Assessment of a Performance-based Surveillance Function in the U-space Architecture in Low/Medium Risk U-space Airspaces

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***Abstract*— This paper introduces an approach to include a surveillance performance monitoring functionality within U-space. First, an introduction to the Performance-Based Surveillance (PBS) paradigm and the tools that make use of it has been made. Then, the U-space service framework and its surveillance functionality were put into context from a regulatory point of view. After this, the source where the surveillance monitoring will take place has been assessed. To validate the approach, a series of simulations of representative U-space scenarios with different densities and traffic mixes was carried out. The surveillance performance monitoring tool has been shown to accurately represent the performance of the surveillance sources in a scenario using different metrics. A discussion on the approach's limitations and on how it could be applied to support U3-advanced U-space services is presented at the end of the paper.**

Keywords-component; UAS; Performance-based surveillance; U-space; Separation Management; BUBBLES;

I. INTRODUCTION

The provision of separation between aircraft and airspace capacity management are significant challenges in unmanned aviation. These concepts have been classified as advanced U3 within the U-space deployment phases and are still being investigated by different research projects such as BUBBLES [1] or DACUS [2] and by companies. These projects have identified several factors that need to be considered in terms of UAS (Unmanned Aircraft Systems) capability and separation. These include: type of airspace, organisation of traffic within the airspace, type of aircraft, etc. Specifically, this paper is focused on one of the pillars of safety within airspaces where U-space services are provided (henceforth, U-space airspaces): the provision of surveillance data and its quality, which depends on the data source performance, as well as on that of the communication channel between the source and the user services.

The European Commission laid down in 2021 CIR (EU) 2021/664 [3] CIR (EU) 2021/665 [4] and CIR (EU) 2021/666 [5] (jointly referred to as 'the U-space regulation' hereinafter) which introduce the concept of 'U-space airspace' as a UAS geographic zone (as per CIR (EU) 2019/947 [6]) where some U-space services have to be provided for safety, privacy and social acceptance purposes. UAS operators have to use these services to operate in U-space airspaces and they are obliged to provide surveillance data, which is received and distributed by the Network Identification Service (NIS). Position reports may be sent to the U-space directly from the Unmanned Aircraft (UA) to the U-space or for the UA to the Ground Control Station (GCS) and from there to the U-space (in both cases, by means of an Internet connexion). In the same way, manned aircraft flying in a U-space airspace and not receiving separation instructions from an Air Traffic Services (ATS) unit have to make themselves electronically conspicuous to the U-space. Both the UAS surveillance data and the e-conspicuity data coming from manned aviation must be displayed to the UAS operator by the Traffic Information Service (TIS). Moreover, before the flights take place, UAS operators have to file a flight plan to the Flight Authorisation service, which shall strategically deconflict them. The UAS surveillance data may be used by the optional Conformance Monitoring service to detect whether the trajectory flown by a particular UA flight deviates from the authorised flight plan by more than the acceptable deviation thresholds.

According to what has been described in the paragraph above, the U-space regulation sets up a U1/U2 U-space environment. Within this framework, it clearly defines a conflict management mechanism aligned with the ICAO model, both at the strategic and tactical levels. Tactical conflict resolution relies on real-time surveillance data, which are processed by a 'surveillance chain' implementing a 'surveillance function'. This paper assesses the architecture of this 'surveillance chain' and on how the paradigm of Performance Based Surveillance (PBS) may be applied to the U-space 'surveillance function' provision.

The rest of the paper is structured as follows: Section II describes how conflict management is provided according to the U-space regulation; Section III describes how the U-space services considered by the U-space regulation and some optional ones may be used to implement the surveillance function in the U-space; Section IV introduces the paradigm of PBS; Section V describes how the PBS paradigm can be integrated into the U-space architecture defined by the U-space regulation; Section VI describes the experiments conducted to assess the effect of positioning and communication errors on surveillance performance metrics; and Section VII presents results, which are discussed in Section VIII. Finally, Section IX presents the conclusions of the assessment.

