

Does Radio Frequency Interference to Satellite Navigation pose an increasing threat to Network efficiency, cost-effectiveness and ultimately safety?

Global Navigation Satellite Systems (GNSS) are essential to safe aviation operations, enabling today's aircraft to rely on accurate and reliable position, speed or time at any point and without interruption. GNSS is used by aviation communications, navigation and surveillance (CNS) systems and air traffic management. However, the downside of the global availability of GNSS is its inherent vulnerability to interruption by Radio Frequency Interference (RFI). In recent years, incidents have rocketed upwards, with most affecting en-route flight. While aircraft can fly safely without GNSS, the massive rise in RFI is clearly reducing the efficiency of the overall aviation system, placing a higher workload on pilots and air traffic controllers, and requiring complementary CNS services to be maintained to more demanding requirements. It also poses a serious potential risk to safety if no further mitigating actions are taken.

This 'Think Paper' analyses the growing trend of RFI incidents, and looks for answers to the following questions:

- what lies behind the massive rise in RFI reported across the European network?
- where are the majority of RFI incidents occurring?
- what needs to be done to mitigate the problem?

Based on work conducted by EUROCONTROL's Voluntary ATM Incident Reporting system (EVAIR) and CNS teams, we reach a number of recommendations for policymakers in order to safeguard the reliability of GNSS for aviation, and maintain safety at the highest possible level.

Main Findings

- A massive rise in GNSS Radio Frequency Interference (RFI) incidents occurred in 2018 (an over 2,000% increase as measured by voluntary incident reporting) and has been sustained ever since.
- 38.5% of European en-route traffic operates through regions intermittently but regularly affected by RFI.
- 5% of traffic in these disruption zones could, given current RFI levels, need special assistance, measurably increasing pilot and controller workload as well as the overall safety risk.
- RFI jamming by state or proxy actors damages network efficiency and risks undermining safety.
- The aviation industry has significantly invested in GNSS as a global utility essential for providing air services safely and efficiently: RFI undercuts that investment in an industry worth billions of euros.
- While EUROCONTROL and other partners have actively enlarged their ability to identify RFI in real-time across the network, and take prompt mitigation actions to facilitate operational management, additional awareness and actions need to be taken at State level in line with international treaties.
- RFI jamming is disproportionate: while the majority of RFI hotspots appear related to conflict zones, they affect civil aviation at distances of up to 300km from these zones, reflecting a use of jamming that appears to go well beyond simple military mission effectiveness.
- States need to be aware of the problem and increase internal cooperation between their civil and military aviation bodies.

GNSS: Essential to efficient Network operations...

Following the fatal shooting down of a Korean Air Lines 747 over the Soviet Union in 1983 after it strayed into prohibited airspace, access to GNSS by civil aviation was steadily opened up, and today there are four main core satellite constellations: the US's GPS, Europe's Galileo, Russia's GLONASS, and China's BEIDOU. Their signals are enhanced for aviation by ABAS, GBAS and SBAS, augmentation systems that are aircraft-based, ground-based and space-based respectively. SBAS and GBAS are used by modern aircraft extensively for approach and landing applications, while ABAS supports aviation operations in the departure, en-route and arrival phases of flight. Currently, almost all air transport aircraft are equipped with at least a GPS receiver augmented by ABAS.

EUROCONTROL has been promoting the use of GNSS for many years at European and global level as a way of increasing network performance in terms of capacity, cost efficiency, safety, environment and/or interoperability through Performance Based Navigation (PBN) and Automatic Dependent Surveillance – Broadcast (ADS-B).

GNSS is an essential enabler of PBN, with 98.5% of aircraft equipped for en-route applications. In turn, PBN is used to optimise network route design, reducing time and fuel burn on every flight across the European network. Through ADS-B, GNSS enables advanced surveillance applications

which increase air traffic controllers' ability to manage traffic through more regular and precise position updates.

