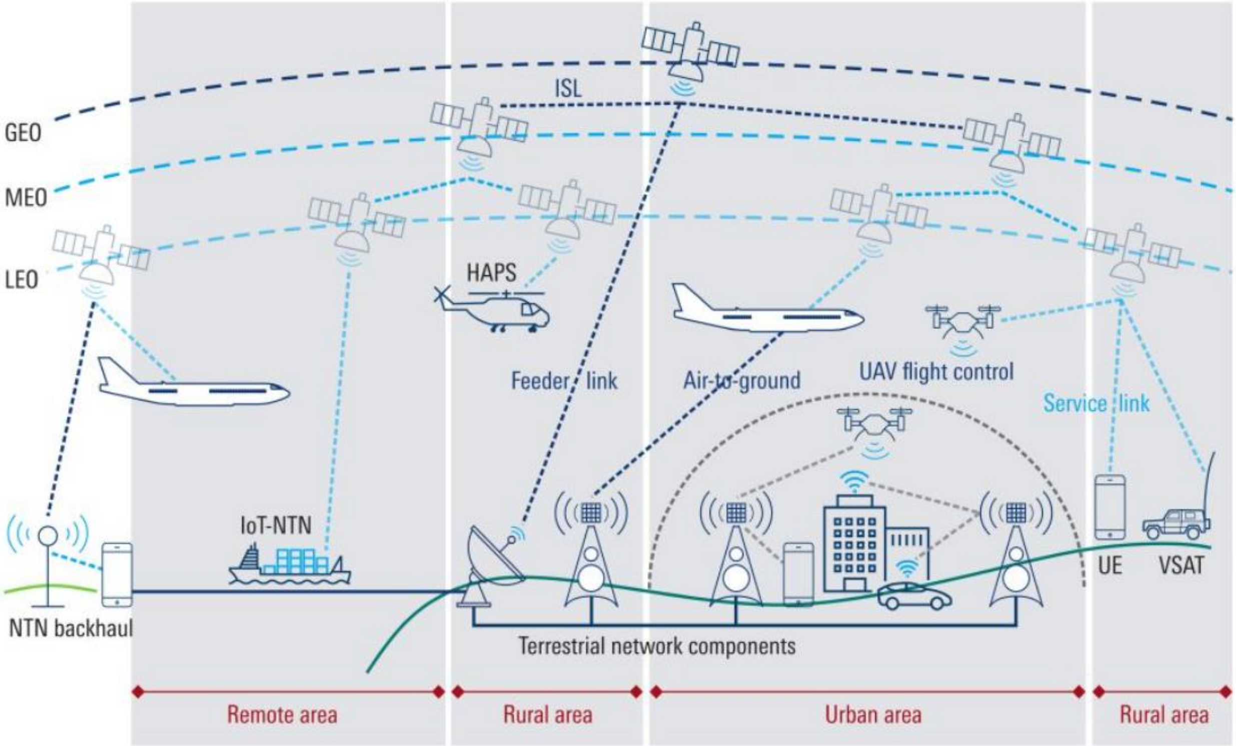

Figure 3.4 - General connectivity overview of NTN [23]

Some specific examples of how NTN technology can be used in navigation:

• NTN technology can be used to transmit data from onboard sensors, such as inertial sensors and magnetic field sensors, to ground servers. Ground servers can use this data to specify aircraft coordinates in areas where there is no access to ground cellular networks.

• NTN technology can also be used to transmit real-time video from an aircraft to the ground in areas where there is no access to terrestrial cellular networks. This may be useful for purposes such as monitoring the condition of the aircraft and assisting passengers in the event of an emergency.

The evolution of NTN.

• NTN has two components:NTN-IoT and NTN-NR. Each address has a different purpose and a distinct audience.

• The NTN market has begun to develop with the release of NTN-IoT. NTN-IoT increases the number of uses of the IoT that are available across the globe, these uses include true land, sea and air coverage. It has a dual role: it functions at both the GEO and LEO altitudes, but the majority of services today are located at GEO.

• With the increasing popularity of NTN technology, the relevance of NTN-NR will increase as well. NTN-NR will directly connect smartphones and other 5G devices such as RedCap-equipped devices that are not on the ground. It will function at the LEO elevation and facilitate low data communication.

Using NTN technology in navigation has several advantages, such as:

• Coverage expansion: NTN technology can provide coverage in areas where there is no access to terrestrial cellular networks.

• Improving reliability: NTN technology can be more reliable than terrestrial cellular networks because it is independent of terrestrial infrastructure.

3.2.2 Terahertz technology

Terahertz (THz) technology is a wireless data transmission technology that uses electromagnetic waves with a frequency ranging from 0.3 to 30 THz and wavelengths from 10 mm to 0.01 mm.

• Advantages of THz technology:

• Very high bandwidth: THz technology provides very high bandwidth, which can reach 100 Gbps or more. This means that THz technology can be used to transmit large amounts of data, such as real-time video from an airplane in very high resolution.

• Short wavelength: The wavelength of electromagnetic waves in the THz range is from 10 to 0.1 mm. This means that THz technology can be used to transmit data over short distances, such as the distance between aircraft and ground servers.

• Low latency: The latency of data transmission in THz technology can be very low, which is important for applications such as flight control.

Electromagnetic spectrum and wavelength of terahertz waves shown in Figure 3.5

Application of THz technology in navigation.

THz technology can be used in navigation for purposes such as:

• Transmission of video from the aircraft: THz technology can be used to transmit video from the aircraft to the ground in real time at very high resolution. This may be useful for purposes such as monitoring the condition of the aircraft and assisting passengers in the event of an emergency.

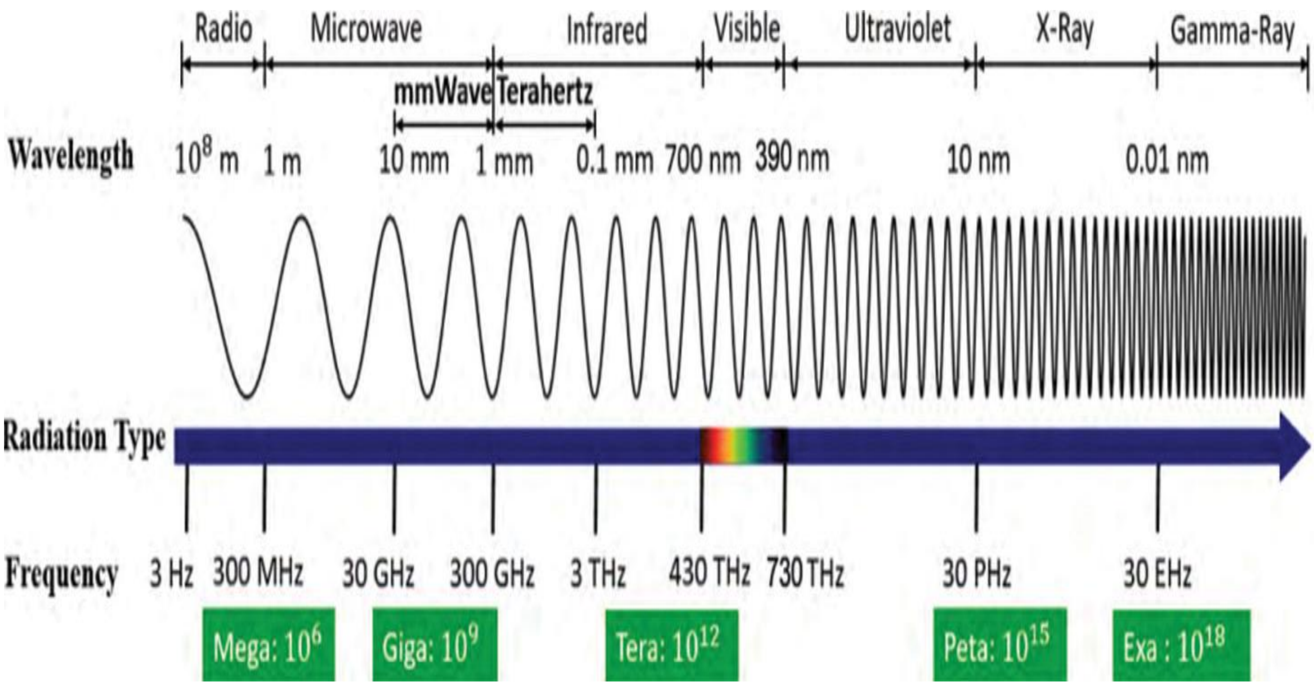

Figure 3.5 - Electromagnetic spectrum of terahertz waves [14]

Application of THz technology in navigation.