II. CONFLICT MANAGEMENT ACCORDING TO THE U-SPACE REGULATION.

Conflict management is a component of the Air Traffic Management (and by extension, of the U-space) aimed at limiting, to an acceptable level, the risk of collision between aircraft and hazards. This is a stepped process in which to conflict detection and resolution layers are applied at Strategic and Tactical layer. There is a third layer, the Collision Avoidance layer, which is an airborne safety net based on onboard short-range surveillance capabilities and, as such, is out of the scope of the U-space.

At strategic level, the U-space regulation assigns the responsibility for detecting and solving conflicts to the Flight Authorisation service. At tactical level, the U-space regulation designates the UAS operator as the separator agent in (CIR 2021/664 Art. 11(4): *Upon receiving the traffic information services from the U-space service provider, UAS operators shall take the relevant action to avoid any collision hazard*). On the other hand, the Conformance Monitoring service is a reinforcement of the strategic conflict resolution barrier which acts during the execution of the flight.

III. THE SURVEILLANCE FUNCTION IN THE U-SPACE.

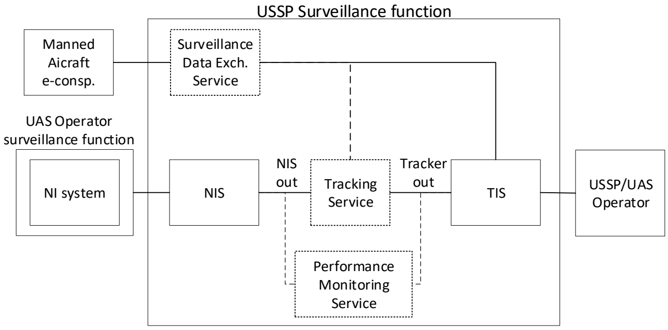


Figure 1. The U-space surveillance function

Both the tactical conflict resolution by the UAS operator and the Conformance Monitoring service rely on the surveillance information provided to the U-space by the UAS and by e-conspicuous manned aircraft. Figure 1 shows how the surveillance function is provided according to the U-space regulation. An additional U2 service not considered by the regulation is included as optional in the figure. The effect of tracking on the surveillance performance will be assessed later in this paper. Figure 1 also includes a Surveillance Data Exchange service (as per the CORUS [7] CONOPS) in charge of collecting the e-conspicuity information and making it available to other U-space services. The figure also includes a Surveillance Performance Monitoring function that will be described in Section V.

The regulation referred to above does not specify the UAS surveillance technology that operators must use. Due to the definition of the requirements that CIR 2021/664 gives for the provision of drone position and due to the maturity of the technology, almost all UAS that implement on-board surveillance technologies use GNSS (Global Navigation Satellite System) satellite positioning systems combined with other sensors (barometers, magnetometer, accelerometer, etc.). These systems provide dynamic information to the UAS, which emits it along with its identification and status. At civilian level and to the authors' knowledge, there is no other drone positioning technology as widespread as GNSS sensors. The main reason for that is that the infrastructure that would be necessary to deploy a new surveillance service, even with a local coverage, would require a significant investment that no company or government is currently willing to make due to the market size of UAS applications. Non-cooperative surveillance sensors used by counter UAS systems are not considered by the U-space regulation as valid source of surveillance data. It can therefore be stated that generally, a USSP (U-space Service Provider) will only have one GNSS-based source of information providing the dynamic information of the UAS aircraft it serves.

IV. PERFORMANCE-BASED SURVEILLANCE

Surveillance systems can be abstracted to be seen as sources of surveillance information. Due to the explosion of emerging surveillance technologies for manned aviation such as Automatic Dependent Surveillance-Broadcast (ADS-B) or Multi-Static Primary Surveillance Radar (MSPSR). The world of aeronautics is moving towards an approach where surveillance systems are specified and evaluated in a technology-agnostic way, based on the performance-based surveillance paradigm. This approach is especially necessary for unmanned aviation, where there are several technologies aiming to be part of the Air Traffic Management (ATM) surveillance ecosystem.

