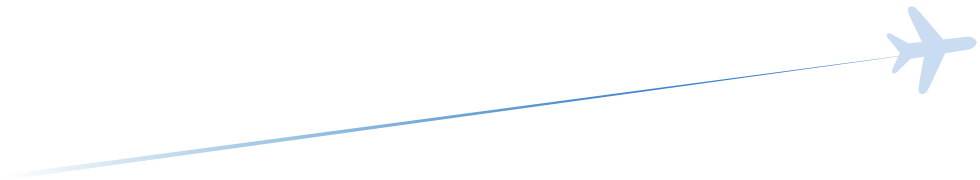

GOF2.0 D2.4 – Appendix G Network Coverage and Population Density

Deliverable ID:	**D2.4-G**
Dissemination Level:	**PU**
Project Acronym:	**GOF2.0**
Grant:	**101017689**
Call:	**H2020-SESAR-2020-1 VLD Open 2**
Topic:	**U-space capabilities and services to enable Urban Air Mobility**
Consortium Coordinator:	**Lennuliiklusteeninduse Aktsiaselts (EANS)**
Edition Date:	**31 October 2022**
Edition:	**00.00.04**
Template Edition:	**03.00.00**

Founding Members
EUROPEAN UNION EUROCONTROL
SESAR JOINT UNDERTAKING

Authoring & Approval

Authors of the document

Name/Beneficiary	Position/Title	Date
Thomas Neubauer / Dimetor	WP2	29.4.2021
Thomas Wana / Dimetor	WP2	29.4.2021
Shengnan Gao / EHANG	WP2	29.4.2021
Hui Zeng / EHANG	WP2	29.4.2021
Juha Lindstedt / Aviamaps	WP2	29.4.2021
Jose Ignacio Rodriguez / EHANG	WP2	29.4.2021
Ada Lu / EHANG	WP2	29.4.2021
Yuhang Yun / EHANG	WP2	29.4.2021
Piotr Luboński / PSNC	WP2	29.4.2021
Damian Soliwoda / PSNC	WP2	29.4.2021
Sven Jürgenson / Threod	WP2	29.4.2021
Piotr Dybiec / DroneRadar	WP2	29.4.2021
Tanel Järvet / CAFA Tech	WP2	29.4.2021
Parmentier Remy / Vaisala	WP2	29.4.2021
Piotr Szymaniak / PSNC	WP2	29.4.2021
Pawel Korzec / DroneRadar	WP2	29.4.2021
Lukasz Gorny-Zajac / Droneradar	WP2	29.4.2021
Gokul Srinivasan / Robots Expert	WP2	29.4.2021
Thomas Lutz / Frequentis	WP2 Lead	29.4.2021
Hubert Künig / Frequentis	WP2	29.4.2021
Peter Cornelius / Frequentis	WP2	29.4.2021
Gregor Mogeritsch / Frequentis	WP2	29.4.2021

Reviewers internal to the project

Name/Beneficiary	Position/Title	Date
Annely Aasalaid / EANS	WP2	29.4.2021
Heikko Jae / EANS	WP2	29.4.2021
Aigar Tarre / EANS	WP2	29.4.2021
Imre Rammul / EANS	WP2	29.4.2021
Armin Sutter / EANS	WP2	29.4.2021
Mateusz Kotliński/PANSA	WP2	29.4.2021

Mateusz Zych/PANSA	WP2	29.4.2021
Thomas Neubauer/Dimetor	WP2	29.4.2021
Sami Alkula / Fintraffic	WP2	29.4.2021
Nunzio Sciammetta / Airbus	WP2	29.4.2021
Maxime Meijers / Airbus	WP2	29.4.2021
Felix Lee/Ehang	WP2	29.4.2021
Pradyumna Vyshnav / Unmanned Life	WP2	29.4.2021

Approved for submission to the SJU By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date

Rejected By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date

Document History

Edition	Date	Status	Author	Justification
00.00.01	2021		Thomas Neubauer, ACJA ServiceCoverage Definition participants. Service Architects: Thomas Wana, Thomas Lutz, Hubert Kuenig, Josef Jahn	
00.00.02	18.03.2021	draft	WP2 Partners	Enhance and update
00.00.03	30.04.2021	released	WP2 Partners	Release
00.00-04	03.11.2022	Released	WP2 Partners	Update

GOF2.0

GOF2.0 INTEGRATED URBAN AIRSPACE VLD

This Updated Service Specification is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 101017689 under European Union's Horizon 2020 research and innovation programme.

Abstract

The Network Coverage service provides information about current and expected data connectivity conditions along a flight route or in a geographical area of interest.

It provides information where connectivity conditions are or are not good enough for safe and reliable data connectivity that adheres to a certain service level, provided by individual communication service providers.

Provided connectivity conditions are provided in terms of quality and performance of network and C2 link data communication between drones and ground stations, as well as coverage information for cellular networks. Targeted service consumers include aviation organisations, drone operators and end users.

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Purpose of the document

This document describes the Network Coverage Service in a logical technology-independent manner, that is:

- the operational and business context of the service
    - requirements for the service (e.g., information exchange requirements)
    - involved nodes: which operational components provide/consume the service
    - operational activities supported by the service
    - relation of the service to other services
- the service description
    - service interface definitions
    - service interface operations
    - service payload definition
    - service dynamic behaviour description
- service provision and validation aspects

Furthermore, this document clearly defines the version of the service.

1.2 Scope

The NetworkCoverage Service described in this document provides a general mechanism between the various stakeholders, interfaces and data models that enable and allow the automated data exchange between the respective parties.

The scope includes the following aspects:

- Operational Context
- Service Interfaces
- Service Interface Definition
- Service Dynamic Behavior
- Service Data Model

There are a number of goals defined that this paper aims to achieve:

1. A goal is to define logical messaging that might be exchanged between a traffic management system (or drone operator, USS/USSP or equivalent) and an MNO.