THz technology can be used in navigation for purposes such as:

• Transmission of video from the aircraft: THz technology can be used to transmit video from the aircraft to the ground in real time at very high resolution. This may be useful for purposes such as monitoring the condition of the aircraft and assisting passengers in the event of an emergency.

• Data transfer from on-board sensors: THz technology can be used to transfer data from on-board sensors such as inertial sensors and magnetic field sensors to ground servers. Ground servers can use this data to clarify the coordinates of the aircraft.

• Unmanned aerial vehicles: THz technology can be used to control unmanned aerial vehicles. For example, THz technology can be used to transmit control commands to a drone or to obtain video from a drone.

Prospects for THz technology in navigation:

THz technology is still in development, but it has the potential to significantly impact navigation. THz technology is expected to be widely used in navigation in the future.

Specific examples of the application of THz technology in navigation:

• Boeing is developing THz technology to transmit video from the aircraft in real time at very high resolution. Boeing plans to use this technology for its next-generation aircraft.

• Airbus is developing THz technology to transfer data from onboard sensors to ground servers. Airbus plans to use this technology for its next-generation aircraft.

• DJI is developing THz technology for controlling unmanned aerial vehicles. DJI plans to use this technology for its next-generation drones.

CONCLUTION TO CHAPTER 3

Cellular communication technology has significant potential to improve aviation safety and efficiency. The latest cellular technologies, such as 5G and Massive MIMO, have a number of advantages for aviation applications, such as higher bandwidth, lower latency and greater immunity to interference. These technologies can be used for a variety of applications such as navigation, data transfer and flight control.

Non-Terrestrial Networks (NTN) technology is another cellular technology that has the potential to revolutionize aviation. NTN technology uses satellites to provide cellular services, which means it can provide coverage in areas where there is no access to terrestrial cellular networks. This makes NTN technology ideal for applications such as navigation in remote areas.

Terahertz (THz) technology is a wireless data technology that has the potential to further improve aviation safety and efficiency. THz technology provides very high throughput, short wavelength and low latency. This makes THz technology ideal for applications such as real-time video transmission and data transmission from onboard sensors.

Cell communication technology is still in the early stages of development, but it has the potential to transform the aviation industry. As cellular technologies evolve, we can expect to see even more innovative applications in the coming years.

CHAPTER 4
AUTOMATED BIG DATA PROCESSING IN AIR NAVIGATION

Automated data processing is a typical task, which is solved by modern air navigation systems. Processing of air navigation data is provided both on board airplanes in particular avionics units and in ground data processing equipment.

Navigation parameters in modern systems are measured using a significant number of different sensors, which ensure creation of a data archive, the processing of whichrequires the use of specialized statistical data processing algorithms. Each sensor performs measurements with a certain amount of error, the effect of which cannot be excluded, but it can be reduced to an acceptable level. Therefore, the combined processing of data in the aeronautical system is performed by taking into account each sensor error. In this case, confidence bands are used, which guarantee getting a particular frame in the interval with a certain probability [19]. The most commonlyused confidence band is the double root mean square deviation, which provides 95% localization of the measured values, based on the assumption of a normal distribution of errors.

The structure of each unit of avionics is more similar to the architecture of a personal computer with the corresponding elements: processor, memory, and analog-to-digital / digital-to-analog converters, which allows processing of measured data at the software level [12]. The sensor's data is converted to digital form by sampling analog values. Results of different value measurements are stored in appropriate registers, variables, matrices, or data archives. Detection of an airplane's exact location is one of the most important tasks in civil aviation [20 ,22, 16]. Continuously growing volumes of air transportation require a constant review of separation minimums to meet needs of modern air transport. Separation minimums between airplanes set up maximum permissible limits of airplane separation in space on vertical plane, lateral and longitudinal sides. One of the possible ways to solve the issue of airspace congestion is to increase the bandwidth of a particular part of the airspace by reducing the safe distances betweenairplanes. In practice, this is implemented by introducing more precise requirements for determining the location of airplanes in the air space. The introduction of more precise requirements for airplane positioning is possible only if there are appropriate systems capable of satisfying them. Operation of on-board positioning sensors of a civil airplane is provided by the field of aeronautical signals created in space by various systems. As an example of big-data processing, we will use the trajectory of particular aircraft and perform its calculation using MATLAB software.

4.1. Input data

The safety of air transportation mostly depends on the accuracy of preplanned trajectory maintained by each airspace user. Flight technique and performance of on board positioning sensor specify the level of airplane deviation from cleared trajectory. The receiver of Global Navigation Satellite System (GNSS) is the main positioning sensor on board a modern airplane of civil aviation. Performance of on-board positioning system specifies an area of airplane location with a certain level of probability.

Airplane operation within a particular airspace volume is regulated by navigation specification which specifies requirements for the performance of on-board positioning system. To guarantee a safe flight through a particular airspace volume each user should perform navigation with the required levels of performance.

Measured position of an airplane is classified as critical data due to its role in the safety of the whole air transport system. According to Automatic Dependent Surveillance-Broadcast (ADS-B), the position is shared with other airspace users to guarantee surveillance and improve the safety of aviation. Today the majority of airplanes are equipped with transponders of mode 1090 ES (extended squitter).

The airplane transponder transmits periodically digital message which includes a position report [21, 15]. This data can be easily received and used on-board of other airplanes for improving situation awareness or can be received by ground receivers. An air navigation service provider uses a national network of ground ADS-B receivers to support surveillance and airspace user identification [17, 18].

Also, there are multiple commercial networks of ADS-B receivers, that process and collect all data transmitted via the 1090 MHz channel. In particular, computation clusters of Flightradar24 and FlightAware companies provide simultaneous processing of data from more than 30,000 software-defined radios of ADS-B signals located all over the globe (Fig. 4.1).

Figure 4.1 – Maps of global traffic [24]

Access to global databases of trajectory data is open and provided on a commercial basis. The application programming interface allows us to easily get any segment of trajectory data for analysis. As input, I use flight path data of DAL375/DL375 (Delta 375) operated by Delta for connection between Miami, USA (MIA) and New York, USA (JFK).

Departure date is December 05, 2023 at 06:49 AM (EST). Landing date is December 05 at 09:29 AM (EST).

The flight ended 36 minutes earlier than the scheduled landing time. This flight was performed by Airbus A321 (twin-jet) (A321) Input data obtained from the archive https://www.flightaware.com/live/flight/DAL375/history/20231205/1210Z/KMIA/KJFK . Table 4.1 shows the first and final 15 rows of flight raw data.