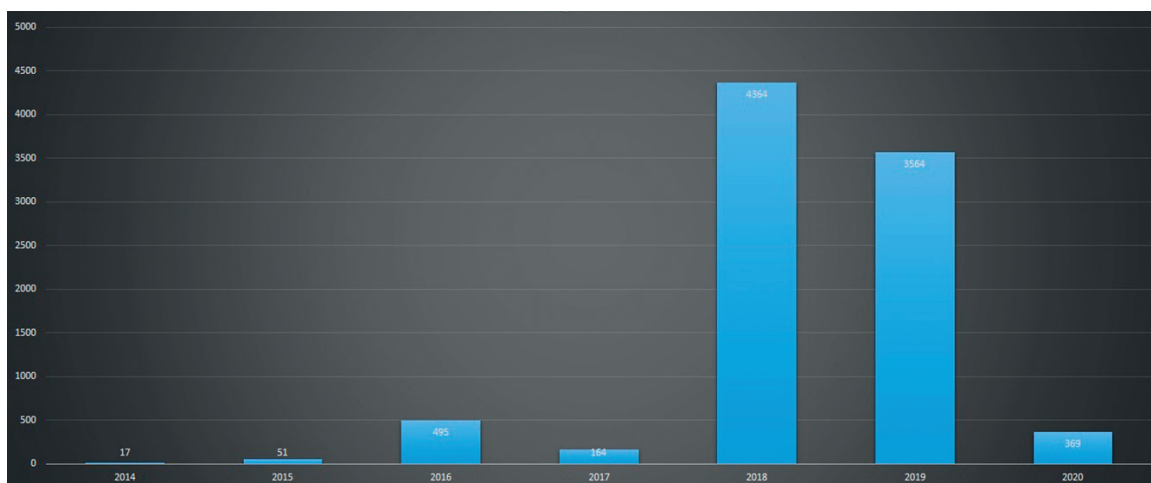
... but increasingly vulnerable to Radio Frequency Interference

Aviation can operate safely when GNSS is unavailable, but increasing RFI reduces the efficiency and cost-effectiveness of the system by requiring complementary CNS services to be maintained to higher standards. GNSS outages also impose a higher workload on pilots and controllers, and damages the significant technological investments made by manufacturers, GNSS providers and air navigation service providers (ANSPs).

Even when augmented by ABAS, GBAS and SBAS, GNSS signals are easy to disrupt. Even a cigarette-lighter powered "Personal Privacy Device" designed to illegally interfere with car and other tracking systems is capable of interfering with an aircraft departure if the gate is near a parking area¹.

RFI incidents affecting commercial aviation are on the rise. EUROCONTROL's EVAIR started collecting GNSS outage reports by pilots in 2014, following up significant numbers of outage reports in a given area to determine cause and impact, and to support the ANSP and operators in question. Figure 1 shows how reported outages rose massively between 2017 and 2018, rising by well over 2,000%, and remaining high in 2019 (2020 data must be understood in the context of reduced traffic triggered by the pandemic):

FIGURE 1: GNSS OUTAGES REPORTED BY PILOTS, 2014-2020



(Source: EUROCONTROL EVAIR)

"Even a cigarette-lighter powered Personal Privacy Device can interfere with signals"

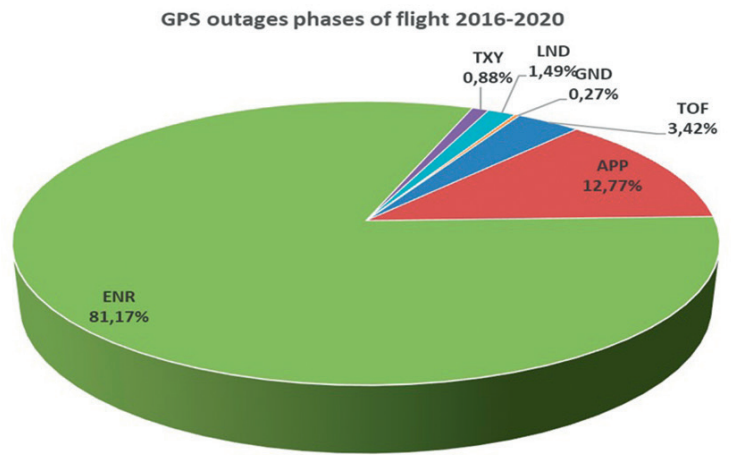
RFI remains the most likely cause for practically all reported outages, we found, after eliminating equipment errors, satellite constellation interruptions, and ionosphere-related anomalies caused by solar activity. Actual radio frequency measurements by flight inspection aircraft confirmed in several cases the presence of strong RFI signals on GNSS frequency bands.