2. A goal is to identify architectures that will be amenable to expedient implementation by a variety of MNOs, given that MNOs have various operating procedures and means of managing their networks.
3. A goal is to identify architectures that would support a variety of business models and data sharing models in a technology independent way (i.e. limiting and avoiding exchange of proprietary and/or sensitive data).
4. A goal is to provide coverage information primarily for C2 but also for payload traffic.
5. A goal is to maintain synchronization with other ACJA Work Tasks, such that the entirety provides regulators and users with confidence on performance-based requirements.
6. A goal is to organize those needs that require standards input from ASTM, 3GPP or other standards developing organizations (SDO) to help close the gap between standards orgs. For example, flight plans may come from ASTM but Key Performance Indicator (KPI) analysis methods may come from 3GPP, EUROCAE and RTCA.
7. A goal is to understand what real time metrics, non-real time and aggregated data can come from the MNO, such as, but not limited to, population density, which could be useful in predicting risk and/or performance-based metrics.

The overall objective is to provide a minimum set of descriptions to standardize the way data between MNOs and the UTM ecosystem can be exchanged. The NetworkCoverage Service does not limit any entity, by any means, to deploy or implement other data exchange in addition to the defined service definitions.

This document is not anticipated to be a complete set of functions and definitions for an implementable API.

This service specification is intended to be read by service architects, system engineers and developers in charge of designing and developing an instance of the NetworkCoverage Service.

1.3 Intended readership

This service specification is intended to be read by service architects, system engineers and developers in charge of designing and developing an instance of the Network Coverage service.

Furthermore, this service specification is intended to be read by enterprise architects, service architects, information architects, system engineers and developers in pursuing architecting, design and development activities of other related services.

1.4 Background

1.4.1 EUROCONTROL Concept of Operations for U-space (CORUS)

The fact that ensuring robust communications is essential for safe drone operations is not new. Other projects and papers have been looking into that extensively.

For example, the CORUS Project [2] identifies a so-called Communication Coverage information service (see CORUS ConOps Volume 2, chapter 5.1.7.6).

This service is described there as "The service to provide information about the communication coverage. It can be specialized depending on the communication infrastructure available (e.g. ground or satellite based). This service is used to plan relying on required coverage."

The CORUS consortium and other references [13] depict the service as U-space level 2 service, likely to be available mid-future.

1.4.2 General principles and research basis

A key principle of the U-spaces architecture is applying a service-oriented architecture approach, where open, interoperable and standard based interfaces are offered based on SWIM principles .

This document is based on both research and commercial environments outlined in a range of references such as [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [18], [19], [20], [21], [22].

1.4.3 Efficient, safe and sustainable traffic at sea (EfficienSea2)

The design method and terminology builds on experience from the EfficienSea2 project [14], [15].

1.5 Glossary of terms

Term	Definition
External Data Model	Describes the semantics of the domain (or a significant part thereof) by defining data structures and their relations. This could be at logical level (e.g., in UML) or at physical level (e.g., in XSD schema definitions), as for example standard data models.
Message Exchange Pattern	Describes the principles how two different parts of a message passing system (i.e.: the service provider and the service consumer) interact and communicate with each other. Examples: In the Request/Response MEP, the service consumer sends a request to the service provider in order to obtain certain information; the service provider provides the requested information in a dedicated response. In the Publish/Subscribe MEP, the service consumer establishes a subscription with the service provider in order to obtain certain information; the service provider publishes information (either in regular intervals or upon change) to all subscribed service consumers.
Operational Activity	An activity performed by an operational node. Examples of operational activities are: Route Planning, Route Optimization, Logistics, Safety, Weather Forecast Provision, …
Operational Model	A structure of operational nodes and associated operational activities and their inter-relations in a process model.
Operational Node	A logical entity that performs activities. Note: nodes are specified independently of any physical realization. Examples of operational nodes are: Control Center, Authority, Weather Information Provider, …

Service	The provision of something (a non-physical object), by one, for the use of one or more others, regulated by formal definitions and mutual agreements. Services involve interactions between providers and consumers, which may be performed in a digital form (data exchanges) or through voice communication or written processes and procedures.
Service Consumer	A service consumer uses service instances provided by service providers.
Service Data Model	Formal description of one dedicated service at logical level. The service data model is part of the service specification. Is typically defined in UML and/or XSD. If an external data model exists (e.g., a standard data model), then the service data model shall refer to it: each data item of the service data model shall be mapped to a data item defined in the external data model.
Service Design Description	Documents the details of a service technical design (most likely documented by the service implementer). The service design description includes (but is not limited to) a service physical data model and describes the used technology, transport mechanism, quality of service, etc.
Service Implementation	The provider side implementation of a dedicated service technical design (i.e., implementation of a dedicated service in a dedicated technology).
Service Implementer	Implementers of services from the service provider side and/or the service consumer side.
Service Instance	One service implementation may be deployed at several places by same or different service providers; each such deployment represents a different service instance, being accessible via different URLs.
Service Instance Description	Documents the details of a service implementation (most likely documented by the service implementer) and deployment (most likely documented by the service provider). The service instance description includes (but is not limited to) service technical design reference, service provider reference, service access information, service coverage information, etc.
Service Interface	The communication mechanism of the service, i.e., interaction mechanism between service provider and service consumer. A service interface is characterized by a message exchange pattern and consists of service operations that are either allocated to the provider or the consumer of the service.
Service Operation	Functions or procedure that enables programmatic communication with a service via a service interface.
Service Physical Data Model	Describes the realization of a dedicated service data model in a dedicated technology. This includes a detailed description of the data payload to be exchanged using the chosen technology. The actual format of the service physical data model depends on the chosen technology. Examples may be WSDL and XSD files (e.g., for SOAP services) or swagger (Open API) specifications (e.g., for REST services). If an external data model exists (e.g., a standard data model), then the service physical data model shall refer to it: each data item of the service physical data model shall be mapped to a data item defined in the external data model. In order to prove correct implementation of the service specification, there shall exist a mapping between the service physical data model and the service data model. This means, each data item used in the service physical data model shall be mapped to a corresponding data item of the service data model. (In case of existing mappings to a common external (standard) data model from both the service data model and the service physical data model, such a mapping is implicitly given.)