Table 4.1 Trajectory data of BAW2202 from 05 September 2023

Time (EST)	Latitude	Longitude	Course	kts	mph	feet	Rate
Tue 07:06:53 AM	25.7995	-80.3033	← 297°	162	186	450	
Tue 07:07:09 AM	25.8046	-80.3139	← 299°	154	177	1,250	2,484 ↑
Tue 07:07:25 AM	25.8107	-80.3257	← 300°	164	189	1,775	1,828 ↑
Tue 07:07:41 AM	25.8171	-80.3382	← 299°	177	204	2,225	1,547 ↑
Tue 07:07:57 AM	25.8242	-80.3522	← 299°	198	228	2,600	1,179 ↑
Tue 07:08:23 AM	25.8375	-80.3782	← 300°	247	284	3,050	1,568 ↑
Tue 07:08:41 AM	25.8483	-80.3988	← 303°	268	308	3,750	2,871 ↑
Tue 07:08:58 AM	25.8635	-80.4142	↖ 329°	273	314	4,725	3,402 ↑
Tue 07:09:22 AM	25.8931	-80.4213	↑ 349°	271	312	6,075	3,341 ↑
Tue 07:09:42 AM	25.9177	-80.4282	↑ 347°	277	319	7,175	3,000 ↑
Tue 07:09:58 AM	25.9373	-80.4283	↑ 10°	287	330	7,875	2,426 ↑
Tue 07:10:16 AM	25.9587	-80.4138	↗ 45°	303	349	8,550	2,375 ↑
Tue 07:10:34 AM	25.9691	-80.3905	→ 75°	309	356	9,300	2,170 ↑
Tue 07:11:12 AM	25.9821	-80.3285	→ 77°	337	388	10,575	1,711 ↑
Tue 07:11:31 AM	25.9884	-80.2957	→ 82°	361	415	10,925	1,397 ↑
…							
Tue 09:17:34 AM	40.5466	-73.6167	↖ 330°	187	215	1,875	
Tue 09:17:50 AM	40.5578	-73.6253	↖ 330°	175	201	1,875	
Tue 09:18:19 AM	40.5781	-73.6409	↖ 329°	174	200	1,875	
Tue 09:18:37 AM	40.5900	-73.6502	↖ 326°	175	201	1,875	-284 ↓
Tue 09:18:56 AM	40.6013	-73.6667	← 305°	174	200	1,700	-789 ↓
Tue 09:19:15 AM	40.6084	-73.6817	← 302°	150	173	1,375	-938 ↓
Tue 09:19:28 AM	40.6126	-73.6907	← 301°	136	157	1,200	-750 ↓
Tue 09:19:31 AM	40.6136	-73.6928	← 301°	136	157	1,175	-632 ↓
Tue 09:19:47 AM	40.6183	-73.7032	← 301°	133	153	1,000	-656 ↓
Tue 09:20:19 AM	40.6282	-73.7251	← 300°	121	139	600	-750 ↓
Tue 09:20:35 AM	40.6325	-73.7345	← 301°	124	143	425	-703 ↓
Tue 09:20:51 AM	40.6375	-73.7456	← 300°	119	137	225	-703 ↓
Tue 09:21:07 AM	40.6418	-73.7551	← 300°	126	145	50	-656 ↓
Tue 09:21:23 AM	40.6467	-73.7658	← 301°	122	140		-656 ↓

4.2. Visualization of trajectory data at specific software

Let`s import trajectory data of DAL375 from 05 September 2023 into specialized software of MATLAB [10]. Results of trajectory data visualization for flight is represented in fig. 4.2 and vertical profile of flight is in fig.4.3.

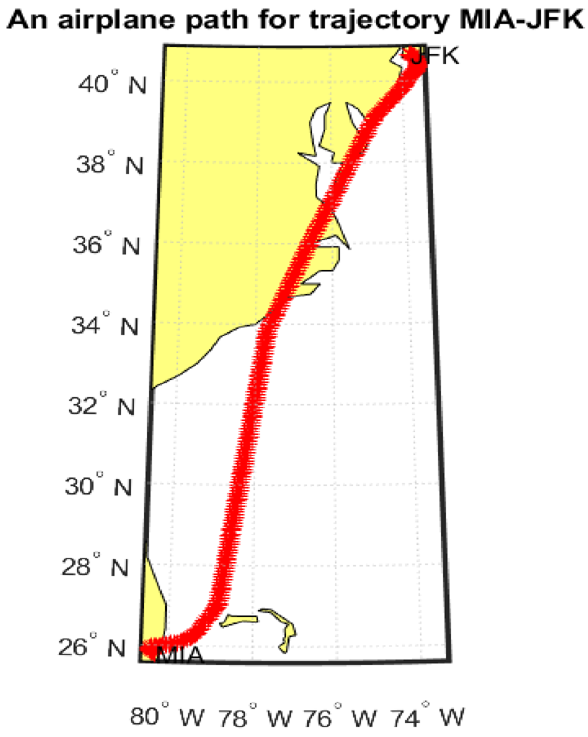

Figure 4.2 - Flight path of DAL375 (05 September 2022)

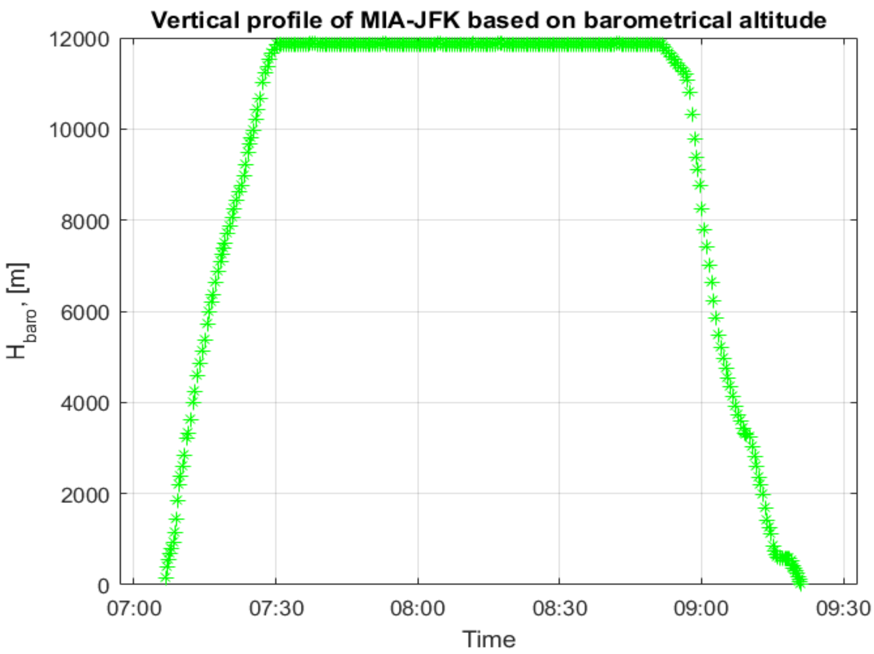

Figure 4.3- Flight path of DAL375 (05 September 2022)

4.3. Trajectory data interpolation

The digital messages transmitted within ADS-B are not synchronized in time. A transmitter of each airspace user can be set to its frequency of digital message generation. In addition, it should be noted that the frequency of 1090 MHz is quite busy, since secondary radars, airborne collision and avoidance systems, and ADS-B use it. This leads to the fact that many digital messages may interfere with each other that destroy data transmitted inside of these messages. Therefore, ADS-B trajectory data includes many gaps in the sequence and broken messages. At the stage of data processing usually, methods of data interpolation are used to solve this problem. The interpolating function can be polynomials or spline functions. The results of interpolation of input data at a frequency of 1 Hz are shown in Fig. 4.4 - 4.6. All subsequent calculations will be performed with interpolated data. Let's display the data in the local NEU system. As the center of the system, we will use the coordinates of the first point of the trajectory. The results of visualization of the trajectory in the local system are shown in fig. 4.7 and fig. 4.8.