This type of surveillance is based on required performance specifications and is applied to air traffic systems. Thus, the information sent by the surveillance system must be adequate in several aspects for the ATM service it is intended to support and shall be provided with minimum conditions related to position data update and accuracy. These are called performance requirements.

In manned aviation, these requirements or specifications are broadly defined in regulations made by the Federal Aviation Administration (FAA) in the United States or the European Union Aviation Safety Agency (EASA) in Europe. These regulations are supported by standards from organizations such as the European Organization for Civil Aviation Equipment (EUROCAE) or the Radio Technical Commission for Aeronautics (RTCA). Detailed specifications for the corresponding surveillance systems within a particular type of airspace are defined in standards such as the EUROCAE ED-261 (the GEN-SUR SPR standard [8]). One of the main objectives of these standardization organizations is to provide technology-agnostic operation, design and verification requirements for surveillance systems.

Regarding unmanned aviation, there is a lack of standardization. In the USA, the FAA defines in [9], the minimum performance requirements for remote identification information, where measurable requirements for surveillance information are detailed. In Europe, regulation CIR 2021/664 sets requirements for data elements, security and, implicitly, integrity of surveillance information. There are standards such as ASTM F3411-19 [10] and EUROCAE-282 [11], with more specific requirements, that can be used as acceptable means of compliance. However, these documents do not define methods for monitoring the performance of the sources of surveillance information.

Tools such as EUROCONTROL SASS-C are specifically designed to perform external performance monitoring according to community standards based on data streams available from the various manned aviation sensors in a scenario. This tool detects degradations and failures in the surveillance systems through exhaustive statistical data processing. Several SESAR PJ14 solutions also addressed PBS for manned aviation [12].

This paper aims to provide an assessment of the translation of the PBS concept to the unmanned aviation surveillance domain. This scenario is clearly more complex than a traditional ATM scenario due to the multiple limitations in terms of surveillance information, the complexity of UAS operations and the lack of a framework linking safety and surveillance in a straightforward manner.

Some works relate CNS performance and UTM airspace structure [13]; these works use metrics computed directly by on-board surveillance sensors and assume factors (such as latencies) that affect performance to determine airspace structure. However, to the authors' knowledge, no research work has applied the PBS paradigm to UAS surveillance systems in any UTM framework.

This paper introduces a framework where PBS is applied to UAS surveillance systems as they are currently implemented in Europe. This allows to assess whether it is feasible to implement the PBS paradigm in the systems the provision of U-space services relies on. To this purpose, this paper evaluates the challenges of using this paradigm by means of a set of simulations in a U-space environment, developed according to the latest regulation and research work, in which a surveillance performance monitoring function is integrated.

V. SURVEILLANCE PERFORMANCE MONITORING IN THE U-SPACE

To assess the concept of performance-based U-space surveillance it is necessary to describe the tools that measure this performance. Figure 2 depicts a generic performance evaluation tool for a generic surveillance system based on GEN-SUR SPR. This document provides general principles and functionalities to demonstrate compliance with the nominal performance requirements of a generic surveillance system.

This tool shall implement the following functional requirements:

- Recording of the inputs and outputs of the tool. Common inputs will include measurements from various sensors and configuration data. The tool should also be able to accept reference measurements made using high-precision instrumentation (e.g. RTK).

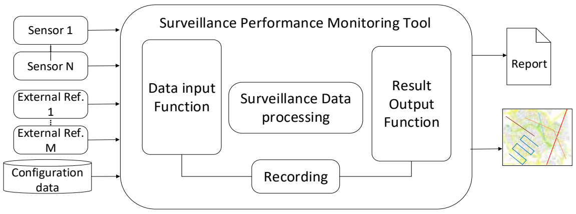


Figure 2. Functional view of a Surveillance Performance Monitoring Tool

- Association of reports to relate measurements from a target to group them into a trajectory. This task will be more or less complex depending on the nature of the monitoring source (cooperative or non-cooperative).
- Creation of reference trajectories by extensive data processing using statistical methods to best determine the 'true' state of an aircraft at a given instant.
- Computation of performance metrics by comparing references and measurements from different sensors. A statistical analysis of the inputs to the tool and the references available to obtain them is performed.
- Evaluation of the analysis result relative to performance requirements given by standards or regulations. Also known as "Conformance assessment".
- Display the most important data of the analysis, such as references, sensor measurements, configuration data, or performance analysis results.