Service Provider	A service provider provides instances of services according to a service specification and service instance description. All users within the domain can be service providers, e.g., authorities, organizations (e.g., meteorological), commercial service providers, etc.
Service Specification	Describes one dedicated service at logical level. The Service Specification is technology-independent. The Service Specification includes (but is not limited to) a description of the Service Interfaces and Service Operations with their data payload. The data payload description may be formally defined by a Service Data Model.
Service Specification Producer	Producers of service specifications in accordance with the service documentation guidelines.
Service Technical Design	The technical design of a dedicated service in a dedicated technology. One service specification may result in several technical service designs, realizing the service with different or same technologies.
Service Technology Catalogue	List and specifications of allowed technologies for service implementations. Currently, SOAP and REST are envisaged to be allowed service technologies. The service technology catalogue shall describe in detail the allowed service profiles, e.g., by listing communication standards, security standards, stacks, bindings, etc.
Spatial Exclusiveness	A service specification is characterized as "spatially exclusive", if in any geographical region just one service instance of that specification is allowed to be registered per technology. The decision, which service instance (out of a number of available spatially exclusive services) shall be registered for a certain geographical region, is a governance issue.

Table 1: Glossary of terms

1.6 List of Acronyms

Acronym	Explanation
3GPP	3rd Generation Partnership Project
ACJA	Aerial Connectivity Joint Activity (by GSMA + GUTMA)
AIXM	Aeronautical Information Exchange Model
AMQ	Advanced Message Queuing
API	Application Programming Interface
ASTM	American Society for Testing and Materials
ATM	Air Traffic Management
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CIS	Common Information Service
CTR	Controlled Traffic Region
DL	Downlink connection, data transmission from a base station to a mobile device
DSS	Discovery and Synchronization Service
EDT	Estimated Time of Departure

Acronym	Explanation
FIXM	Flight Information Exchange Model
FPL	Flight Plan
GSM	Global System for Mobile Communication
GSMA	GSM Association
GUTMA	Global UTM Association
JMG	Java Message Service
KPI	Key Performance Indicator
MEP	Message Exchange Pattern
MNO	Mobile Network Operator
NAF	NATO Architectural Framework
NOTAM	Notice To Air Man
REST	Representational State Transfer
RF	Radio Frequency
RSRP	Reference Signal Received Power
SDO	Standards Developing Organization
SINR	Signal to Interference and Noise Ratio (in communication networks)
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SSD	Service Specification Document
SWIM	System Wide Information Management
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UL	Uplink connection, data transmission from a mobile device to a base station
UML	Unified Modelling Language
URL	Uniform Resource Locator
URN	Uniform Resource Name
USS	UAS Service Supplier
UTM	UAV Traffic Management
UUID	Universally Unique Identifier
WXDM	Weather Information Exchange Model
WSDL	Web Service Definition Language
XML	Extensible Mark-up Language

Acronym	Explanation
XSD	XML Schema Definition

Table 2: List of acronyms

2 Service Identification

The purpose of this chapter is to provide a unique identification of the service and describe where the service is in terms of the engineering lifecycle.

Name	*Traffic Telemetry Service*
ID	*urn:gof2:services:NetworkCoverageService*
Version	*1.1*
Description	The NetworkCoverage Service provides three-dimensional information about data connectivity conditions along a flight route or in an area of interest. It provides information where connectivity conditions are or are not good enough for safe and reliable data connectivity that adheres to a certain service level, provided by individual connectivity providers.
Keywords	*IP connectivity, data connectivity, data coverage, mobile communication, mobile connectivity, mobile coverage, cell connectivity, cell communication, cell coverage, LTE, 4G, 5G, command and control, C2*
Architect(s)	*2020-2021 Thomas Neubauer, ACJA ServiceCoverage Definition participants. Service Architects: Thomas Wana, Thomas Lutz, Hubert Kuenig, Josef Jahn* *2021 The GOF2 U-Space Project Consortium*
Status	*Provisional*

Table 3: Service identification

3 Operational Context

Safe operation of UAS / UAM may likely require knowledge of expected RF communications link quality (performance) and coverage during planning and flight operation, as well as measurement and monitoring of these parameters during the flight.

Communication coverage is not static information and is subject to continuous change due to a multitude of factors. Consequently, the coverage information comprises real-time and non-real-time data. Real-time data may include live performance indicators, alerts on significant changes, but also real-time network outage information. Non-real-time data for instance could include, but is not limited to, aggregated and historic information as well as planned events (such as planned maintenance outages of the network), which allows connectivity analytics and projections into the future. Both types of data complement each other.

3.1 Planning Phase

Before the start of a flight, there may likely be a need to determine how the planned flight path or flight operations area fits into the following geographic areas:

Areas with or without cellular network coverage

Areas where non-cellular RF coverage is bad or non-existent, either due to atmospheric conditions, terrain/building obstruction, or others.

These factors can be determined via network / surveillance coverage maps, RF propagation modeling, as well through public space weather services. Deriving the necessary OK/not-OK information will require automated processing and data exchange.

3.2 Flight Phase

During a flight, adherence to the flight plan needs and limitations to be monitored, and any non-conformance outside of pre-established thresholds and safety margins defined in the operational authorization, should trigger appropriate mitigation actions.

In addition, UTM service providers receive data about the link quality between UAV and ground station / pilot, measuring current signal strength, cumulative signal strength, data transmission latency, number of packet retransmissions, network notifications, etc.

