International Journal of Innovative Research in Computer Science & Technology (IJIRCST)
ISSN: 2347-5552, Volume-12, Special Issue-1, March-2024
https://doi.org/10.55524/CSISTW.2024.12.1.52
Computing for Sustainable Innovation: Shaping Tomorrow's World (CSISTW-2024) on 16th-17th February, 2024
Organized by B.N. College of Engineering and Technology, Lucknow, India

5G Technology Effects On Aircraft

Jyoti Kumari[1], Syed Habeeb[2], and Kaneez Zainab[3]

[1,3] B N College of Engineering and Technology, Lucknow, Uttar Pradesh, India
[2]Research Centre Imarat, Hyderabad, India

Correspondence should be addressed to Jyoti Kumari; jsjyotisingh402@gmail.com

ABSTRACT- The advent of 5G technology has sparked considerable interest and scrutiny within the aviation industry due to potential effects on aircraft systems. This abstract explores the impact of 5G networks, particularly in the C-Band, on crucial aviation components such as radio altimeters. The Federal Aviation Administration (FAA) has responded by implementing Airworthiness Directives, mandating the use of 5G C-Band-tolerant radio altimeters or approved filters in certain aircraft categories. The study delves into concerns related to interference during critical flight phases and highlights collaborative efforts to establish buffer zones around airports to mitigate potential 5G disruptions. Ultimately, the aviation sector faces the challenge of adapting to evolving telecommunication technologies while maintaining the safety and reliability of flight operations.

KEYWORDS- 5g, Radio Altimeter, C-Band Spectrum, Filter Implementation. 5G Transmission Control, Buffer Zones.

I. INTRODUCTION

5G, short for fifth-generation, represents the latest advancement in wireless communication technology, aiming to enhance the speed and responsiveness of wireless networks. With 5G, data transmitted through wireless broadband connections can achieve speeds of up to 20 Gbps and a latency as low as 1 millisecond. This marks a substantial improvement compared to the speeds offered by 4G networks, which reach up to 1 Gbps. Notably, 5G networks have the capability to connect numerous devices simultaneously, making them a pivotal component in the Internet of Things (IoT). The implementation of 5G technology is poised to usher in a new era of technological progress, enabling developments such as autonomous vehicles, smart cities, and advanced augmented and virtual reality experiences. However, it's crucial to recognize that realizing these advancements will necessitate substantial infrastructure development and pose novel regulatory challenges [1].5G, the latest advancement in wireless communication technology, has been a focal point in the aviation sector due to its potential benefits and challenges. This technology aims to boost the speed and responsiveness of wireless networks, which can have significant effects on aircraft and their equipment.In the aviation context, the potential of 5G technology to improve aircraft communication systems is being explored. The advent of 5G has raised concerns about its potential to disrupt aircraft operations, especially during landings at airports. However, the aviation industry, in partnership with wireless service providers and regulatory bodies like the Federal Aviation Administration (FAA), is striving to ensure that 5G and aviation can coexist safely.A key concern is the potential for 5G signals to interfere with aircraft instruments, specifically radio altimeters. These devices play a critical role in determining an aircraft's altitude above the ground and supplying data for safety and navigation systems. To address this, the FAA has proposed measures such as equipping aircraft with 5G C-Band-tolerant radio altimeters or installing suitable radio frequency filters [2]. Furthermore, the aviation industry is investigating the use of 5G technology for various purposes, including enhancing passenger connectivity, improving cockpit communication data transmission, and streamlining ground operations. However, the introduction of 5G in aviation necessitates careful consideration of several factors, including spectrum allocation, potential interference with existing systems, and the requirement for new infrastructure.In conclusion, while 5G technology presents considerable opportunities for the aviation industry, its implementation needs to be meticulously managed to ensure the safety and efficiency of aircraft operations.

II. CONCERNS HAVE EMERGED IN AVIATION ABOUT THE ADOPTION OF 5G TELECOMMUNICATION NETWORKS.

Indeed, there are multiple other issues related to the application of 5G in aviation.
The introduction of 5G technology has resulted in disruptions, due to fears of potential interference with critical aviation equipment on board the aircraft such as radio altimeter.

A. Radio Aaltimeter

A radio altimeter, also referred to as a radar altimeter, is an electronic device onboard an aircraft that calculates the aircraft's altitude above the ground directly underneath it. It determines the altitude by measuring the time it takes for a radio wave beam to travel from the aircraft to the ground and back.