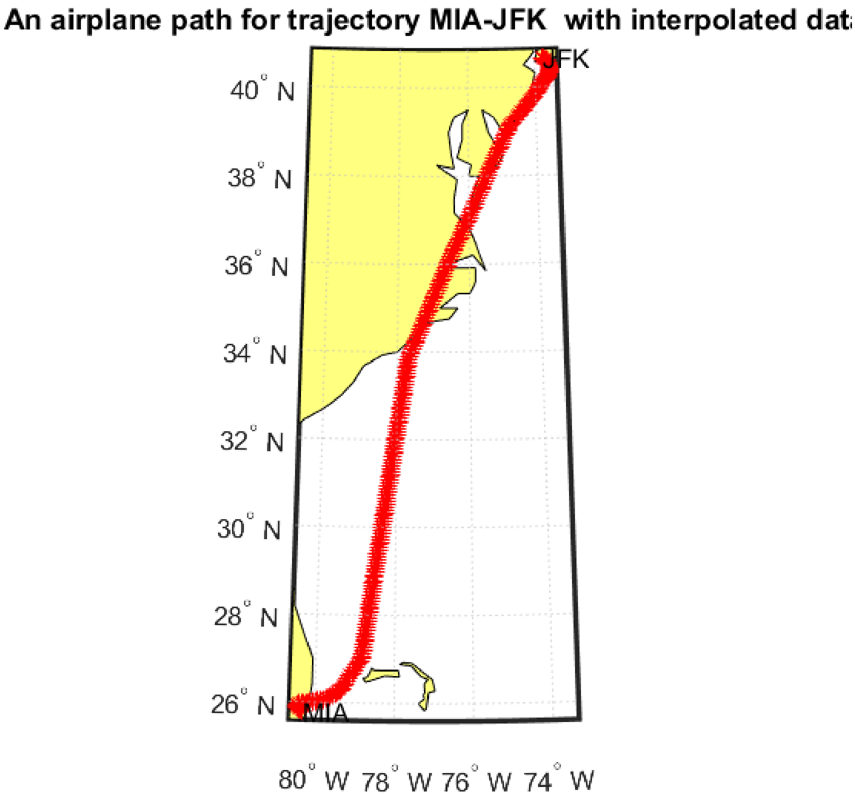

Figure 4.4 -Interpolated flight path of DAL375 (05 September 2022)

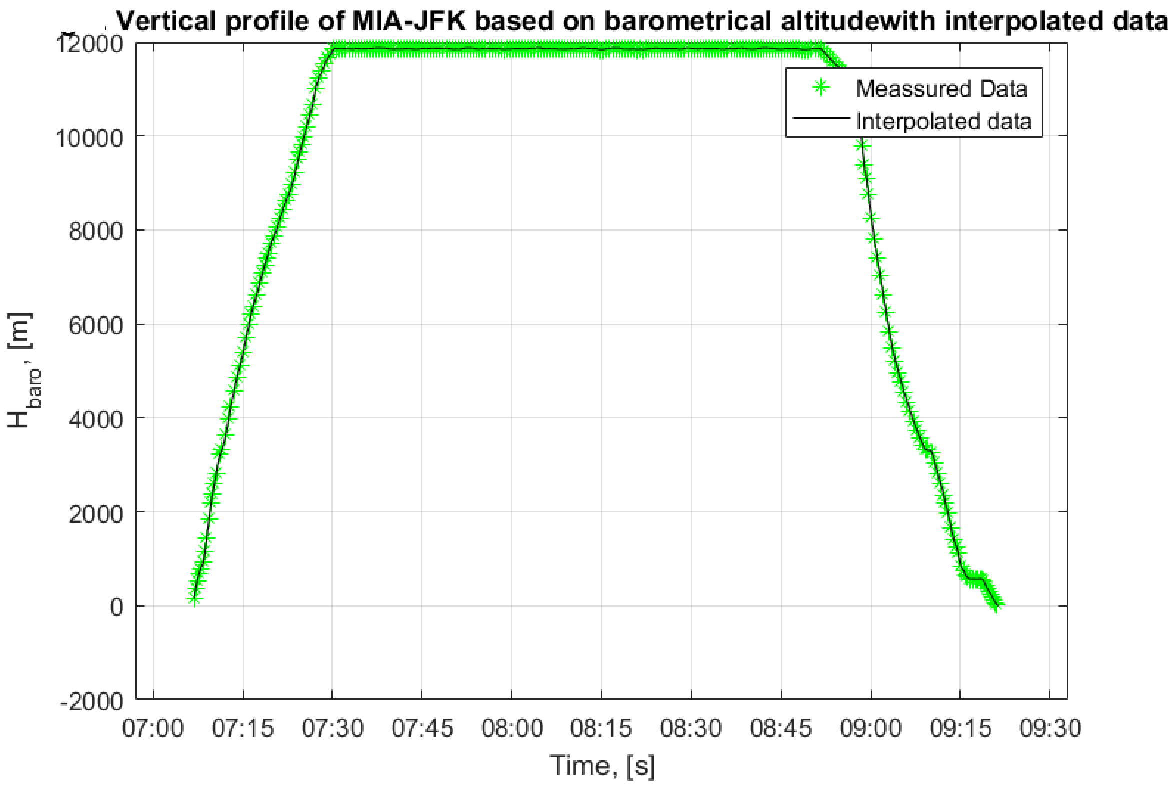

Figure 4.5 -Interpolated vertical profile of DAL375 (05 September 2022)