This data indicates the real time link quality and may be used to react to possible deterioration of link quality, or even a complete loss of link. Although the safety criticality of the C2 link depends on characteristics of the UA and the contingency procedures proposed by a UAV operator, some UAV may pose a safety risk in case of C2 outage time beyond the expected availability as they are essentially uncooperative drones that do not respond to commands until link is reestablished.

3.3 Example Use Case

An example service use is shown in Figure 1 and described in more detail below:

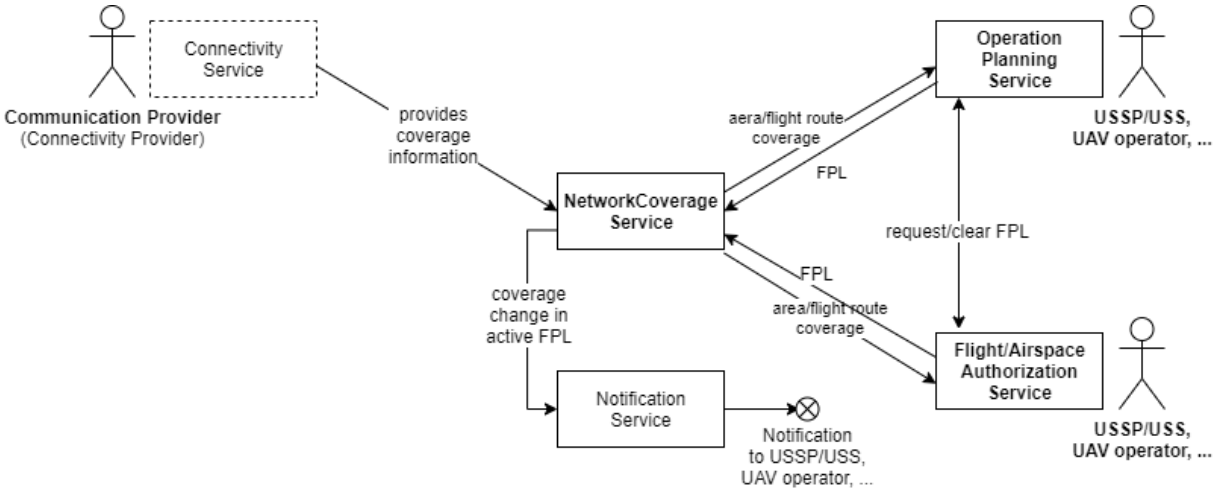

Figure 1 - Operational model diagram

A UAV operator wants to fly a mission from A to B.

In order to estimate the general feasibility of the flight, among other things, the connectivity situation in the general area of the flight must be checked by the Operation Planning Service[1]. The Communication Provider provides the area coverage information utilizing the NetworkCoverage Service. Coverage information may also be complemented with measured data.

If the flight is feasible in a given area, a concrete route must be planned. Considering among others the weather, airspace restrictions, aircraft performance, etc., one or more route candidates are created by the drone operator (and/or USS/USSP or equivalent), which are checked with the support of the NetworkCoverage Service whether the minimum service level (for example: continuous C2 availability) is met along the candidate routes. If requested, the NetworkCoverage Service can also propose alternate routes to assure the minimum service level of the connectivity.

The drone operator prepares a flight intent plan ahead of ETD in line with the operational limitations of his/her authorization. The operator can be assisted in this task by the Operation Planning Service which may coordinate with the NetworkCoverage Service if the planned flight route meets the minimum service level requirements.

Shortly before the flight actually commences, the Operation Planning Service may recheck that the connectivity service level requirements are still met (together with meteorology, NOTAMs, etc.), and,

[1] "Operational Planning" is derived from the FAA UTM Conops v2.0 section 2.4.4 [16]: "The Operation Planning service supports the operator to define prior to the operation a four-dimensional (4D) volume of airspace within which the operation is expected to occur, the times and locations of the key events associated with the operation, including launch, recovery, and any other information deemed important (e.g., segmentation of the operation trajectory by time)."

where necessary, alternate routes can be proposed. Then, clearance is requested from Flight/Airspace Authorization Service[2] to commence the flight.

During the flight, due to an outage at the communication provider, a certain segment of the flight planned route ahead of the aircraft loses connectivity. For this the link quality could be used as key performance indicator. A Connectivity Service at the Communication Provider identifies this situation and informs the Notification Service[3] by utilizing the NetworkCoverage Service.

The drone operator may have to re-plan the rest of the flight, and coordinate the changes using the Operation Planning Services, again with the assistance of the NetworkCoverage Service, to stay on a route that meets the connectivity minimum service level requirements, or apply contingency/emergency procedures in line with the approved Concept of Operations.

Providers and actors might / will be different depending on the local legislation/regulations.

3.4 Functional and Non-functional Requirements

The table below lists applicable existing requirements for the *Network Coverage* service.

Requirement Id	Requirement Name	Requirement Text	References
REQ-AIRPASS-D31-PACM-0010	Communication for Procedural ATC Interface	The on-board system should provide a wireless data link and protocol to coordinate procedural directions from ATC services with the UAS ground control station	SESAR U-space requirements

[2] This service is called "Airspace Authorization" service in FAA UTM Conops v2 section 2.4.3 [16] and "Flight Authorisation" in EASA draft Commission U-Space regulation in Europe, Article 12 [17].

[3] The Notification Service may provide such information to the “Constraint Information & Advisories” Service as defined in the FAA ConOps v2.0, Section 2.4.5 [16] or equivalent. Similarly, in the SESAR CORUS “U-Space Concept of Operations” [2] there are services defined in sections 5.1.5.1 and 5.1.6.6 that require “… to provide status information about communication infrastructure. … The service should give warnings of degradation of communications infrastructure”.

