Enhanced Air Traffic Control Safety Using low Earth orbit Satellites: Non-TCAS Aircraft

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Abstract. This paper presents a study on a novel TCAS design that combines the exploitation of low-orbit satellites with the existing TCAS system to improve operational efficiency and overcome challenges. With the continuous growth of air traffic, ensuring safety remains a top priority. TCAS was developed to mitigate the risks of aircraft collisions and is mandatory on large transport aircraft. TCAS uses information and data to determine the altitude and relative positions of nearby aircraft. However, despite the advances in air traffic control (ATC) systems, non-TCAS-equipped aircraft continue to operate in the airspace, potentially increasing the risk of mid-air collisions. In addition, existing TCAS systems often generate frequent and unnecessary alarms, especially in densely populated terminal areas, leading to erroneous pilot actions. The proposed solution aims to detect non-TCAS-equipped aircraft by other aircraft, whether they are equipped with TCAS or not. Therefore, the goal is to optimize the efficiency of TCAS to reduce the risk of mid-air collision and improve overall aviation safety. The management applications are distributed on the cloud to save resource exploitation, including energy consumption by processing and air traffic control-related exchanges.

1.Introduction

The Traffic Alert and Collision Avoidance System (TCAS) is an essential onboard system that ensures aircraft safety by detecting and resolving conflicts in airspace [1]. Unlike traditional ground-based equipment, TCAS operates independently, relying on secondary surveillance radar (SSR) [2] transponder signals. Equipped aircraft receive real-time advice and information from TCAS, alerting them to potential conflicts with other aircraft.

TCAS II meets the stringent requirements of Airborne Collision Avoidance System (ACAS) II. It provides resolution advisories (RAs) to pilots, recommending vertical escape maneuvers to avoid intruding aircraft. While TCAS II Version 7 represents significant advancements in safety, efficiency, and technology, it still has limitations that must be addressed [3]. One significant concern is addressing aircraft that lack TCAS equipment. In fact, since these aircraft rely on traditional air traffic control (ATC) services and the vigilance of the flight crew to maintain safe separation from other aircraft, the role of air traffic control and pilot vigilance becomes even more

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critical in ensuring safety.

To enhance aviation safety, a proposed solution integrates Low Earth Orbit (LEO) satellites with TCAS. By using LEO satellites on aircrafts that are not equipped with TCAS, they can be detected by the system without TCAS or transponder mode C or S capabilities. The goal is to improve the current TCAS system and elevate safety standards in the aviation industry. Ultimately, the objective is to optimize system efficiency, accuracy, and safety, ensuring a more secure and reliable airspace for aircraft operators and passengers.

The exploitation of LEO satellites gives us a network similar in topology to known computer networks. Applications and management data can be distributed in the cloud to save the exploitation of resources especially the consumption of energy by processing and exchanges related to air traffic control.[4]

This paper is structured as follows. The first section presents related works, followed by an explanation of our approach. Subsequently, we will discuss this approach and conclude our paper.

2. Related works

The objective of ATM is to manage all air traffic by ensuring good regulation of the latter while respecting many safety standards. To do this, an organization of tasks is necessary, different actors are involved at different geographical scales and at different time scales. The different challenges of ATM become apparent when considering the problem from the passenger's point of view. We therefore see two of the major challenges of ATM appear: guaranteeing maximum safety for users of the system and respecting the announced schedules as best as possible.[5]

The first challenge is essential, it is safety. Concretely, this translates, for aircraft, into avoiding congested areas, dangerous weather zones, and of course, other surrounding aircraft.

The second challenge is compliance with the plans made. This translates concretely into compliance with schedules and therefore, by the desire to stay as close as possible to the planned trajectories.

Compliance with these two issues may seem simple, but ATM is a complex system, containing many uncertainties. We will see later that compliance with these rules requires a large organization, a vision at different scales, and involves many actors.

New trends allow using information collected from LEO satellites to warn of collision risks and advise pilots on the choice of trajectories to follow. In a previous study, we used the intersection points of trajectories to achieve separation and avoid collisions.[6][7]

To conduct our study, we will begin by analyzing the distinct data models of TCAS, including TCAS I and TCAS II. We will delve into a comprehensive description of TCAS II, focusing on its technical aspects and functionalities. Subsequently, we will introduce the proposed system and provide a detailed description of its components. Through a comparative analysis, our study aims to underscore the strengths and advantages of the new system in comparison to the existing TCAS models.[8]

Moreno et al.[9] proposes the two-dimensional structuring of traffic density in a set of air traffic flows identified from historical operational data in the analysis sector. In the vertical dimension, traffic will always be structured in flight levels. In a later step, a prediction of this structured traffic density is attempted by means of machine learning models. This methodology has made it possible to facilitate the work of the ATC service by allowing it to have a picture of the air traffic organization of the ATC sector before the actual operation occurs. The application of this methodology will allow adjusting the resources of the ATC service.