Figure 1: Radio altimeter working principle

In the early stages, radio altimeters calculated this time difference between the transmission of a radio signal from the aircraft and the reception of the reflected signal. However, contemporary systems employ different methods, such as assessing the phase shift between the transmitted and reflected signals.

The radio altimeter plays a crucial role in the functioning of ground proximity warning systems and in the operation of aircraft during specific types of approaches. It is used to ascertain the aircraft's position relative to the applicable decision height. The judicious use of the radio altimeter can serve as an effective safeguard against Controlled Flight Into Terrain (CFIT) [3].

The advent of 5G technology, specifically the C-Band 3.7-3.98 GHz spectrum, has sparked concerns in the aviation sector due to its potential to disrupt aircraft radio altimeters.Radio altimeters, which operate on a frequency of 4.2-4.4 GHz, are used to gauge an aircraft's altitude above the ground level by transmitting a radio frequency (RF) energy beam to the ground and capturing a reflected portion of this energy back from the terrain or obstacles, particularly in adverse weather conditions. They function by emitting radio waves and measuring the time it takes for these waves to reflect off the ground and return.

The issue arises because the frequency band utilized by 5G (3.7-3.98 GHz) is in close proximity to that of the radio altimeter. This closeness could potentially lead to interference, resulting in inaccurate altitude readings. If the waves from an altimeter fail to reflect back due to interference signals from a dense network of 5G cellular towers, the altimeter could provide an incorrect reading or cease to function entirely.To address this risk, the Federal Aviation Administration (FAA) has issued guidelines indicating that 5G 3.7-3.98 GHz networks could interfere with aircraft operations when flying within a mile of a 5G tower with 3.7-3.98 GHz service enabled. The FAA also highlights that the issue can impact other onboard systems, including the Terrain Awareness Warning Systems (TAWS-A), the Traffic Alert and Collision Avoidance Systems (TCAS II), and the Take-off guidance systems.The following is a highly simplified C code that demonstrates a basic approach to mitigate potential interference. This C code assumes that the altimeter receives analog signals and attempts to filter out potential interference from 5G signals and This C code includes a simple check for potential 5G interference during altitude updates.

```
#include <stdio.h>
#include <stdbool.h>
// Define constants
#define MAX_ALTITUDE 5000.0  // Maximum altitude in feet
#define MAX_5G_SIGNAL 10.0    // Maximum strength of 5G signal
// Structure to represent the radio altimeter
typedef struct {
   double altitude;  // Current altitude in feet
   bool isPowerOn;   // Power status of the altimeter
} RadioAltimeter;
// Function to initialize the radio altimeter
void initializeAltimeter(RadioAltimeter *altimeter) {
   altimeter->altitude = 0.0;
   altimeter->isPowerOn = false;
}
// Function to turn on the radio altimeter
void powerOn(RadioAltimeter *altimeter) {
   altimeter->isPowerOn = true;
}
// Function to turn off the radio altimeter
void powerOff(RadioAltimeter *altimeter) {
   altimeter->isPowerOn = false;
}
// Function to update the altitude reading, considering 5G interference
void updateAltitude(RadioAltimeter *altimeter, double newAltitude, double strengthOf5GSignal) {
   if (altimeter->isPowerOn) {
      // Check for potential 5G interference
      if (strengthOf5GSignal > MAX_5G_SIGNAL) {
         printf("Warning: Potential 5G interference detected. Altitude readings may be affected.\n");
      } else {
         altimeter->altitude = newAltitude;
      }
   } else {
      printf("Error: Altimeter is not powered on.\n");
   }
}
// Function to display the current altitude
void displayAltitude(RadioAltimeter *altimeter) {
   printf("Current Altitude: %.2f feet\n", altimeter->altitude);
}
int main() {
   // Create a radio altimeter instance
   RadioAltimeter altimeter;
   // Initialize the altimeter
   initializeAltimeter(&altimeter);
   // Power on the altimeter
   powerOn(&altimeter);
   // Simulate altitude updates with potential 5G interference
   updateAltitude(&altimeter, 1000.0, 8.0);
   displayAltitude(&altimeter);
   updateAltitude(&altimeter, 2500.0, 12.0);
   displayAltitude(&altimeter);
   // Power off the altimeter
   powerOff(&altimeter);
   // Attempt to update altitude (should display an error)
   updateAltitude(&altimeter, 3000.0, 6.0);
   return 0;
}
```