Our analysis also showed (Figure 2) that the vast majority of RFI – 81% – affected en-route flight, even though this is where RFI should be at its lowest, as the aircraft is as far away from a ground-based interferer as possible, while the GNSS antenna is on top of the aircraft pointing towards satellites.

While the individual pilot reports submitted to EVAIR are subject to confidentiality, they overall show that the regions near the Black and Caspian Seas, and in the Eastern Mediterranean, are most impacted. This affects flights between Europe and the Middle East or Asia, as well as cross-polar routes from the US or Canada to the Middle East.

This picture is confirmed by other data sources. Pilot reports are a good indicator of real operational impact,

FIGURE 2: EVAIR ANALYSIS OF GPS OUTAGES IN FLIGHT PHASES



(Source: EUROCONTROL)

but are subject to several human factors limitations, such as reporting fatigue. However, data collected via ADS-B and other aircraft or satellite-based data collection systems show a very similar set of GNSS RFI hotspots. Global RFI hotspots detected by Airbus aircraft are largely consistent with those indicated by the EVAIR reports, as Figure 3 shows. Similar problems have been reported in the maritime sector in these regions as well, with global shipping also significantly reliant on GNSS to optimise operations².

FIGURE 3: GLOBAL RFI HOTSPOTS DETECTED BY AIRBUS AIRCRAFT, 2H2020

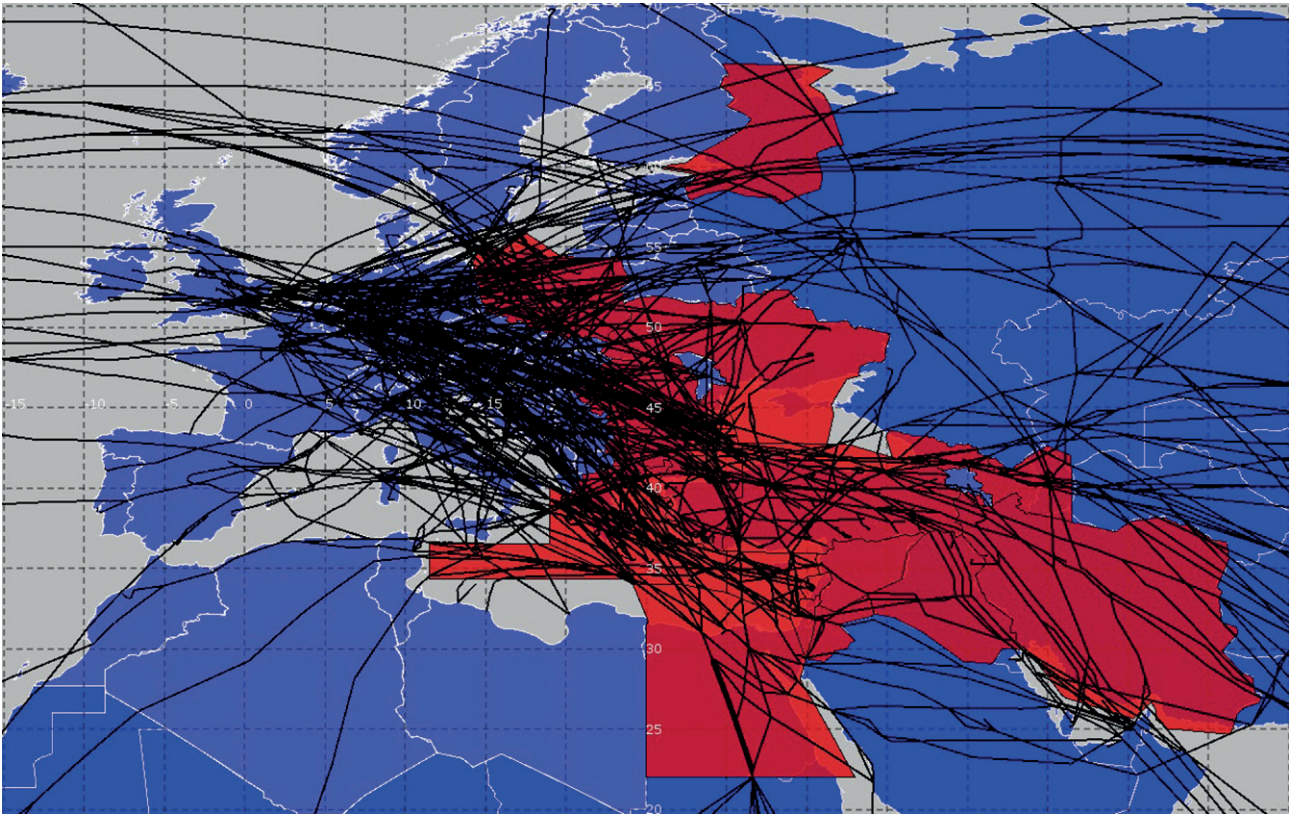
Note: This information is indicative and should not be used for flight planning purposes.