REQ-AIRPASS-D31-EACM-0010, REQ-AIRPASS-D31-MNCM-0010, REQ-AIRPASS-D31-TICM-0010, REQ-AIRPASS-D31-DFCM-0010, ...	Communication for Emergency Management, Communication for Monitoring, Communication for Traffic Information, Communication for Dynamic Geofencing, ...	Additional communication requirements like above, but for different use-cases: Emergency Management, Monitoring, Traffic Information, E-Identification, Geofencing, ...	SESAR U-space requirements
REQ-DREAMS-D32-OPER.0008	Definition amendments are proposed to include the U-Space context COM (Communication)	"Two different definitions are proposed: 1) ATS COM: 'ATS communication services' means aeronautical fixed and mobile services to enable ground-to-ground, air-to-ground for ATS purposes. 2) SWIM-COM: 'SWIM communication services' means fixed and mobile services to enable end systems, either at fixed location, mobiles or in flight, to exchange digital information for ATM/ANS purposes."	SESAR U-space requirements
REQ-IMPETUS-D31-INTR.0012	DTM-UAV Interface	The UAV shall provide continuous information about its position to the DTM, ensuring that at least this direct link with U-Space is not compromised.	SESAR U-space requirements
REQ-IMPETUS-D31-DECO.0017	Legacy networks	Legacy networks such as cellular and GPS networks shall beused to support drone operations and provide communications between different roles. The networks can be used to communicate U-space services needed to carry out safe drone operations. The system will programmatically communicate with these networks for facilitate safe drone operations.	SESAR U-space requirements
REQ-TERRA-D32-FPER-0190	General Communications availability	The selected communication infrastructure shall ensure the connectivity of the ground segment with the external systems with which the system shall interface.	SESAR U-space requirements
REQ-TERRA-D32-FPER-0192	General Communications latency	V2I latency has to be lower than 3 second.	SESAR U-space requirements
REQ-TERRA-D32-FPER-020	Connectivity	The selected communication infrastructure shall provide connectivity between the central system and all nodes.	SESAR U-space requirements

REQ-DROC2OM-D21-PERF.0010	WP2-GENUS-PER-001	The C2 Link System shall offer, for all addressed data exchanges, an end-to-end availability of provision of at least 99.3%	SESAR U-space requirements
REQ-DROC2OM-D21-PERF.0020	WP2-GENUS-PER-002	The C2 Link System shall offer, for all addressed data exchanges, an availability of use of at least 99%	SESAR U-space requirements
REQ-DROC2OM-D21-PERF.0030	WP2-GENUS-PER-003	The C2 Link System shall offer integrity performance in terms of packet error rate measured at the interface between network and logical link layer of at least 10-3	SESAR U-space requirements
REQ-DROC2OM-D21-FUNC.0050	WP2-GENUS-FUN-005	The C2 Link System shall provide communication links for the whole duration of flights as well as prior to take-off and after landing.	SESAR U-space requirements
REQ-DROC2OM-D21-FUNC.0080	WP2-GENUS-FUN-008	The C2 Link System shall support air-ground communications for drones.	SESAR U-space requirements
REQ-DROC2OM-D21-FUNC.0100	WP2-DATLI-FUN-001	The C2 Link System shall be compatible with data links which will support all security related countermeasures to prevent identity theft, theft-of-service and eavesdropping threats.	SESAR U-space requirements
REQ-DROC2OM-D21-FUNC.0200	WP2-TERST-FUN-001	The C2 Link System shall be compatible with a 3GPP LTE/LTE-Advanced or 5G NR terrestrial communication system operating in the 3GPP defined frequency bands.	SESAR U-space requirements
REQ-DROC2OM-D21-FUNC.0220	WP2-TERST-FUN-003	When using a 3GPP LTE/LTE-Advanced or 5G NR terrestrial communication system, the C2 Link System shall be able to satisfy the baseline traffic profile requirements listed in Section 3.1.*	SESAR U-space requirements
REQ-DROC2OM-D21-FUNC.0240	WP2-INTSE-FUN-001	The C2 Link System shall define an interface layer for multi-network service integration, including terrestrial and satellite networks relying on the IP protocol for global interconnection.	SESAR U-space requirements
REQ-DROC2OM-D21-FUNC.0420	WP2-MULOP-FUN-001	The C2 Link System shall allow deployment of competing C2 Link Service providers and operators in samegeographical locations.	SESAR U-space requirements
REQ-DROC2OM-D21-FUNC.0450	WP2-MULOP-FUN-004	The C2 Link System shall allow Interworking, i.e. having the C2 Link data sent from the drone to ground network through a provider, and reaching the U-Space infrastructure servers through another provider	SESAR U-space requirements

Table 4: Functional and Non-functional Requirements

3.5 Operational Nodes

Operational Node	Remarks
Connectivity Provider	A provider of communication services like a Mobile Network Operator or a Satellite Data Communications Provider.
Connectivity Service	Service deployed close to mobile network operator infrastructure, providing connectivity data for the Network Coverage Service.

Table 5 - Operational Nodes providing the Connectivity Service

Operational Node	Remarks
Operation Planning Service	Service defined in FAA UTM Conops v2.0 section 2.4.4 [16]: "The Operation Planning service supports the operator to define prior to the operation a four-dimensional (4D) volume of airspace within which the operation is expected to occur, the times and locations of the key events associated with the operation, including launch, recovery, and any other information deemed important (e.g., segmentation of the operation trajectory by time).".
Flight/Airspace Authorization Service	Service providing authorization for a specific flight. Depending on local regulation this service works with flight trajectories or airspace volumes.
Notification Service	Notifies drone operators of relevant changes that occurred typically in-flight, or pre-flight after the initial planning phase. It could consume events from different services, not only the Network Coverage Service.