The tool can conduct the analysis per trajectory, per complete surveillance scenario or in the cells of a grid defined in the scenario.

Due to the methods used for obtaining the performance metrics, this kind of tools are designed to operate offline from datasets where the trajectories are already known for the entire time window comprising the analysis. The size of this window must allow to collect the minimum number of samples from which the results of the metrics computation are statistically representative [14]. Thus, surveillance performance monitoring tools may conduct 'quasi real-time' analysis and may be used in the tactical phase in successive time slots, provided that the number of target reports during each slot is large enough to deliver statistically representative metric values. Regarding computation time, this should not be an issue since it is below the second for the number of reports processed in the time window.

The question that arises at this point is where such a performance assessment tool should be located in the U-space architecture. This question is linked to the node in the surveillance data network chain to be evaluated and the U-space services it will support.

As advanced in Section III, an optional Tracking Service is shown between the two mandatory previous services in the central part of Figure 1. Although this service is not defined by any regulatory document today, it is common to find USSPs implementing it to provide UAS tracks with a smoothed position error. Furthermore, depending on the design requirements, the Tracking Service will guarantee, to a greater or lesser extent, the continuity and integrity of the surveillance information provided by the Traffic Information service.

Within the division of the surveillance data chain depicted in Figure 1, the performance monitoring service of the surveillance systems can be located at two points: at the "NIS out" or at the "Tracker in", in case the USSP has a tracking service. If " NIS out " is chosen, the conformance analysis is performed at the "sensor level". If "Tracker out" is selected, the analysis is performed on the tracker data stream. If, from here on, the surveillance data is not further processed, the performance analysis is done at the level of the closest node where the surveillance data will be used.

This paper addresses both cases. In the first one, considering the Tracking service, the quality of the data is evaluated at the point "Tracker out". In the second case, the analysis is done without considering the Tracking service so regardless of which point is chosen in Figure 1, the conformance assessment is performed at the same point.

VI. EXPERIMENTS

Each U-space agent defined in Figure 1 is simulated in these experiments. The surveillance information used to compute surveillance performance metrics will be parametrically degraded for two purposes: to obtain conformance analysis results and to support the discussion at the end of the paper.

A. *Scenarios*

For these experiments, two scenarios of 25 km2 base and 120 m height have been defined, Figure 3:

- Scenario_LD: Low Density (LD) scenario (1.2 UAS/km2). This scenario has 30 trajectories.
- Scenario_MD: Medium Density (MD) scenario (2.4 UAS/km2). This scenario has 60 trajectories.

These trajectories were generated and simulated by a tool developed by BUBBLES project. Trajectories include: recreational, scan, delivery and power line inspection flights.

The maximum and minimum heights of the operational volume are 16 and 100 meters, respectively. To represent a more realistic environment, the trajectories were generated considering the dynamic characteristics of different types of multirotor UAS, classified according to their operational risk. The traffic mix of these scenarios is presented in Table I.

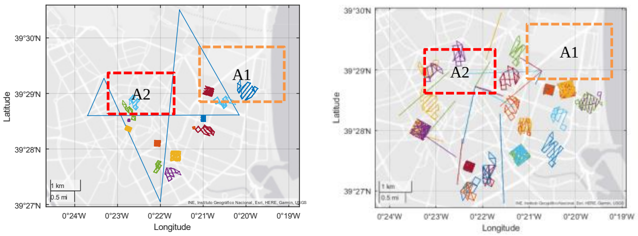
B. *Methodology*

Each scenario is generated with certain performance parameters. Two of the parameters considered most representative in terms of the final effect they produce within the performance analysis were modelled.