(Source: AIRBUS)

“Reported outages rose massively between 2017 and 2018 by well over 2,000% and remained high in 2019 - with 81% affecting en-route flight”

FIGURE 4: FLIGHTS CROSSING FLIGHT INFORMATION REGIONS AFFECTED BY GNSS RFI IN THE EUROPEAN NETWORK



(Source: EUROCONTROL, analysing affected FIRs derived from the AIRBUS map (Figure 3))

EUROCONTROL GNSS RFI Operational Risk Assessment

To evaluate the potential operational impact of RFI on the European network, we analysed all flights on one of the busiest days in 2020, using the Airbus map to analyse the affected FIRs as per Figure 4. In total, 38.5% of en-route traffic that day crossed FIRs where persistent RFI has been detected.

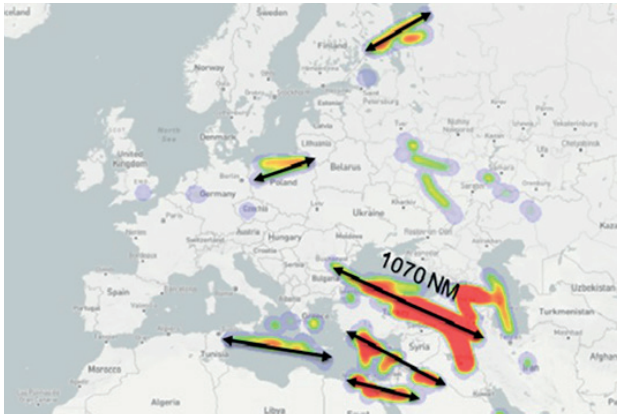
While on any given day only a much smaller region is likely to be affected by RFI, the widespread, irregular and intermittent nature of the RFI means that pilots and controllers have to be prepared to deal with the additional workload which may arise at any time. We analysed the actual avionics capability per flight plan and correlated this with available ground CNS infrastructure, especially DME/DME coverage. This led to the following conclusions:

- 2.17% of flights possibly affected have no alternative navigation capability to GNSS to support en-route operations, and will therefore likely require ATC vector assistance using conventional surveillance and communications capabilities.
- 3.14% of traffic needs ATC assistance where the coverage of alternate terrestrial navigation aids, such as DME and VOR, is marginal (e.g. over water) or is of such a long duration that coasting with Inertial Navigation Systems (INS) does not cover the navigation gap.
- 5.3% of traffic in total could need special ATC assistance in a given sector, which equates to 2 or 3 aircraft.

In a worst-case scenario, we calculated the longest possible outage duration, and found that one aircraft trajectory spent 1,070 NM or about 3.5 hours of flight time in the likely areas affected by RFI, as shown in Figure 5. Were such an outage duration to occur, it would be beyond the

“The regions most affected by RFI are near the Black and Caspian Seas, and in the Eastern Mediterranean”

FIGURE 5: LONGEST FLIGHT TRAJECTORY CROSSING RFI ZONES



(Source: AIRBUS & EUROCONTROL)

navigation gap which can be overcome by INS coasting, since the navigation performance requirements in this airspace are more demanding than for oceanic crossing.