Table 6 - Operational Nodes (directly) consuming the Connectivity Service

3.5.1 Operational Activities

Operational Activity	Remarks
Get area and flight route coverage	Returns information about connectivity coverage for a certain area or flight route for a particular technology and communication provider for a particular time period in the future
Notify about changes in coverage	For a given area or flight route, get notifications about changes to connectivity.
Provide communication services	The communication provider provides its infrastructure to the drone operators for data communication.

Table 7 – Operational Activities supported by the NetworkCoverage service

4 Service Overview

4.1 Service Interfaces

The following diagram depicts the Service Interfaces of the NetworkCoverage Service, and their allocations to the Service Provider and the Service Consumers, respectively:

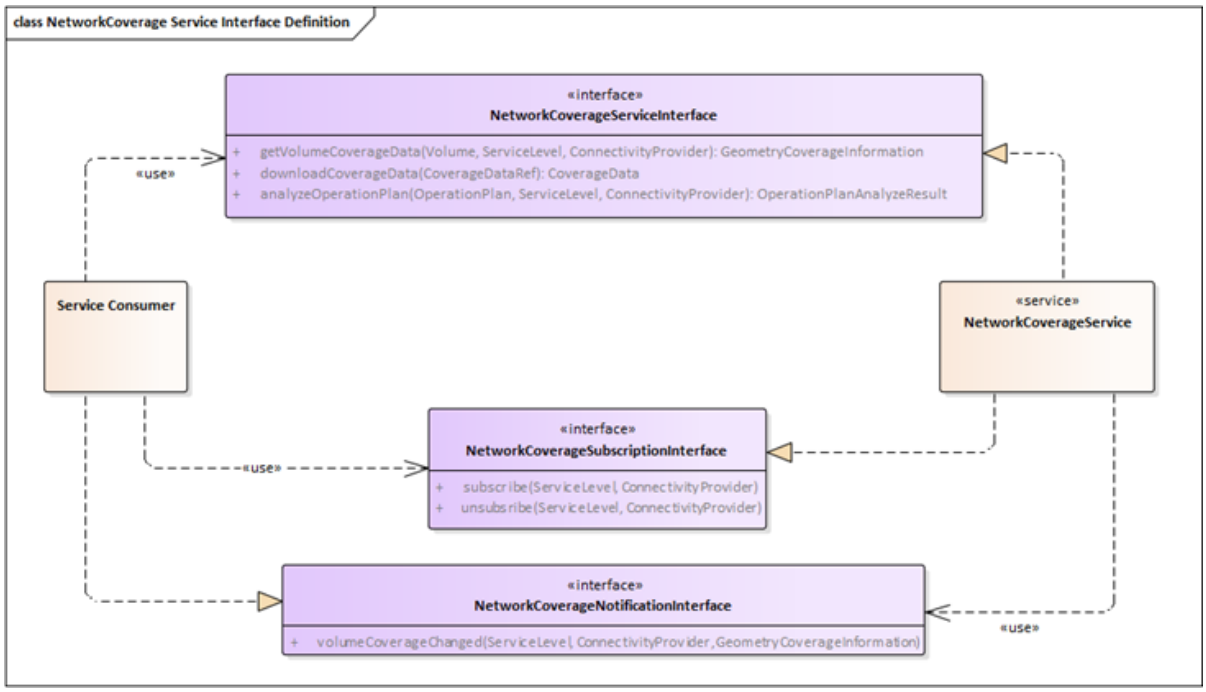

Figure 2: Network Coverage Service Interface Definition diagram

ServiceInterface	Role (from service provider point of view)	ServiceOperation
NetworkCoverageServiceInterface	Provided	getVolumeCoverage downloadCoverageData analyzeOperationPlan
NetworkCoverageSubscriptionInterface	Provided	subscribe unsubscribe
NetworkCoverageNotificationInterface	Required	volumeCoverageChanged

Table 8: Service Interfaces

5 Service Data Model

This section describes the information model, i.e., the logical data structures to be exchanged between providers and consumers of the service.