TABLE I. MIX OF TRAFFIC IN EVERY SCENARIO [1]

Traffic class	***Traffic mix (%)***
A1	12
A2	17
A3	20
SAIL I-II	30
SAIL III-IV	17.6
SAIL V-VI	3
No passenger	0.2
Passenger	0.1
VFR	0.1
IFR	0

The two scenarios are shown in the following figures:



a) b)

Figure 3. (a) Scenario_LD. (b) Scenario_MD

On the one hand, there is the loss of position information and latencies. From the time the UAS position information is generated by the on-board equipment in the GNSS sensor until the ground equipment receives it, a drone position message may not be processed. If it is processed, it may present latencies. In mobile communications using airborne transmitters, this is caused by propagation effects characteristic of this type of communication systems, such as multipath and doppler. These phenomena strongly degrade the radio signal, increasing bit error metrics and therefore impairing the correct processing of UAS position reports. Depending on the protocol, corrupted reports due to aerial communication channel may force the UAS or ground station to transmit these reports again, hence causing latencies. Once the report has been successfully delivered to the ground equipment, the likelihood of information degradation is drastically reduced due to the communication protocols (e.g. TCP/IP) commonly used for the transport of this information through the internet and the aviation domain.

On the other hand, there is the random satellite positioning error characterised by the Dilution Of Precision (DOP) effect, which depends on the geometry of the constellations in use, and the error due to the phenomena caused by the transmission and reception of positioning signals.

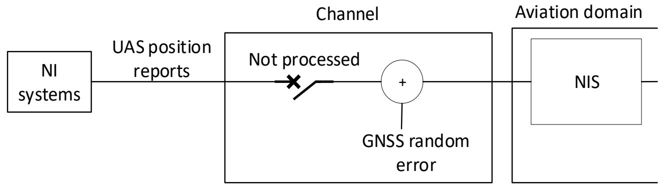


Figure 4. Position report degradation diagram.

Figure 4 shows a diagram describing how errors are modelled within the simulation environment. The NIS systems block represents the Network Identification system in its two forms: pilot connected to the internet or UAS connected to the internet. The "Channel" block represents the errors due to the communications channel. This models both the satellite channel and the channel between the point where the UAS position information is fixed by the GNSS receiver to the point where the operator has access to the internet. The NI system, on the left of the figure, provides the remote identification information to the Network Identification service according to Figure 4.

Thus, in the simulations performed, the NI systems block in Figure 4 represents UAS from the scenarios sending telemetry data at a rate of 1 report/second/UAS to the aviation domain. The “Channel” block injects degradations into the data stream, and in USSP domains, this information is received by the NIS and made available to the U-space. Each of the previous modules is programmed separately and is orchestrated by a main code.

A simulation strategy based on the variation of the parameters modelling the degradations of the surveillance performance has been applied in the experiments.

Two types of degradations will be considered: missed reports and GNSS random error. The first degradation type models target reports that could not be processed and therefore have been "lost" in their time interval. It also models target reports with latencies. Target reports arriving at the USSP with a data age above a specific value will be considered lost. These latencies may have been generated on board the aircraft or in the propagation and transmission channel to the USSP. The second degradation type models typical satellite positioning errors due to the channel, receiver, and the constellation.

In this study, two cases have been defined for the scenarios defined above (LD and MD): S1 and S2. Scenarios with uniform nominal performance parameters across the analysis volume will be referred to as S1 scenarios. Scenarios with degraded performance in certain areas are defined as S2 scenarios. In the latter, specific zones will be defined where a degradation of the data is simulated. These zones are zones A1 and A2 and are depicted in Figure 3. A1 zones will be remote areas where the communication network coverage is poor and therefore, 10% of the reports cannot be processed. A2 zones are areas where below a certain height (< 60 m), the signal quality of GNSS positioning systems is poor due to dilution of accuracy and multipath in urban environments thus increasing position errors. The common parameters for the degradations in each scenario, as well as the degradation parameters in areas A1 and A2, are presented in Table II. Here, three parameters have been defined, random GNSS error standard deviation in the horizontal and vertical planes which has a normal distribution (GNSS_σ_{HE} and GNSS_σ_{VE}) and the Ratio of Lost Target Reports (RLTR).