GNSS Vulnerability Case Study: Cyprus

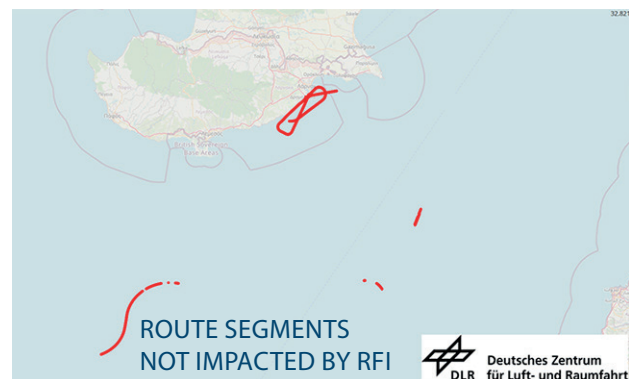
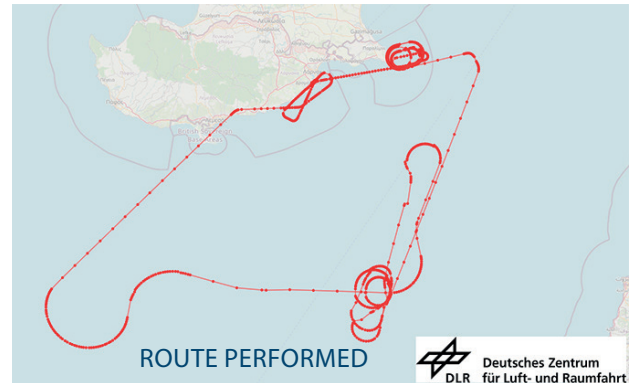
Cypriot airspace is one of the most regularly affected by RFI in the network, with 395 cases reported between March 2018 and September 2020 that caused significant GNSS outages over international waters where alternative navigation system coverage is limited.

Efforts to obtain explanations were requested from neighbouring States via the International Telecommunications Union (ITU) Radio-communications Bureau, in accordance with international treaty, but to no avail.

An investigation on 13 February 2020 by DLR, the German Aerospace Center, saw an Airbus 320 equipped with radio frequency measurement devices conduct a 3-hour research flight, and covering 250 x 170 km, at altitudes of up to 10 km.

The flight confirmed that RFI targeting GNSS at 1575 MHz was responsible for the outages, with Figure 6 showing the dramatic extent to which most portions of the flight were impacted by RFI.

FIGURE 6: DLR FLIGHT IN CYPRIOT AIRSPACE, RFI INTERFERENCE ANALYSIS

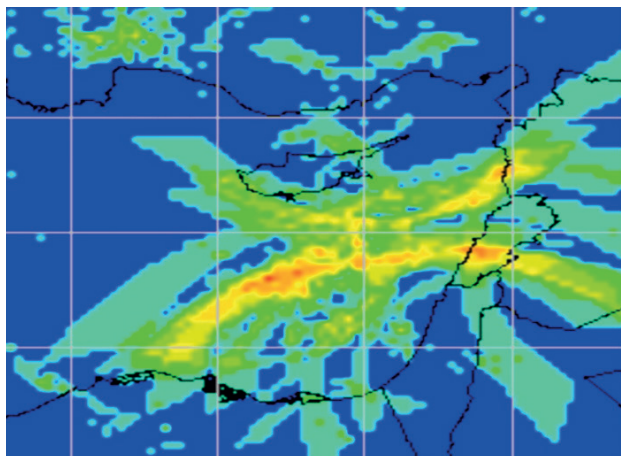


(Source: DLR)

EUROCONTROL then took the ADS-B track data for the duration of the DLR flight for all 179 flights crossing the Nicosia FIR, and found that 21% (38 flights) were impacted – rising to around 50% when considering adjoining areas.

EUROCONTROL is also developing a complementary method to geo-locate probable interference sources, using aircraft as a sensor. Preliminary results in Figure 7 indicate multiple RFI sources, some of them over the high seas, and possibly moving.

FIGURE 7: PROBABLE RFI SOURCE LOCATION HEATMAP, DLR CYPRUS FLIGHT, USING ADS-B DATA



(Source: EUROCONTROL)

Widespread GNSS jamming has major safety, financial and efficiency implications for aviation

RFI is both increasingly widespread and highly random. Aircrews flying in certain areas have become accustomed to having to be ready to navigate without GNSS, which only a few years ago was seen as a permanently reliable source.

Such persistent GNSS outages increase the safety risk. Aviation safety can best be illustrated using the Swiss cheese model. Each system element (humans, machines, procedures) contributes a slice, each of which can stop an accident from happening. However, human error and system error mean that each slice has some holes. If all the holes in all the slices line up, this leads to an accident. Regular jamming puts too many holes in the GNSS slice, raising the likelihood of an accident if another system element were to fail at the same time.

This risk was clearly recognised at the 40th ICAO Assembly, resulting in the publication of a letter asking all States to mitigate the risk of GNSS jamming by applying ICAO guidance developed by EUROCONTROL³.