We will review and analyze the relevant literature and previous research studies that contribute to enhancing aviation safety by the development of TCAS principles. International Civil Aviation Organization (ICAO) has described three levels of ACAS [10]: ACAS I, ACAS II and ACAS III:

- ACAS I provides information as an aid to "see and avoid" action but does not include the capability to generate Resolution Advisories (RAs). (Fig. 1)
- ACAS II provides vertical resolution advisories (RAs) in addition to Traffic Advisories (TAs). (Fig. 1)
- ACAS III provides vertical and horizontal Resolution Advisories (RAs) in addition to Traffic Advisories (TAs).

ACAS X [11] represents a main revolution in how the advisory logic is generated and represented.

Fig. 1. The description of TCAS I and TCAS II

3. Our Approach

In our research approach, we aim to explore the feasibility of tracking aircraft without TCAS (Traffic Collision Avoidance System) equipment. We propose utilizing Low Earth Orbit satellites to accurately determine the position, altitude, and heading of such aircraft. By doing so, we seek to enhance the overall safety of aviation operations by ensuring effective separation between these non-TCAS-equipped aircraft and others in the airspace. However, one limitation of TCAS is its reliance on beacon-only surveillance. This restricts its ability to effectively track and detect aircraft in certain scenarios, especially in areas with limited or no beacon coverage. To overcome this limitation, the new model introduces a surveillance architecture that incorporates data from Low Earth Orbit satellites, enabling more comprehensive and accurate surveillance capabilities.

Another limitation of TCAS is its current inability to cater to certain user classes, such as small general aviation aircraft or some military aircraft that are not equipped with TCAS [12]. This exclusion poses a risk to collision avoidance in airspace shared by diverse aircraft types. With the introduction of the new system, collision avoidance protection will be extended to these user classes, thereby enhancing overall aviation safety.

3.1. Presentation of the LEO satellite constellations

There are two primary network architectures in LEO satellite communication systems [13]. The first is the ground-based network architecture, where the satellites transponders act transparently.

Data transmission between any two users necessitates passing through ground gateways. As a result, establishing global coverage requires deploying extensive ground infrastructures worldwide. The second is the space-based network architecture, comprising a space subnetwork and a ground subnetwork. In this design, Inter-Satellite Links (ISLs) connect the satellites, and only a limited number of gateways are necessary. (Fig 2)

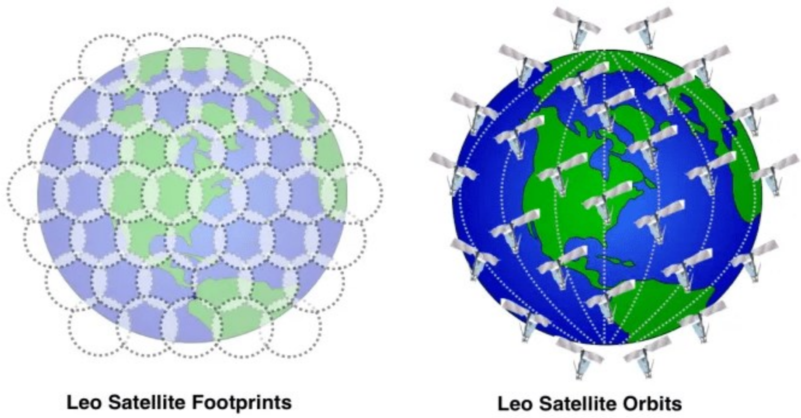

Fig. 2. Representation of the coverage area of a low Earth orbit (LEO) satellite constellation and their orbits

This architecture is particularly suitable for scenarios where acquiring gateway sites is challenging. Additionally, if onboard processing (OBP) is utilized as the regenerative payload on the satellite, data transmission between user terminals (UTs) can directly traverse the satellites. Only data transmissions between users and terrestrial networks, such as the Internet, need to be routed to the gateway via ISLs and feeder links. This one-hop communication scheme further reduces the capacity requirements of feeder links and the number of gateways [14][15]. (Fig 3 and 4)