B. Spectrum Allocation

The distribution of the spectrum for 5G usage is a major issue. The International Air Transport Association (IATA) emphasizes that the preservation of current safety standards for civil aviation must remain a top priority for governments.The recently auctioned C-Band 3.7-3.98 GHz spectrum is an essential part of the radio spectrum for 5G networks. It offers wider, dedicated channels to enhance throughput and capacity across the entire network.This band is part of the mid-band spectrum, which spans from 1-6 GHz. The mid-band spectrum, inclusive of the C-Band, strikes a perfect balance between coverage and capacity. While it provides high capacity for optimal connectivity and supports a multitude of devices and applications, it has limitations such as the inability to penetrate some buildings and walls, and its coverage lies between low and high bands.The C-Band is of particular significance for 5G communications as it augments the network with 5G capability, a robust layer for enhanced connectivity that caters to both coverage and capacity demanded by mobile subscribers using cellular technology.

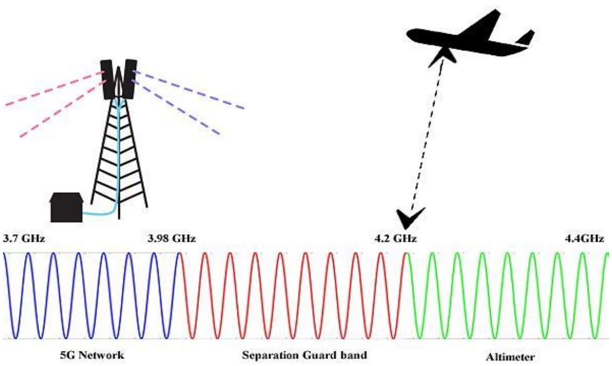

Figure 2: Frequency of C Band spectrum

The C-Band 3.7-3.98 GHz spectrum, vital for 5G networks, is alarmingly close to the frequency utilized by aircraft radio altimeters. These altimeters, operating on a frequency of 4.2-4.4 GHz, are employed to ascertain an aircraft's altitude above the ground[4].The apprehension is that 5G signals in the C-Band could potentially disrupt these altimeters, resulting in a loss of radar altitude data or even yielding dangerous and deceptive information. This disruption could cause a radar altimeter to display an incorrect altitude or cease functioning altogether.In response to safety concerns, the FAA issued two Airworthiness Directives that require updates to the limitations section of the current aircraft flight manual (AFM). These revisions include specific limitations to prevent certain operations that rely on radio altimeter data in the presence of 5G C-Band interference. Recognizing the potential impact of these safety measures on flight schedules and operations, telecommunications carriers have put forth a voluntary proposal to delay 5G deployment and restrict antenna operations in areas close to critical airports, where interference could cause the most significant disruptions.
The following is a highly simplified C code that demonstrates a basic approach to mitigate potential interference from the C-Band spectrum. This C code assumes that the altimeter receives analog signals and attempts to filter out interference within the C-Band and it includes a simple check for potential C-Band interference during altitude updates.

```
#include <stdio.h>
#include <stdbool.h>

// Define constants for C-Band spectrum
#define C_BAND_MIN_FREQUENCY 4.0e9 // Minimum frequency in Hertz
#define C_BAND_MAX_FREQUENCY 8.0e9 // Maximum frequency in Hertz

// Structure to represent the radio altimeter
typedef struct {
   double altitude;  // Current altitude in feet
   bool isPowerOn;   // Power status of the altimeter
} RadioAltimeter;

// Function to initialize the radio altimeter
void initializeAltimeter(RadioAltimeter *altimeter) {
   altimeter->altitude = 0.0;
   altimeter->isPowerOn = false;
}

// Function to turn on the radio altimeter
void powerOn(RadioAltimeter *altimeter) {
   altimeter->isPowerOn = true;
}

// Function to turn off the radio altimeter
void powerOff(RadioAltimeter *altimeter) {
   altimeter->isPowerOn = false;
}

// Function to update the altitude reading, considering C-Band interference
void updateAltitude(RadioAltimeter *altimeter, double newAltitude, double signalFrequency) {
   if (altimeter->isPowerOn) {
      // Check for potential C-Band interference
      if (signalFrequency >= C_BAND_MIN_FREQUENCY && signalFrequency <= C_BAND_MAX_FREQUENCY) {
         printf("Warning: Potential C-Band interference detected. Altitude readings may be affected.\n");
      } else {
         altimeter->altitude = newAltitude;
      }
   } else {
      printf("Error: Altimeter is not powered on.\n");
   }
}

// Function to display the current altitude
void displayAltitude(RadioAltimeter *altimeter) {
   printf("Current Altitude: %.2f feet\n", altimeter->altitude);
}

int main() {
   // Create a radio altimeter instance
   RadioAltimeter altimeter;
```

```
    // Initialize the altimeter
    initializeAltimeter(&altimeter);

    // Power on the altimeter
    powerOn(&altimeter);

    // Simulate altitude updates with potential C-Band interference
    updateAltitude(&altimeter, 1000.0, 5.0e9);   // C-Band frequency
    displayAltitude(&altimeter);

    updateAltitude(&altimeter, 2500.0, 9.0e9);  // Not in C-Band frequency
    displayAltitude(&altimeter);

    // Power off the altimeter
    powerOff(&altimeter);

    // Attempt to update altitude (should display an error)
    updateAltitude(&altimeter, 3000.0, 6.0e9);   // C-Band frequency

    return 0;
}
```