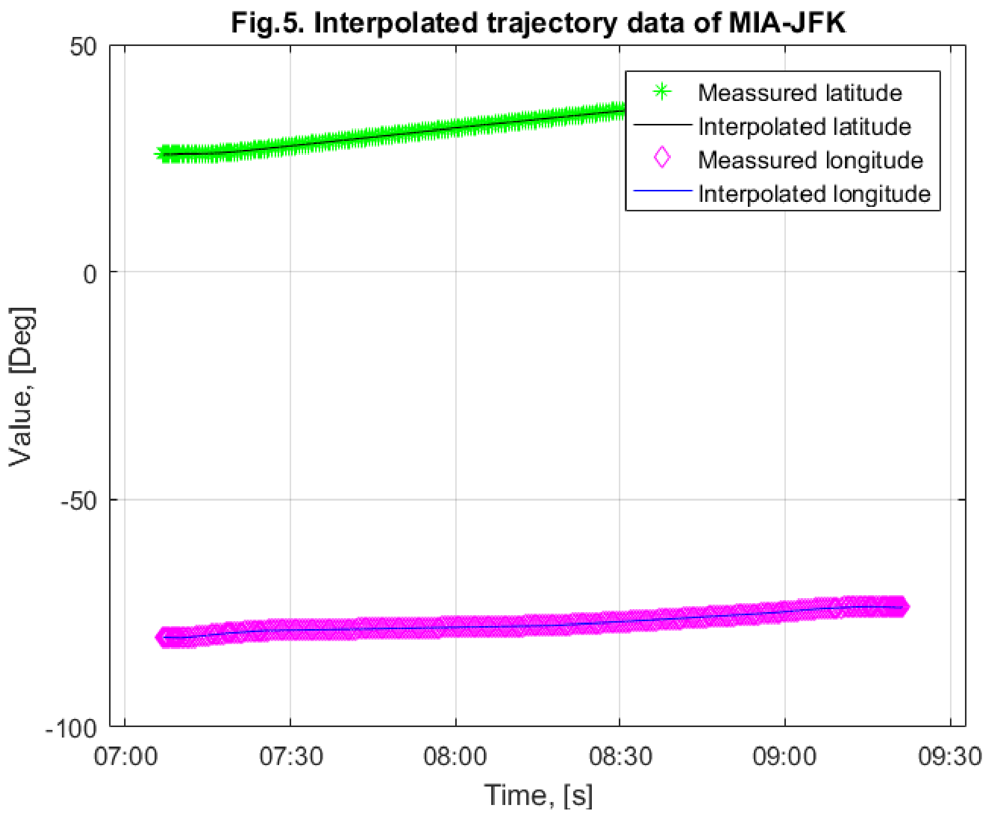

Figure 4.6 - Interpolated data for 1 Hz of DAL375 (05 September 2022)

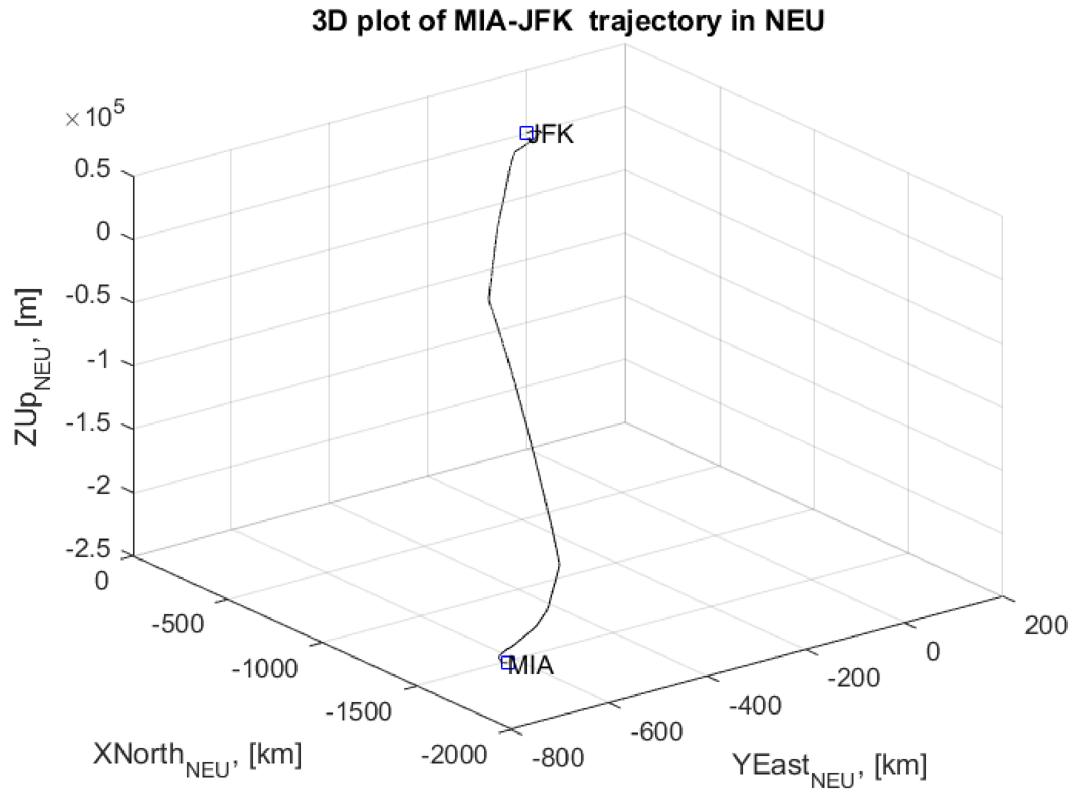

Figure 4.7 - 3D trajectory of DAL375 in NED reference frame

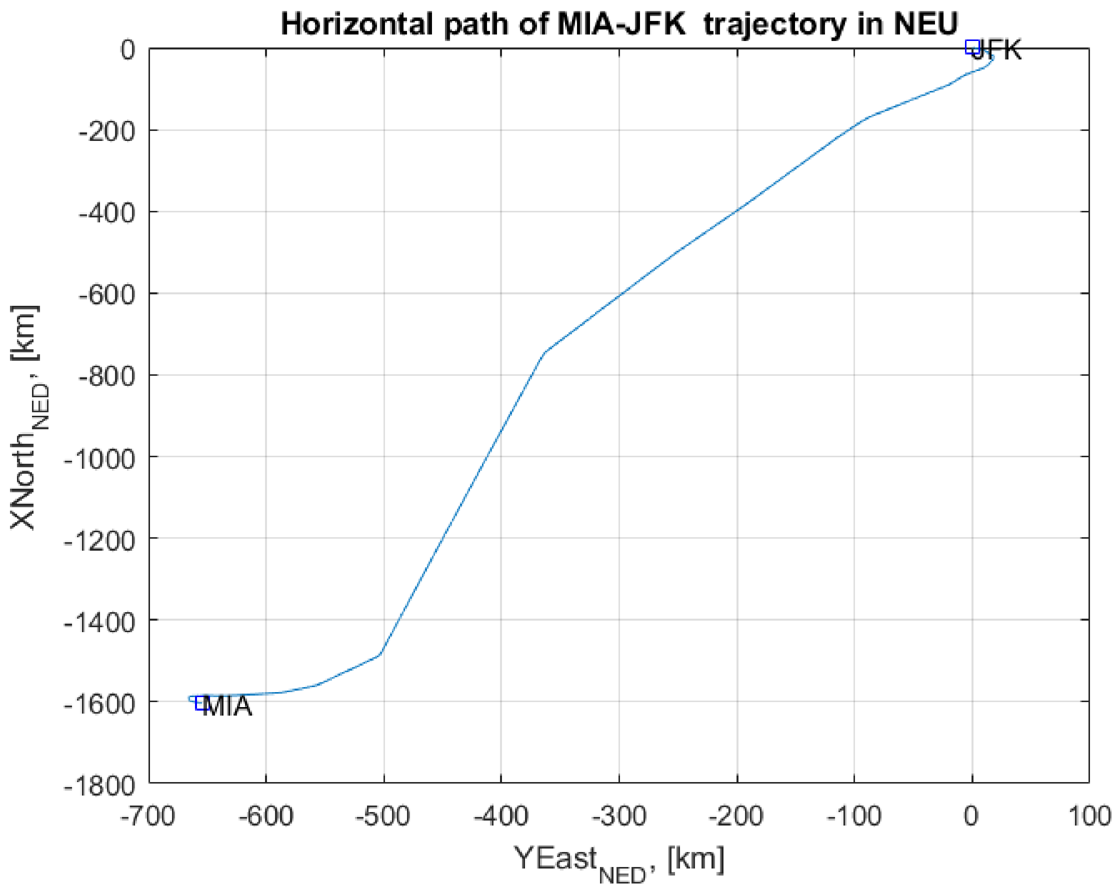

Figure 4.8 – Flight path of DAL375 in local NED

4.4. Trajectory data calculation

Based on the data set of the three-dimensional movement trajectory, we will calculate the speed components. In particular, I calculate the full speed of an airplane, vertical, and horizontal components. The results of the ground speed calculation are shown in fig. 4.9, vertical speed fig. 4.10 and the estimated course of the plane in fig. 4.11 Also, I calculate the total flight time and the length of the route.