TABLE II. DEGRADATION PARAMETERS PER SCENARIO

Parameter	**S1 Type Scenarios LD - MD**	**S2 Type Scenarios LD - MD**		
		Nominal	***A1 Zone***	***A2 Zone***
GNSS_σ_{HE} (m)	14 - 7	14 - 7	14 - 7	21
GNSS_σ_{VE} (m)	20 - 10	20 - 10	20 - 10	30
RLTR(%)	3 - 2	3 - 2	10	3 - 2

According to the table above, the degradation parameters in the LD scenario are larger than those applied to the MD scenario. Thus, these parameters are swept to evaluate their impact on the performance metrics. Regarding the S2 scenarios, areas A1 and A2 are affected by fixed and larger degradation parameters; outside these areas, the degradation parameters for each scenario are the same as for the S1 scenarios. This way, two sets of experiments will be carried out. The first set is dedicated to analyse scenarios S1 and the second set to analyse scenarios S2. Following this approach, it is possible to see the effects of both a reduction in overall performance and the impact on scenario performance of having a reduction in the quality of monitoring data in a specific area. Moreover, as stated before, this work considers two cases, depending on whether the Tracking service is present or not. If present its update rate is 1 s.

Two types of performance metrics are used in this study: update and accuracy metrics [8]. These metrics are considered the most basic and essential to assess the basic quality of the surveillance data provided by the NIS. Update metrics evaluate the provision of certain information, within a time interval, to an agent using this information. Therefore, this type of metrics will evaluate reports that could not be processed and reports that did not arrive within the given time interval due to latencies. On the other hand, accuracy metrics are related to errors in the dynamic information that an aircraft processes and transmits. The metrics to be considered are the following:

- Probability of Update (PU): Probability that a data source delivers a valid target report within a given Update Interval (UI). In this analysis, UI = 1 s. This report shall contain the 3D position information of the aircraft together with a timestamp.
- Probability of Long Gap = n (PLG_n): Probability that a data source does not deliver a valid target report during a defined number of consecutive update intervals.
- Horizontal Position Root-Mean-Square Error (HP-RMS): Quantifies the uncertainty of position measurements delivered in target reports in the horizontal plane.

- Vertical Position Root-Mean-Square Error (VP-RMS): Quantifies the uncertainty of position measurements delivered in target reports in the vertical plane.

The metrics used in this paper and the methods implemented to compute them are inspired by those described in the standards ED-129B [14] and GEN-SUR SPR [8], conveniently adapted for UAS. The analysis volume comprises the entire 25 km2 scenario; therefore, the result for each simulation is a set of metrics representing the performance of that scenario.

VII. RESULTS

The results obtained in the simulations for the S1-type scenarios are shown in Table III. The "Sensor" columns show the performance results obtained for the simulations at sensor level. On contrary, the "Tracker" columns depict performance metrics at the Tracker output when the Tracking service is considered.

TABLE III. PERFORMANCE METRICS RESULTS FOR S1 SCENARIOS

Metric requirements	***Scenario_LD***		***Scenario_MD***	
	Sensor	***Tracker***	***Sensor***	***Tracker***
Probability of Update (%)	96.89	100	97.95	100
Probability of Long Gap n=3 (%)	0.014	0	0	0
HPArms (m)	8.91	3.67	3.7	1.91
VPArms (m)	18.23	2.11	8.53	1.15

In terms of the sensor level analysis, it is observed that the analysis performed by the surveillance performance monitoring tool has obtained performance values in line with the degradation parameters simulated in each scenario. This is mainly true for the update metrics. Regarding the accuracy metrics computed, one can observe something interesting. Considering that the modelled GNSS errors follow a normal distribution, the values of the horizontal and vertical mean square error metrics are lower than expected. Here arises one of the limitations existing today in the U-space surveillance ecosystem, the diversity in surveillance technologies. This will be discussed in the next section.