C. Infrastructure Requirements

The incorporation of 5G into aviation requires the creation of new infrastructure, which can be a complicated and expensive endeavor.

D. Potential Economic Impact

Senior executives at Boeing and Airbus have cautioned that 5G technology could have a substantial adverse effect on the aviation sector.

In conclusion, while 5G offers considerable promise for enhancing communications and operations in the aviation industry, its implementation must be carefully overseen to address these issues and ensure the safety and efficiency of aircraft operations.

III. POSSIBLE SOLUTIONS AND MEASURES

To address the potential disruption of 5G networks on aircraft radio altimeters, a number of strategies have been suggested:

A. Managing Distance

A strategy to address the issue involves regulating the distance between the 5G-C band tower and the airport runway. This measure aims to avoid interference from 5G-C band transmissions and ensure the precision of radar altimeter readings.

B. Filter Implementation

To mitigate potential problems, it is advised that airlines and other organizations operating aircraft equipped with the impacted radio altimeters promptly install filters or other enhancements. The provision of filters and replacement units for the primary commercial fleet is anticipated to coincide with a schedule that facilitates the completion of most of the required work by July 2023.

C. Non-transmission Mode for 5G Devices

It is suggested that all 5G Personal Electronic Devices (PEDs) on board the aircraft be set to a non-transmission mode to prevent them from transmitting on the cellular networks (for example, airplane mode) or be turned off. For necessary communications, crew members should use only 3G or 4G communication devices.

D. 5G C-Band-Tolerant Radio Altimeters

are a crucial component in aviation technology, designed to ensure the safe coexistence of 5G C-Band transmissions with aircraft operations. The Federal Aviation Administration (FAA) has introduced measures, including Airworthiness Directives, mandating the use of radio altimeters tolerant to 5G C-Band or the installation of approved radio frequency filters in transport category airplanes engaged in scheduled passenger or cargo flight operations. This is aimed at preventing interference from 5G signals, particularly during critical phases such as approach and landing. Additionally, the FAA has implemented buffer zones around airports where wireless companies voluntarily make adjustments to minimize potential 5G interference. These advancements and regulatory actions underscore the importance of adapting aircraft systems to accommodate evolving telecommunications technologies for the continued safety and reliability of air travel.

E. 5G Transmission Control

The Federal Aviation Administration (FAA) has worked in conjunction with both the aviation sector and wireless service providers to guarantee the secure coexistence of radio signals from recently deployed wireless telecommunication systems alongside flight operations. This effort involves establishing specific power limits for 5G C-band transmissions and modifying the tilt of 5G C-band antennas in a downward direction.

F. Establishing Buffer Zones

In an effort to minimize potential interference with sensitive aircraft instruments used in low-visibility landings, the FAA has defined buffer zones around 50 airports. Wireless companies have voluntarily committed to turning off transmitters and making necessary adjustments for a six-month period within these zones to mitigate potential 5G interference.

IV.5G AND ITS IMPACT ON AVIATION SAFETY

The introduction of 5G technology for wireless technology (such as telecommunication), has sparked considerable debate in the aviation sector due to its potential to disrupt aircraft systems [5].

A. 5G and Its Impact on Aviation Safety

The U.S. Federal Aviation Administration (FAA) has been working closely with the aviation sector and wireless service providers to ensure the harmonious coexistence of radio signals from the recently introduced 5G telecommunications
networks alongside flight operations. On January 9, 2023, the FAA issued an Airworthiness Directive (AD) aimed at facilitating the safe integration of aviation and 5G C-Band. This directive mandates that transport category

airplanes engaged in scheduled passenger or cargo flights must either be equipped with radio altimeters capable of tolerating 5G C-Band or have an approved radio frequency filter installed[6].