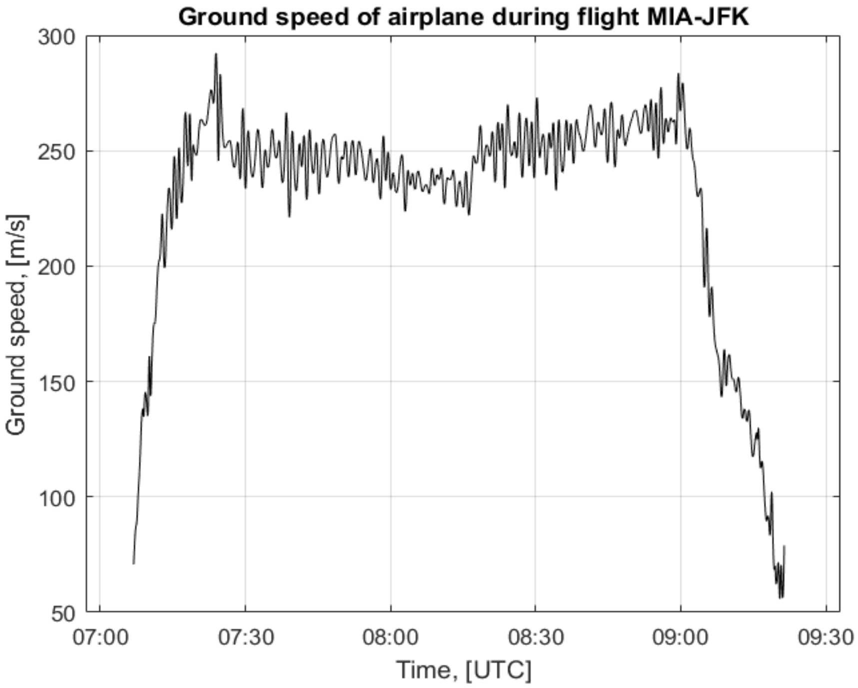

Figure 4.9 – Ground speed of DAL375

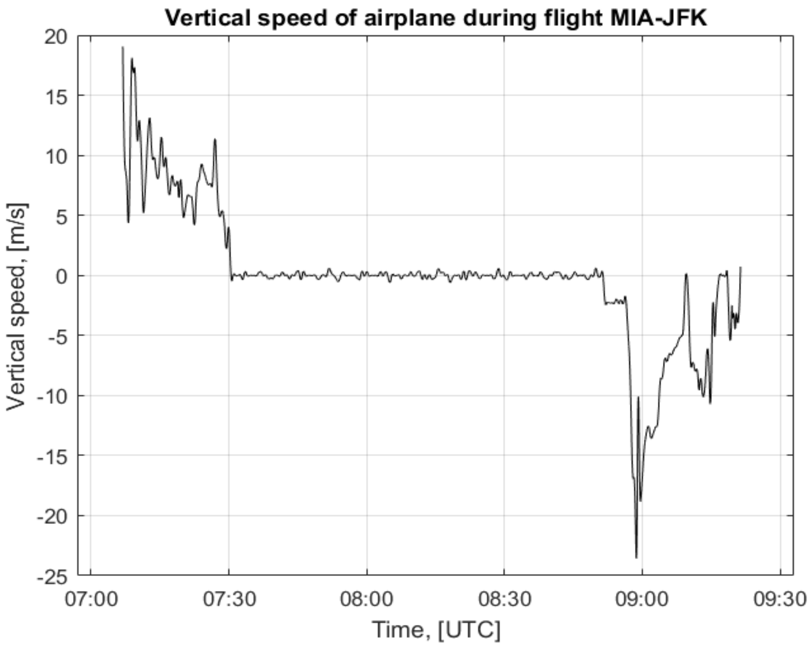

Figure 4.10 – Vertical speed of DAL375

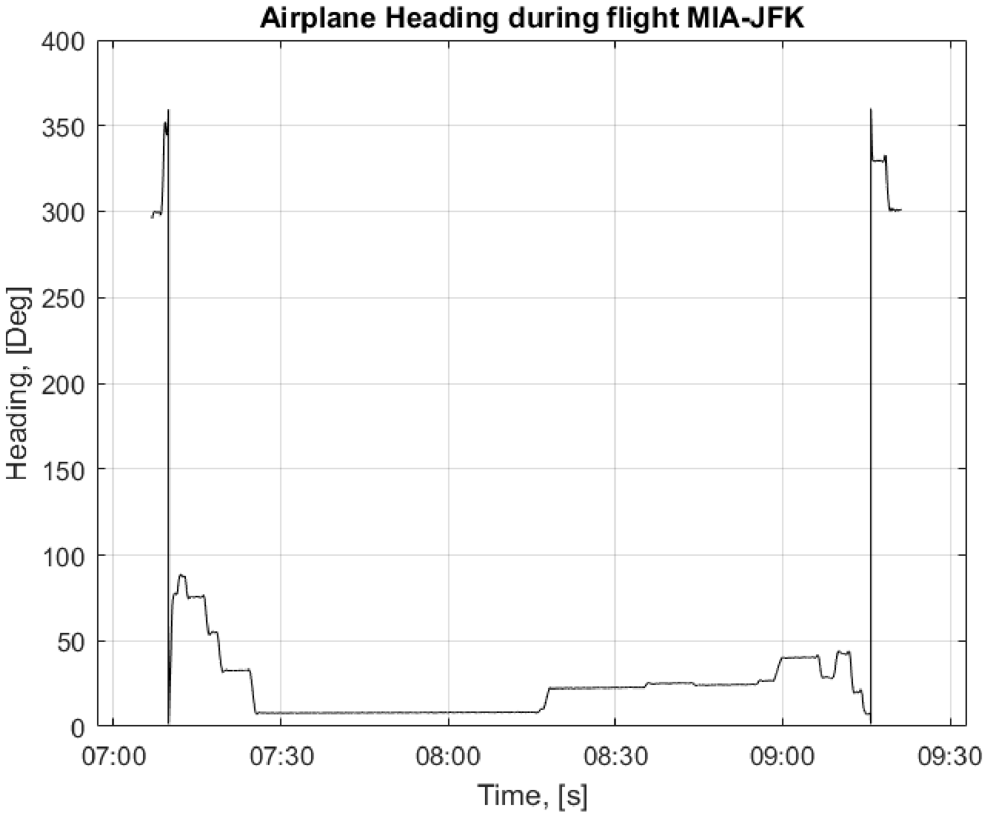

Figure 4.11 - Results of heading angle calculation of DAL375

The total flight time of DAL375 on December 05, 2023, was 2 hours 40 minutes and the length of the trajectory is 1862 km.

CONCLUSION TO CHAPTER 4

Based on the analysis of the flight path of flight DAL375, performed on December 5, 2023 by Airbus A321, it can be concluded that the flight lasted 2 hours 40 minutes and covered a distance of 1862 kilometers. The speed of the aircraft during the flight varied, reaching a maximum value of 840 km/h. The vertical speed of ascent and descent also varied depending on the stage of the flight.

ADS-B data contains gaps and interrupted messages due to frequency congestion and possible interference. Interpolation is used to fill the missing data and provide a smoother analysis. The local NEU coordinate system is a convenient way to analyze the relative position and movement of the aircraft. The calculated speed and flight time components give an idea of the characteristics of the aircraft.