From a EUROCONTROL Network Manager perspective, RFI has a heavy impact on network efficiency and cost effectiveness. It increases pilot and controller workloads; it

obliges aircraft manufacturers and system integrators to analyse the impact of GNSS RFI on their systems and publish detailed guidance for operators; and it requires ANSPs to maintain or increase investment in hybrid or multiple alternative CNS systems to mitigate GNSS outages.

Jamming also undermines confidence and trust in a significant global investment that is at the heart of future economic progress in many industries – and increases the cost of anti-jamming mechanisms, which a recent study estimates could be worth \$ 5.9 billion by 2025⁴.

Conflict zones: A clear and increasing source of RFI

Most of the airspaces particularly affected by RFI have one thing in common: proximity to regional conflict zones, but with RFI negatively impacting GNSS at large distances of up to 300km from these areas.

A likely culprit for the dramatic increase in RFI since 2018 is jamming designed to interfere with battlefield Unmanned Aerial Vehicles (UAVs), which have in recent years begun to play an increasing role in regions within or just beyond the EUROCONTROL network, such as Libya, Nagorno-Karabakh, Syria or the areas claimed by separatists in Ukraine. GNSS jamming at a distance appears to be a temporary defence measure against armed UAVs, which typically rely on other sensors when approaching their target, but may be vulnerable to interference further out⁵.

Working to mitigate the risk of RFI across the EUROCONTROL network

At network level, EUROCONTROL's CNS team is busy developing methods for detection and mitigation of RFI in near-real time. This includes correlating pilot reports from the EVAIR team with data of affected aircraft equipment capabilities and available coverage of ground-based CNS services. The findings are coordinated with the ANSPs responsible for the affected airspace, and aircraft operators are informed when appropriate. In more significant cases, advice from EASA, the European Union Aviation

“The experience of Cyprus gives an idea of the huge problems RFI can cause in some areas of the European network”

Safety Agency, is requested. A first set of handbooks for operational contingency measures to facilitate operational management has been developed and published on the European PBN portal⁶.

At national level, local RFI mitigation measures need to be taken, ideally including the ability to conduct in-flight RFI measurements. These complement EUROCONTROL's ability to coordinate with 'big data' analysis and business intelligence. International protocols to resolve interference can only be brought to bear when the presence of RFI and its probable source location are confirmed.

Such local capabilities need to be enhanced, with recent analysis revealing that only 36% of flight inspection aircraft possess a basic ability to detect GNSS RFI, and even fewer have geo-location capabilities⁷.

Our civil-military experts are currently working with military stakeholders to develop guidance material to help foster such coordination, recognising the continued importance of balancing the needs of civil aviation with those of national security and defence. Where jamming is concerned, military actors need to limit jamming to the absolute minimum necessary to fulfil their missions, in full awareness that jamming can massively impact civil aviation far beyond the areas they are exercising in. This is particularly the case for the world's superpowers, which on one hand operate and invest in the main GNSS satellite constellations; and on the other, also have the highest capacity to disrupt those same constellations.

Conclusions: A way forward on RFI is achievable

EUROCONTROL invites policymakers to consider the following main conclusions of this analysis:

- The massive and sustained increase in intermittent but regular GNSS RFI since 2018 can affect 38.5% of European en-route network traffic and can lead to measurable increases of pilot and ATC workload, with up to 5% of traffic needing ATC assistance, imposing additional requirements on complementary CNS infrastructure performance.
- While the majority of RFI hotspots appear to originate in conflict zones, they affect commercial aviation at large distances from these zones, reflecting a disproportionate use of jamming that appears to go well beyond simple military mission effectiveness.
- RFI jamming by state or proxy actors damages network efficiency and risks undermining safety.
- The aviation industry has significantly invested in GNSS as a global utility essential for providing air services safely and efficiently: RFI undercuts that investment and efficiency gains in an industry worth billions of euros.
- While EUROCONTROL and other partners have actively enlarged their ability to identify RFI in near real-time across the network, and take prompt mitigation actions to facilitate operational management, additional awareness and actions at State level are required to ensure that aviation can continue to operate safely without radio interference, in line with the protections afforded by the radio regulations of the ITU.

“Jamming undermines confidence and trust in a significant global investment and increases the cost of anti-jamming mechanisms”

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