B. Concerns About Interference

The primary concern with 5G technology is its potential to disrupt aircraft instruments, specifically the radio altimeter. A radio altimeter calculates the altitude above the current terrain under an aircraft by measuring the time it takes for a radio wave frequency or beam to travel to the ground, bounce back, and return to the aircraft. The frequency used by 5G wireless technology, known as the C-band, is very similar to that used by a radio altimeter.

C. Steps to Mitigate Interference

To minimize the potential for interference, the FAA established a deadline requiring airlines to upgrade their aircraft altimeters by July 1, 2023. This deadline was strategically imposed ahead of the introduction of new regulations that restrict specific landings in conditions of low visibility unless altimeters have been upgraded. Additionally, the FAA entered into a voluntary agreement with Verizon and AT&T, leading to the postponement of certain C-Band and 5G usage until July 1, 2023. This collaborative effort provided air carriers with a timeframe to retrofit their aircraft altimeters, ensuring effective measures were in place to prevent interference.

D. Cooperation with Wireless Companies

On January 3, 2022, the FAA and AT&T as well as Verizon came to a mutual understanding. In this agreement, the wireless companies voluntarily committed to a delay and implemented measures aimed at substantially decreasing disruptions to air operations. Their collaborative efforts included the deactivation of transmitters and the implementation of various adjustments in proximity to chosen airports over a six-month period, all geared towards minimizing the potential interference of 5G signals with delicate aircraft instruments crucial for low-visibility landings[7].

E. Current Situation

By the end of September 2023, the entire U.S. airline fleet had upgraded their equipment, effectively mitigating the risk of 5G interference.

In conclusion, while the deployment of 5G technology has raised concerns in the aviation industry, steps have been taken to ensure the safe coexistence of 5G signals and aviation operations.

V. ANALYSIS OF SOLUTIONS

A number of strategies have been suggested to protect radio altimeter and communication systems from potential disruption:

A. 5G System to Radio Altimeter Interference Analysis Method

This technique examines the sources of interference between aircraft radio altimeters and 5G radio network frequencies. It offers theoretical backing for related research and risk evaluation of the radio altimeter (RA) system due to 5G interference[1].

B. Investigating Radar Altimeter Interference from Wireless Avionics Intra-Communication Systems

This study employs an extensive finite-difference time-domain method to examine the interference of radar altimeters caused by wireless avionics intra-communication (WAIC) systems. It conducts a thorough analysis of the electromagnetic field (EMF) surrounding a three-dimensional model of an Airbus A320 aircraft.

C. Study on the Interference Impact of Wireless Avionics Intra-Communication Systems

This research encompasses a comprehensive examination of the spectral characteristics of WAIC signals identified in the radio altimeter detection stage and evaluates their impact on altitude detection reliability.

D. Latest Findings on Compatibility Studies between WAIC Systems and Radio Altimeters

This update provides information on the latest findings from compatibility studies between internal WAIC systems and radio altimeters within the frequency band of 4200 – 4400 MHz.

These strategies are designed to ensure the safe and effective functioning of aircraft communication systems in the presence of 5G network technology.

VI. CONCLUSION

In conclusion, the introduction of 5G technology has ushered in a new era of enhanced communication speed and reliability. However, its deployment has sparked concerns within the aviation sector, especially with respect to potential disruptions to aircraft radio altimeters. These critical devices, which measure an aircraft's altitude above the ground, operate on a frequency band that is in close proximity to that used by 5G networks, leading to potential signal interference.A variety of strategies have been suggested to alleviate these concerns. These include the regulation of 5G transmissions, the implementation of filters on altimeters, the establishment of buffer zones around airports, the upgrading of altimeters, and the use of 5G devices in non-transmitting mode. Each of these strategies is designed to ensure the safe coexistence of 5G signals and aviation operations.

To sum up, while 5G technology poses challenges for aircraft communication systems, proactive measures and ongoing research are facilitating a smooth integration process. The objective is to harness the advantages of 5G technology while maintaining the safety and efficiency of aviation operations. As technology continues to advance, so too will the strategies for managing its impact on various sectors, including aviation. This is a reflection of the dynamic and adaptable nature of technological advancement.

CONFLICT OF INTERREST

The authors declare that they have no conflict of interest.

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