Automated data processing is an important task for modern air navigation systems. Data on navigation parameters are used both on board aircraft and on ground equipment. Combining data from different sensors is used to reduce the impact of measurement errors. The widespread use of ADS-B improves aviation safety and efficiency of air traffic control.

Overall, the findings confirm the importance of accurately determining and processing aircraft flight path data to ensure the safety and efficiency of air travel.

CHAPTER 5
LABOR PRECAUTION AND ENVIRONMENT SAFETY

5.1 Labor precaution

The aviation industry is considered one of the safest professions. However, this risk still pertains to the area's accidents and occupational diseases. The safety of aviation workers, including the crew and passengers, is reliant on the safety of the airport.

The primary responsibilities of labor protection in flight:

• Preventing the safety of employees of aviation companies, airports and other organizations associated with aviation.

• Avoiding accidents and diseases that occur during work.

• The creation of safe working conditions.

The primary protections for labor in aviation are:

• Legislative oversight of labor protection.

• Implementation of protective legal regulations regarding labor protection.

• The brief and training of employees on labor safety.

• Providing employees with personal protection equipment.

• Maintenance and sửa chữa of equipment and mechanisms.

• Constant observation of safety-related matters.

The legislative oversight of aviation's labor protection is described.

Labor protection in the aviation industry is enforced by the Law of Ukraine "On Labor Protection" as well as other relevant laws. The Law of Ukraine "On Labor Protection" describes the legal, economic, social and institutional components of labor protection in Ukraine.

Occupational Safety Regulation

On the basis of the Law of Ukraine "On Labor Protection," laws regulating labor protection are created. Regulatory laws on labor protection define the requirements for working conditions, protection from injury, safety during labor, health during occupation, sanitation during industrial processes and fire safety.

Safety briefings and instructional programs

Employees of aviation organizations, airports and other organizations associated with aviation should be taught and instructed in regards to labor protection. Occupational safety briefings are organized to educate employees about the requirements of legal regulations regarding occupational safety and health. Occupational safety training is implemented in order to educate employees and increase their knowledge of safety-related issues.

Employees should be given personal protective equipment.

Employees of aviation companies, airports and other organizations associated with aviation must be given personal protective equipment (PPE). PPE is intended to shield workers from the potential dangers and harmful effects of the production environment.

Maintenance and repair of equipment and mechanisms.

The equipment and mechanisms used in the aviation industry must be in decent condition and follow the regulations regarding labor protection. Maintenance and mending of equipment and mechanisms is conducted in order to avoid accidents and illnesses associated with occupation.

Constant observation of safety-related activities.

At organizations, enterprises and institutions associated with aviation, the constant surveying of the safety state should be conducted. Occupational safety monitoring is employed in order to identify and remediate hazardous and harmful aspects of the production environment.

The task of safety in aviation is considered a complex endeavor that necessitates the collaboration of companies, organizations and institutions associated with aviation as well as the state.

The implementation of cellular technology in aircraft has the potential to have both positive and negative effects on labor protection.

Positive results:

Increasing flight safetya: Cellular technology can be employed to transmit data from on-board sensors like inertial and magnetic sensors to servers in the ground.

Ground servers can utilize this information to determine the aircraft's location and identify any potential dangers.

Increased efficiency in flight control: cellular communication can be employed to transmit commands to the aircraft or to receive video from the aircraft to the ground. This can assist the pilot in better managing the aircraft and responding to unexpected situations.

Enhanced communication between the crew and the passengers: cellular technology can be employed to disseminate information to the passengers or to communicate with other passengers. This can enhance the comfort and confidence of passengers during the flight.

Negative consequences

Increased risk of electromagnetic radiation: Cellular networks use electromagnetic waves to transmit data. These electromagnetic waves can be harmful to people's health if they are too strong or if a person is exposed to them for a long time.

Increasing the risk of hacker attacks: cellular networks are a potential target for hacker attacks. Hackers can access cellular data, or they can use cellular communication to remotely control an aircraft.

Increase in weight and cost of aircraft: cellular communication requires additional equipment that increases the weight and cost of aircraft.

Below is a table 5.1 on the impact of cellular communications on aviation safety.

Here are some specific actions that can be taken to ensure the safety of the cellular communication in aircraft:

- Use cellular networks that operate at low frequencies of electromagnetic radiation that are less detrimental to health.
- Inject special components into aircraft that defend against radiation from the electromagnetic spectrum.

Here are some specific actions that can be taken to ensure the safety of the cellular communication in aircraft:

Table 5.1 - The impact of cellular communications on aviation safety

Impact	Positive	Negative
Flight safety	* Improved flight safety by transmitting data from on-board sensors to ground servers.	* Increased risk of electromagnetic radiation.
Flight efficiency	* Improved flight efficiency by transmitting control commands to the aircraft or receiving video from the aircraft to the ground.	* Increased risk of hacking attacks.
Communication between crew and passengers	* Improved communication between crew and passengers by providing passengers with flight information or connecting passengers with each other.	
Weight and cost of aircraft		Increased weight and cost of aircraft.

- Use cellular networks that operate at low frequencies of electromagnetic radiation that are less detrimental to health.
- Inject special components into aircraft that defend against radiation from the electromagnetic spectrum.
- Ensure the safe use of cellular technology aboard the aircraft.

Also, it's crucial to create and implement safety protocols for cellular aviation communications. These standards should describe the necessities of the aircraft's equipment, as well as the requirements for the procedures used to ensure safety.

The implementation of cellular technology in aircraft is a complicated process that involves careful analysis of the potential dangers and the development of strategies to reduce them. If these steps are taken, the implementation of cellular technology in aircraft will have a significant positive impact on safety and efficiency of flight control.

5.2 Environment safety

Environmental protection in the aviation industry.

The aviation sector is considered one of the most evolving economies. Recently, the number of air travel has increased significantly. This indirectly causes an increase in the environmental impact of aviation.

The primary contributors to the environmental impact of aviation are:

• Emissions of harmful substances into the air: aircraft engines emit into the atmosphere substances that are detrimental to the environment such as carbon dioxide, nitrogen dioxide, sulfur and metals that are heavy. These substances can cause air pollution, acidity, temperature changes, and other issues.

• Sound pollution: Aircraft engines and other aircraft vehicles produce noise that can negatively affect the health of humans and animals.

• Soil and water pollution: Aircraft accidents can cause soil and water to become polluted with oil, chemicals and other deleterious substances.

Emitting substances that are harmful into the atmosphere.

One of the most significant areas of environmental protection in aviation is to reduce the release of harmful substances into the atmosphere. To accomplish this, new engine technologies are being developed and implemented that reduce the release of carbon dioxide, nitrogen oxide and other harmful substances. The utilization of more effective fuels and oils also has a positive effect on reducing the release of harmful substances.

One promising direction of aviation growth is the utilization of alternative energy sources in the aircraft. For instance, scientists are attempting to create aircraft that utilize hydrogen as their fuel. Hydropower is a renewable energy source that doesn't release harmful substances into the atmosphere.

Reduce noise pollution.

Another serious issue associated with aviation is noise pollution. To eradicate noise pollution, new engine designs are being pursued that diminish noise. The implementation of more effective noise mitigation measures also has the potential to reduce noise pollution.

Avoiding accidents on aircraft.

Aircraft accidents can cause soil and water pollution. To lower the probability of aircraft accidents, the qualification of pilots and other aviation professionals is increased. Other more dependable and secure technologies are also being advanced.

Environmental protection in aviation is a significant responsibility that necessitates the collective efforts of companies, organizations and institutions associated with aviation as well as the government.