Regarding the analysis at the output of the Tracker, the results show a significant improvement in the metrics. This is achieved thanks to the design features chosen for the tracker with an update ratio that complies with the Update Interval required in the performance analysis thus achieving a perfect update probability (PU). A correct modelling of the drone dynamics in the tracking achieves a smoothing of the position error, especially the vertical error.

The results obtained in the simulations of the S2-type scenarios, as defined in Table II, are shown in Table IV and Table V. In these tables, columns "A1" and "A2" represent the results of the conformance assessment performed on the A1 and A2 volumes, as can be seen in Figure 3. The "Total" columns show the metrics computed for the whole scenario. Within these columns the "Sensor" columns contain the results obtained without using the Tracking service and "Tracker" columns presents the simulation results considering it.

As it can be seen in Figure 3, in Scenario_LD within A2 zone, the low performance region affected to 3 UAS trajectories partially and 1 trajectory completely. Within A1 zone the trajectory performance was degraded for three UAS partially and for two UAS completely. As for Scenario_MD A2 zone, degraded performance affected to 10 UAS partially. Within A1 zones 4 UAS trajectories were degraded partially as well.

At sensor level, the PU and PLG are notably affected in scenarios 1 and 2 due to the introduction of A1 areas. It can be noted that a strong degradation of performance in a particular area of the scenario has a clear impact on the metrics of the entire scenario.

The A1 area has deteriorated the PU by less than 0.5% in Scenario_LD and 0.31% in Scenario_MD. In terms of accuracy metrics, the insertion of the A2 areas in the scenarios has degraded the overall accuracy metrics by less than 1 meter. In this case, the same is true as for the previous set of simulations, the accuracy results obtained are below the expected values.

Regarding the metrics computed considering the Tracking service, it can be observed that despite the strong degradations introduced in areas A1 and A2 for LD and MD scenarios, the tracker allows offering full continuity in the whole analysis window achieving a perfect PU for the areas A1 and A2 as well as in the whole scenario.

TABLE IV. PERFORMANCE METRICS RESULTS FOR S2 SCENARIOS (LD)

Metric req.	***Scenario_LD***					
	A1		***A2***		***Total***	
	Sensor	***Tracker***	***Sensor***	***Tracker***	***Sensor***	***Tracker***
PU (%)	90.85	100	97.1	100	**96.44**	**100**
PLG n=3 (%)	0.16	0	0.06	0	**0.02**	**0**
HPA$_{rms}$ (m)	8.93	3.57	14.14	5.30	**9.71**	**3.69**
VPA$_{rms}$ (m)	17.98	2.15	28.30	3.27	**19.31**	**2.13**

TABLE V. PERFORMANCE METRICS RESULTS FOR S2 MD SCENARIOS

Metric req.	***Scenario_MD***					
	A1		***A2***		***Total***	
	Sensor	***Tracker***	***Sensor***	***Tracker***	***Sensor***	***Tracker***
PU (%)	90.31	100	97.93	100	**97.64**	**100**
PLG n=3 (%)	0.3	0	0	0	**0.01**	**0**
HPA$_{rms}$ (m)	3.64	1.94	15.27	5.43	**4.49**	**2.1**
VPA$_{rms}$ (m)	8.8	1.13	28.43	2.90	**9.21**	**1.86**

VIII. DISCUSSION

The results obtained in the previous section show the performance of Network Identification Systems conducted according to European standards and regulations within a U-space service simulation environment.

The experiments carried out indicate that, as the regulations currently stand, degradations in the surveillance data received by the Network Identification Service directly affect and have a major impact on the information received by the Traffic Information service, which distributes UAS surveillance data to operators and/or other USSPs.