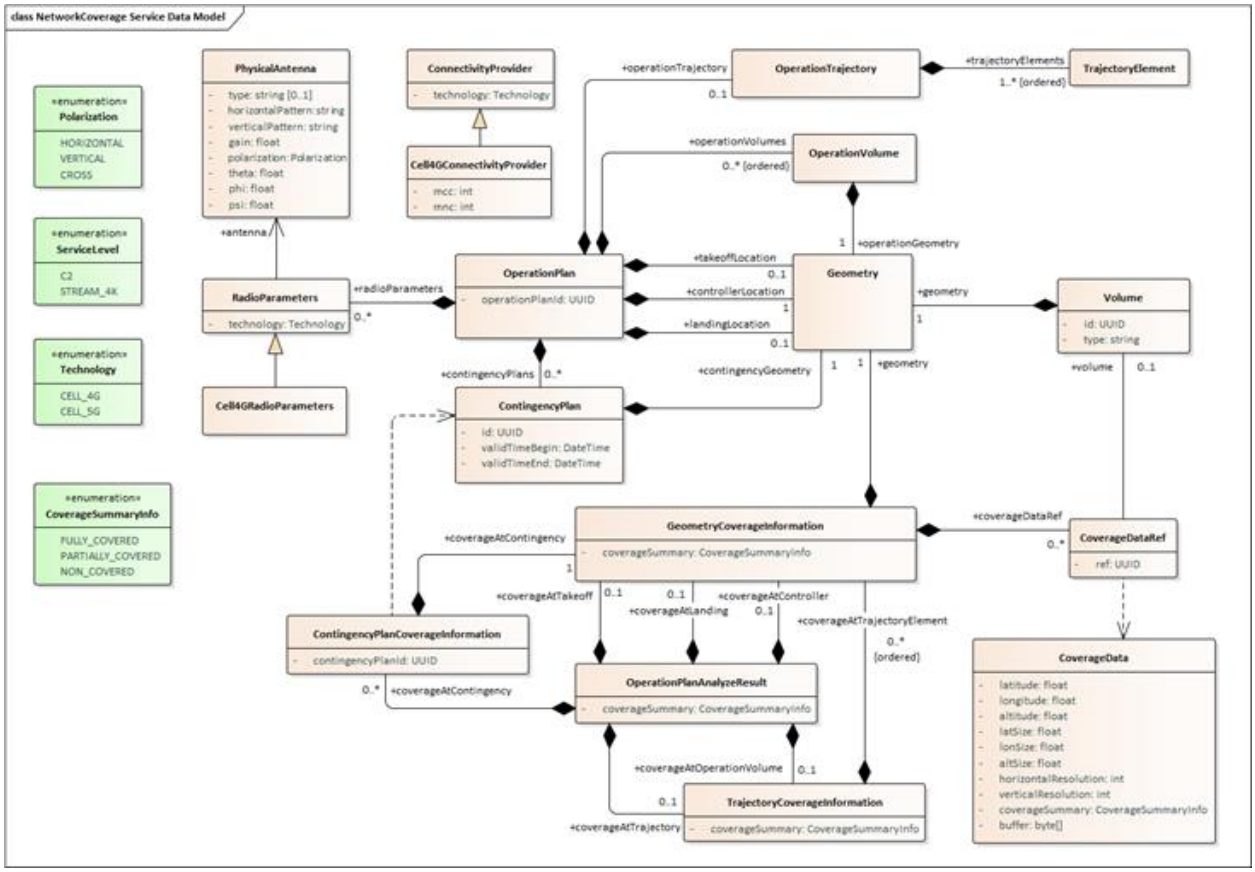

Figure 3: Data Model diagram of the Network Coverage Service

The Service Data Model focuses on the core service model and the diagram includes structures (OperationPlan, Volume, Pose), whose detailed specification are out of scope of this document.

The data model supports and is compatible with a number of industry standards, such as ICAO, ASTM F3411-19 [18], EUROCAE ED-269 [20], FIXM, etc. It is important to note that the data model can be extended, for example for future requirements and additional information that may need to be exchanged.

The following tables describe the entities and their attributes in more detail.

5.1 The *ConnectivityProvider* Data Structure

The ConnectivityProvider represents a connectivity provider, e.g. a provider of communication services like a Mobile Network Operator or a Satellite Data Communication Provider.

Property	Type	Multiplicity	Description	Note
technology	Technology	1	The technology of the radio parameter.	

Table 9: The ConnectivityProvider data structure

5.2 The *Cell4GConnectivityProvider* Data Structure

The Cell4GConnectivityProvider is an example specialization of the ConnectivityProvider class. It contains additional attributes to identify a Mobile Network Operator that offers 4G cellular connectivity services.

It works the same for 5G, while for satellite or other connectivity technology providers the attributes might be different.

Property	Type	Multiplicity	Description	Note
MCC	int	1	Mobile Country Code.	
MNC	int	1	Mobile Network Code. MCC and MNC together uniquely identify the Mobile Network Operator globally.	

Table 10: The Cell4GConnectivityProvider data structure

5.3 The *ContingencyPlan* Data Structure

Note: *ContingencyPlan* is fullly described in a separate Operation Plan service specification, selected attributes are listed here to provide context for better understanding.

The *ContingencyPlan* describes an alternative trajectory location for a flight by providing a three-dimensional volume in space together with the applicable time span.

Property	Type	Multiplicity	Description	Note
id	UUID	1	Identifier of the contingency plan.	
contingencyGeometry	Geometry	1	Three-dimensional space fragment, specifying the envelope of contingency trajectory. Can be for example a cube, cylindar, quader, or other geometry.	
validTimeBegin	DateTime	1	UTC point in time when the flight is expected to enter the given contingency volume.	
validTimeEnd	DateTime	1	UTC point in time when the flight is expected to leave the given contingency volume.	

Table 11: The ContingencyPlan data structure

5.4 The *ContingencyPlanCoverageInformation* Data Structure

The *ContingencyPlanCoverageInformation* holds an analysis in regards to connectivity coverage for a contingecy plan belonging to an operation plan.

Property	Type	Multiplicity	Description	Note
contingencyPlanId	UUID	1	Reference to the contingency plan.	
coverageAtContingency	GeometryCoverageInformation	1	Coverage information corresponding to the contingency plan.	

Table 12: The ContingencyPlanCoverageInformation data structure

5.5 The *CoverageData* Data Structure

The CoverageData structure contains 3D aerial coverage information in a raster of a certain resolution. Full capabilities are to be described in an external CoverageData specification document for further processing.

It is essentially a 3D grid where each grid cell has an assigned a value. CoverageData is like a 3D bitmap, where the pixel content represents attributes relevant for exchanging network coverage information, e.g. boolean values true/false to describe whether the requested service level is met at that particular point or not.

In future versions of this data structure, CoverageData could support exchange of numeric values or other types that can be encoded in a byte, allowing to transport e.g. minimum throughput in a grid cell.

How exactly values are encoded in the byte array has to be described in a separate document specific to and available for an implementation of CoverageData.

Property	Type	Multiplicity	Description	Note
latitude	float	1	Latitude of the north-west corner of the area covered in WGS84.	
longitude	float	1	Longitude of the north-west corner of the area covered in WGS84.	

altitude	float	1	Altitude of the lower boundary of the 3D area.	
latSize	float	1	Height of the Area, in WGS 84 degrees. Typically 1.0	
lonSize	float	1	Width of the Area, in WGS 84 degrees. Typically 1.0	
altsize	float	1	Altitude of the Area, in meters. Typically 500 (?)	
horizontalResolution	int	1	Horizontal resolution of the raster, in arc seconds (WGS 84). Typically 2.	
verticalResolution	int	1	Vertical resolution of the raster, in arc meters Typically 15.	
coverageSummary	CoverageSummaryInfo	1	Overview information about how the requested service level is met for the whole area. If this is FULLY_COVERED or NON_COVERED, then the buffer may be omitted.	
buffer	byte	0..*	The actual 3D array that contains the raster's values.	May be omitted depending on coverageSummary value.