Engineers and scientists are always attempting to invent new methods of technology that lessen the negative impact of aviation on the environment. For example, in 2023, Airbus released a new aircraft with a new engine design that could reduce the release of harmful substances by 25%.

In the future, we can expect additional growth in environmental protection technologies that are associated with aviation. This can lead to a decrease in the release of harmful substances, noise and the potential for aircraft accidents.

The introduction of cellular communications in aircraft can have both positive and negative consequences for environmental protection.

Positive effects:

• Reducing emissions of harmful substances into the air: cellular communication can be used to transmit data from on-board sensors, such as inertial sensors and magnetic sensors, to ground servers. Ground servers can use this data to clarify aircraft coordinates and identify potential hazards. This can lead to a decrease in emissions of harmful substances into the air, since the aircraft will be able to avoid unnecessary maneuvers and save fuel.

• Reduction of noise pollution: cellular communication can be used to transmit control commands to the aircraft or to obtain video from the aircraft to the ground. This can reduce noise pollution, as the aircraft will be able to use more effective control methods and avoid unnecessary maneuvers.

Negative consequences:

• Increased emissions of electromagnetic radiation: cellular networks use electromagnetic waves to transmit data. These electromagnetic waves can contribute to environmental pollution because they can damage ecosystems and affect human and animal health.

• Increasing the risk of aircraft accidents: cellular communication is a potential target for hacker attacks. Hackers can use cellular communication to remotely control the aircraft, which can lead to accidents and environmental pollution.

To minimize the negative consequences of the introduction of cellular communication in aircraft, it is necessary to take measures to ensure the safety of electromagnetic radiation, protect against hacker attacks and reduce the risk of aircraft accidents.

Here are some specific measures that can be taken to ensure the safety of the introduction of cellular communications in aircraft from the point of view of environmental protection:

• Use cellular networks that use low-frequency electromagnetic waves that are less harmful to the environment.

• Install special equipment in aircraft to protect against electromagnetic radiation.

• Ensure safe use of cellular communication on board the aircraft.

• Develop and implement safety standards for cellular communications in aircraft.

The introduction of cellular communications in aircraft is a complex task that requires careful study of possible risks and the development of measures to minimize them. If these measures are taken, the introduction of cellular communications in aircraft can have a significant positive impact on environmental protection.

Here are some specific examples of how cellular communications can be used to reduce aviation's environmental impact:

• Cellular communication can be used to transmit data from on-board sensors, such as emission sensors, to ground servers. This can help aviation companies track and control their aircraft emissions.

• Cellular communication can be used to transmit control commands to the aircraft or to obtain video from the aircraft to the ground. This can lead to reduced emissions of harmful substances into the air and noise pollution, as the aircraft will be able to use more effective control methods and avoid unnecessary maneuvers.

- Cellular communication can be used to provide communication between the crew and passengers. This can help the crew respond to unforeseen situations and provide a more comfortable flight for passengers.

In general, the introduction of cellular communications into aircraft has the potential to significantly reduce the environmental impact of aviation. However, in order to achieve this potential, it is necessary to take measures to ensure the safety of electromagnetic radiation, protect against hacker attacks and reduce the risk of aircraft accidents.

CONCLUTION TO CHAPTER 5

The introduction of cellular communications in aircraft has the potential to both positively and negatively affect labor and environmental protection.

On the one hand, cellular communication can be used to improve flight safety, reduce emissions of harmful substances and noise pollution. For example, cellular communication can be used to transmit data from onboard sensors, which will allow pilots to better navigate in space and avoid unnecessary maneuvers. This can lead to reduced fuel consumption and emissions of harmful substances. In addition, cellular communications can be used to remotely control aircraft, which can reduce the risk of accidents.

On the other hand, cellular communication can lead to an increase in electromagnetic radiation emissions, which can adversely affect human and animal health. In addition, cellular communications can be a potential target for hacker attacks, which can lead to aircraft crashes.

To minimize the negative consequences of the introduction of cellular communications in aircraft, it is necessary to take measures to ensure the safety of electromagnetic radiation, protect against hacker attacks and reduce the risk of aircraft accidents.

GENERAL CONCLUSION

The introduction of cell communication technology in the aviation industry represents a transformational step towards improving the safety, efficiency and satisfaction of passengers. The research conducted in this work emphasizes the numerous advantages that cellular communication brings to various participants in the aviation industry.

The study highlights the critical role of reliable communications during aviation operations. Cellular technologies provide a constant and stable link between the aircraft and the ground, offering benefits such as real-time updates for pilots, improved situational awareness for dispatchers, and overall safety improvements. The integration of cellular communication into electronic systems allows for the rapid exchange of information regarding flight status and emergencies, contributing to a more operational and coordination approach in critical situations.

The positive impact extends to traffic control and navigation, where 4D-navigatsiï technologies supported by cellular communication contribute to effective traffic control and optimal use of airspace. Passengers can also benefit from these advances through in-flight internet access, mobile connectivity, and improved entertainment options, ultimately increasing their overall level of comfort.

In addition, the study addresses pressing issues facing the aviation industry, including outdated infrastructure and limited capacity. Recommending innovative solutions such as 5G technology, Internet of Things (IoT) and satellite communications is crucial to overcome these difficulties. The implementation of a comprehensive infrastructure improvement plan, including updating the technical base, expanding coverage areas and integrating modern navigation systems, is noted as a key aspect.

The study recognizes the importance of considering performance and reliability requirements in aviation communications. The growing demand for high-speed data exchange, compatibility with other technologies and the need for innovative solutions highlight the dynamic nature of the aviation industry.

The described advantages of cellular communication for pilots, airlines, dispatchers and passengers emphasize improved operational efficiency, safety and cost reduction. The potential of cell technology for the revolution of navigation through higher accuracy and economy is highlighted.

Even while recognizing the promising potential of cellular communication in aviation, the study also recognizes the technical difficulties that need to be addressed, such as providing reliable connections under interference conditions and managing the cost of equipment and services.

In general, this work provides a comprehensive overview of the possibilities and advantages of introducing cell communication technology in air transport. The findings and recommendations are a valuable resource for aviation industry participants, guiding further development that can transform the landscape of air communication systems into a safer, more efficient and connected aviation environment.

The study determines that the transition from outdated technologies to the latest ones, such as 5G and the Internet of Things, is a strategically important step in the development of aviation communications. The use of such innovations contributes to increasing the speed of data transmission, ensuring the stability of communication with a large concentration of air traffic and in various weather conditions.

An in-depth study of the problems that arise in connection with the use of outdated technologies in aviation indicates the need for large-scale updating of infrastructure and the establishment of modern standards. Proposals for the development of aerospace communications include the introduction of 5G technologies, the development of satellite communications and the use of the Internet of Things, which indicates the readiness of the industry to move to more advanced and efficient systems.

Systematic analysis highlights that cellular communication in aviation solves not only technical challenges, but also contributes to solving problems of efficiency, safety and passenger satisfaction. Measures to expand coverage, optimize airports, introduce energy-efficient technologies and protect against cyber threats reinforce the idea of an integrated approach to the development of aviation communications.

Particular attention is paid to the consideration of the benefits for pilots, airlines, dispatchers and passengers, which emphasizes the importance of cellular communication for all participants in the aviation industry. Reliable communication is a key element to ensure safety, efficiency and comfort in aviation.

Overall, this study represents an important contribution to understanding the possibilities and challenges associated with the introduction of cellular communication in the aviation field. The knowledge and recommendations gained from this study are of high strategic value to all participants in the aviation industry, setting the path for further innovation and improvement in the field of air communication systems.

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