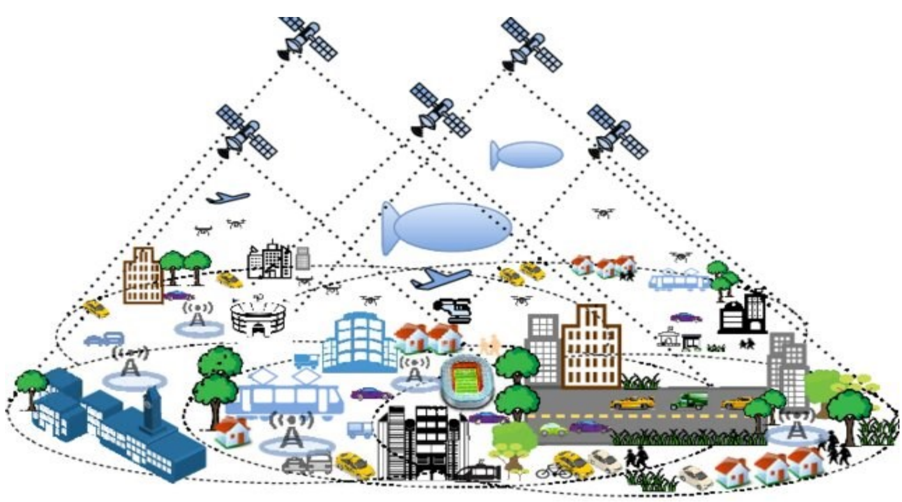

Fig. 3. LEO satellite-based mobile BS serving thousands of users. Darwish et al. [14]

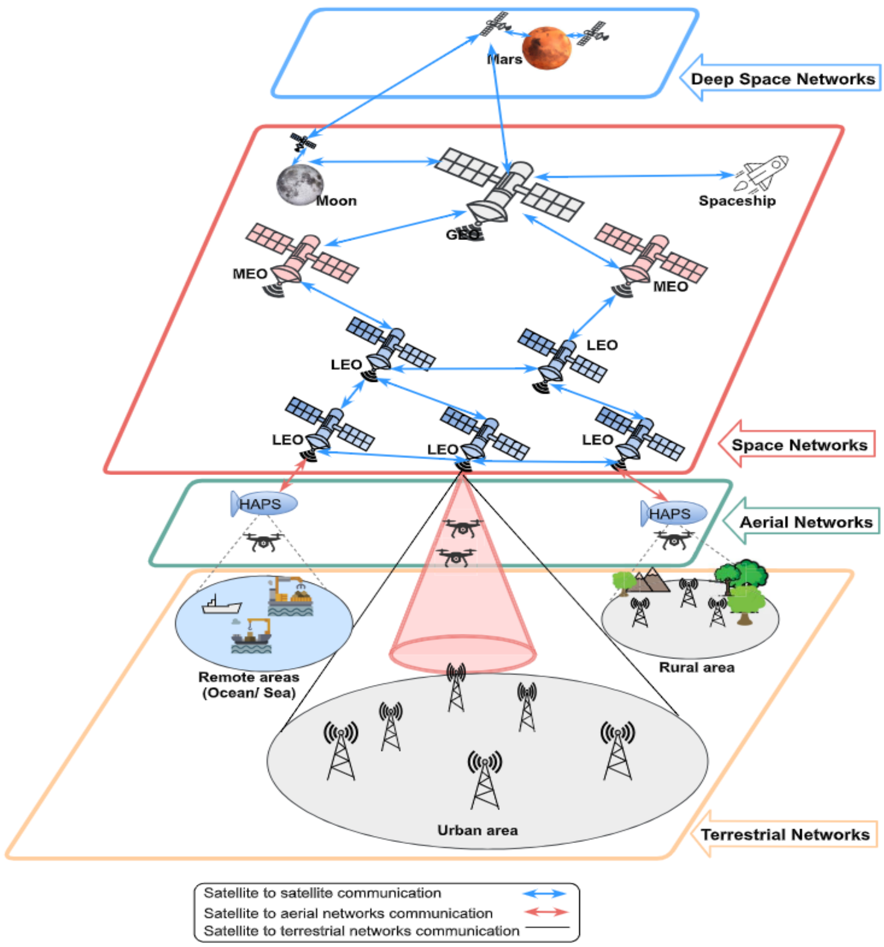

Fig. 4. LEO satellites connected to multiple networks. Darwish et al. [14]

3.2. Exploitation of LEO satellites

By investigating the implementation of this satellite-based tracking system, we aim to contribute to the advancement of aviation safety protocols and provide an additional layer of protection in the increasingly crowded skies of today's airspace.

Figure 5 clearly describes our proposal. A non-TCAS-equipped aircraft can identify other aircraft and be identified by other aircraft. The system continuously calculates positions and frames the trajectories according to the flight plans initially declared. The Air Traffic Controller ATC and pilots are warned in time in the event of a risk of collision. Communication technologies improve the quality of exchanges and processing, namely cloud architectures for applications such as SAAS, PAAS and others as well as high-availability data warehouses. New generations of telecommunication networks ensure permanent connectivity of all aircraft.