In an ATM environment where the surveillance infrastructure is reaching a solid level of maturity, the failure of a system to meet certain minimum performance requirements is a relative safety issue as there is usually supported by other surveillance layers. However, the availability and coverage of surveillance sources is a pending task in a UTM scenario such as U-space, where the future vision is of Very Low-Level airspace with high aircraft density. Having independent layers of surveillance offers robustness against hardware/software failures, external phenomena, Radio Frequency attacks, cyber-attacks, etc.

In this work, it has been shown that the continuity in the provision of surveillance information, which affects the update metrics, can be guaranteed to some extent by a Tracking service that predicts the gaps when there are lost target reports. This would also reduce the instantaneous and total position error in the trajectories received by the USSP as the tracking algorithms smooth out the error in the trajectories. Indeed, although performance thresholds for the U-space are not defined yet, the values obtained in several degraded scenarios are quite poor in absence of the Tracking service. Therefore, the assessment presented in this paper points out that this service should be considered, at least as an optional feature of the U-space implementation in areas where poor communication and GNNS performance is expected.

With regard to the metrics, accuracy metrics, lower than expected results have been obtained. As discussed in Section V, surveillance performance monitoring tools obtain the metrics by comparing the measurements of the surveillance sensors being evaluated with a reference. This reference is obtained by using statistical methods and leveraging the diversity of information sources available. Therefore, for a trajectory, the more monitoring data from different sources, the better the quality of the computed reference trajectory. The reference will be of poorer quality as the sources of information decrease and become increasingly similar to the measurements from the surveillance sources available in the analysis. That said, it is understood that the accuracy metrics are consistently below the expected value. In a conformance assessment with only one source of information, such metrics are not entirely reliable as the reference will be too much conditioned by the available system measurements. This indicates that to apply PBS to the U-space environment, it is necessary to enhance the surveillance infrastructure environment with new systems, preferably non-cooperative systems or independent cooperative systems.

Several surveillance technologies are now candidates to become part of the U-space surveillance architecture. Some of these technologies use cellular networks together with radiolocation algorithms [15] using UAS radio signals while others use electro-optical, infrared sensors and Artificial Intelligence [16]. Therefore, to create a CNS framework in which new technologies can be integrated and harmonised to ensure minimum safety, it makes sense to abstract the technology used by applying the PBS paradigm.

In this hypothetical scenario, a Tracking service is even more critical since a fusion of the data from the different surveillance sensors is necessary to obtain common surveillance data as accurately as possible as this would be the main surveillance source for the USSP's TIS service.

When the U-space regulation is upgraded to support Urban Air Mobility operations, a surveillance function including tracking and performance monitoring will become a key enabler of U3 services, such as Tactical Conflict Resolution or Dynamic Capacity Management, which will be crucial for them. Moreover, in this case, the effect of CNS performance on the separation minima applied by the Tactical Conflict Resolution service is crucial and must be thoroughly considered. CNS performance thresholds will have to be defined so that the applicable Target Level of Safety can be attained.

IX. CONCLUSION

The surveillance function in the U-space has been put into context. Within this, a performance monitoring sub-function has been assessed. This determines the quality of the surveillance information processed by the Network Identification Service.

The results obtained show that the performance monitoring tools and methods proposed are able to reflect, through appropriate metrics adapted from the ATM domain, the performance of a scenario in which the surveillance data from NI systems is impaired parametrically. Therefore, it is possible to establish a relationship between these metrics and future U-space services, such as the Tactical Conflict Resolution and Dynamic Capacity Management services which will require CNS performance information.

Furthermore, it has been identified that a Tracking service, in addition to reducing the error of dynamic aircraft data, would help to improve the continuity in the provision of surveillance information to the designated separator, even in the simplest scenarios.

Limitations have been found in this concept. In terms of surveillance, having a single sensor providing surveillance information limits the reliability of accuracy metrics results. An additional surveillance system is necessary, especially in high-density urban environments.

In this work, only the introduction of a surveillance performance monitoring concept within U-space and experiments to validate its operation have been considered. Future work with the PBS concept described in this work will focus on defining the surveillance performance requirements for the metrics and how the PBS concept is integrated into the separation management service defined by BUBBLES.

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