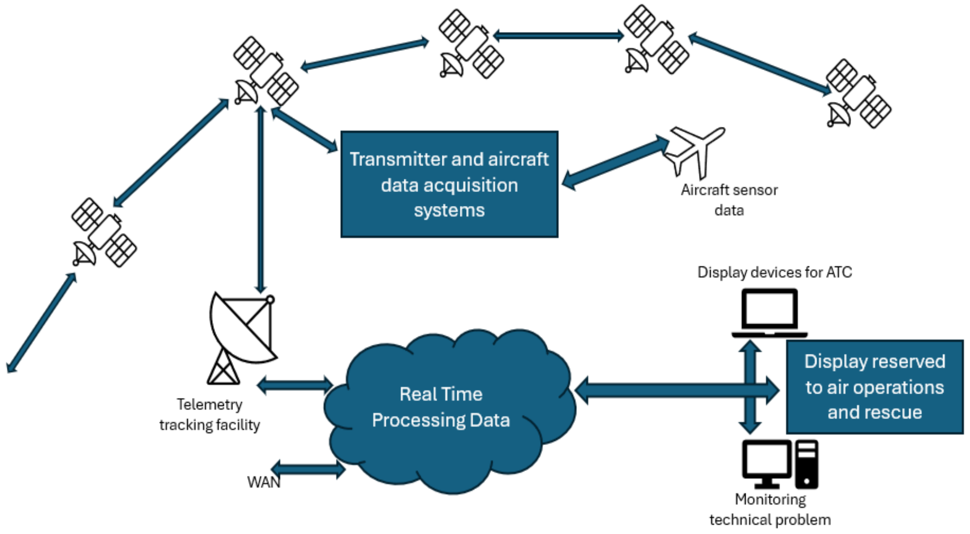

Fig. 5. Simplified Block Diagram of Satellite air Communication System

4. Discussion

By introducing the new system LEO aircraft without TCAS can be not only tracked and detected but also made visible and identifiable to all airspace users. This innovative approach ensures that not only TCAS-equipped aircraft but also all other aircraft within the airspace are aware of the presence, position, altitude, and heading of non-TCAS-equipped aircraft. This comprehensive and shared awareness leads to a collaborative environment among airspace users, significantly enhancing situational awareness and safety for all parties involved. In essence, this technology transforms non-TCAS-equipped aircraft into identifiable and trackable entities, allowing for more effective collision avoidance and coordination in shared airspace.

We can combine our solution with the development of a model for assessing the resilience of ATM systems based on the Complex Network Theory CNT, its metrics and analysis tools. The model has already been applied to the Brazilian ATM system. [20]

The high-speed movement of aircraft and the limited coverage of LEO satellites generates the Handover problem. We have already addressed this problem for land mobile telecommunications networks [21][22]. The Handover problem for aircraft mobility is solved by the new communication protocols exploited by the LEO satellite constellations.

5. Conclusion

The SESAR Joint Undertaking (SESAR JU) has initiated the VOICE (Reduced separations and improved efficiency based on VHF communications over LEO satellites) project. VOICE aims to demonstrate the benefits of utilizing LEO satellites for efficient and real-time communication with aircraft [23] (Fig. 6).

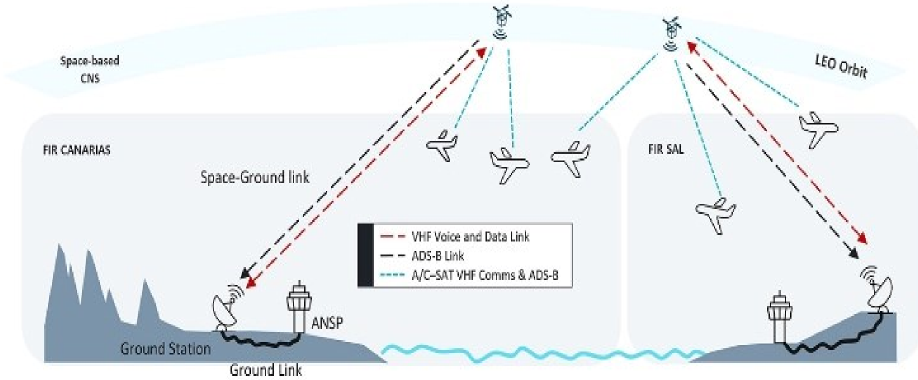

Fig. 6. The SESAR Project. Source (https://www.sesarju.eu/news/demonstrating-space-enabled-air-traffic-control)

The vision of our new system encompasses enhanced performance capabilities and utilizes different surveillance systems compared to traditional TCAS-equipped aircraft. Its primary objective is to prioritize safety, particularly in anticipation of future airspace where reduced separation standards may be implemented to enhance efficiency. Importantly, this advanced service does not require ground-based infrastructure; instead, it relies on a satellite constellation and transponders. Our goal is to provide pilots with vital visual information through a satellite data link, empowering them to verify safe operations, execute correct maneuvers, and operate with reduced stress.

We have shown that the exploitation of LEO satellites provides a network similar in topology to known computer networks. Consequently, applications and management data are distributed in cloud structures to reduce the exploitation of resources, namely the consumption of energy by processing and exchanges related to air traffic control.

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