Table 13: The CoverageData data structure

5.6 The *CoverageDataRef* Data Structure

The *CoverageDataRef* structure contains a reference to a CoverageData object. Actual coverage data can be downloaded by passing a CoverageDataRef object to the downloadCoverageData method.

Property	Type	Multiplicity	Description	Note

ref	UUID	1	Unique reference.	
volume	Volume	0..1	optional definition of the space volume.	

Table 14: The CoverageDataRef data structure

5.7 The *CoverageSummaryInfo* Enumeration

The *CoverageSummaryInfo* enumeration type specifies the level of coverage related to a certain entity or volume.

Property	Description	Note
FULLY_COVERED	Network coverage is given for the whole entity/volume.	
PARTIALLY_COVERED	Network coverage is given for a part of the entity/volume.	
NON_COVERED	Network coverage is not given at all for the whole entity/volume.	

Table 15: The CoverageSummaryInfo enumeration

5.8 The *GeometryCoverageInformation* Data Structure

The *GeometryCoverageInformation* holds an analysis in regards to connectivity coverage for certain volume of 3-dimensional space.

Property	Type	Multiplicity	Description	Note
geometry	Geometry	1	Describes the volume of space.	
coverageSummary	CoverageSummaryInfo	1	Overview information about how the requested service level is met for the whole volume. If this is FULLY_COVERED or NON_COVERED, then the coverageDataRef elements may be omitted.	
coverageDataRef	CoverageDataRef	0..*	A series of references to CoverageData structures, describing the coverage of individual cells of a raster of 3D partitions of the volume.	

Table 16: The GeometryCoverageInformation data structure

5.9 The *OperationPlan* Data Structure

Note: *OperationPlan* is fullly described in a separate Operation Plan service specification, selected attributes are listed here to provide context for better understanding.

The *OperationPlan* represents a complete flight plan. It refers to Pose instances providing spatial orientation of the aircraft for positions along the planned flight trajectory.

The communication equipment used on the aircraft is provided when requesting a network coverage analysis.

Property	Type	Multiplicity	Description	Note
operationPlanId	UUID	1	Unique identifier of the operation plan. A gufi: globally unique flight identifier if form of a UUID	More information for a flight could be retrieved using a respective Flight Information Service
operationTrajectory	OperationTrajectory	0..1	The OperationTrajectory is an (ordered) list of 3-dimensional points, associated with time span, representing the flight route.	
operationVolumes	OperationVolume	0..*	An ordered list of 3-dimensional space fragments, associated with time span, representing the flight route in a more rough sequence of space voluemes.	
contingencyPlans	ContingencyPlan	0..*	Holds information on preplanned contingency situations, especially regarding volumes and when they are used.	
takeoffLocation	Geometry	0..1	Explicit indication of the starting point of the flight.	Optional. Redundant with the information given in the first trajectoryElement.
landingLocation	Geometry	0..1	Explicit indication of the landing point of the flight.	Optional. Redundant with the information given in the last trajectoryElement.
controllerLocation	Geometry	0..1	Location of controller (e.g. the ground control station).	

radioParameters	RadioParameters	0..1	Information about the communication equipment used during the flight.	

Table 17: The Flight data structure

5.10 The *OperationPlanAnalyzeResult* Data Structure

The *OperationPlanAnalyzeResult* holds an analysis in regards to connectivity coverage for an *OperationPlan*.

Property	Type	Multiplicity	Description	Note
coverageSummary	CoverageSummaryInfo	1	Overview information about how the requested service level is met for the whole OperationPlan. If this is FULLY_COVERED or NON_COVERED, then all the other entries of the OperationPlanAnalyzeResult structure may be omitted.	
coverageAtTakeoff	GeometryCoverageInformation	0..1	Coverage information related to the takeoff location of the operation plan.	This is optional, as it is redundant information also available in the trajectory.

coverageAtLanding	GeometryCoverageInformation	0..1	Coverage information related to the landing location of the operation plan.	This is optional, as it is redundant information also available in the trajectory.
coverageAtController	GeometryCoverageInformation	0..1	Coverage information related to the ground controller location of the operation plan.	
coverageAtTrajectory	TrajectoryCoverageInformation	0..1	Coverage information related to the trajectory of the operation plan.	
coverageAtOperationVolume	TrajectoryCoverageInformation	0..1	Coverage information related to the operation volumes of the operation plan.	
coverageAtContingencyPlan	ContingencyPlanCoverageInformation	0..*	Coverage information related to a contingency plan of the operation plan.	

Table 18: The OperationPlanAnalyzeResult data structure

5.11 The *PhysicalAntenna* Data Structure

The *PhysicalAntenna* provides information about the physical antenna used for communication on the aircraft. There can be more than one such antennas. The orientation of the antenna on the aircraft is modelled using Euler angles (more specifically, the orientation of the antenna *pattern*).

Property	Type	Multiplicity	Description	Note
type	string	0..1	A type specifier of the antenna. Optional; can be used instead of specifying the pattern, gain and polarization attributes if the antenna type is well-known.	
horizontalPattern	string	1	Horizontal antenna pattern string.	

verticalPattern	string	1	Vertical antenna pattern string.	
gain	float	1	Antenna gain, in dBi.	
polarization	Polarization	1	Antenna polarization.	
theta, phi, psi	float	1	Orientation angles of the antenna.	

Table 19: The PhysicalAntenna data structure

5.12 The *Polarization* Enumeration

The *Polarization enumeration* type specifies polarization types.

Property	Description	Note
HORIZONTAL	Horizontal polarization.	
VERTICAL	Vertical polarization.	
CROSS	Cross polarization.	

Table 20: The Polarization enumeration

5.13 The *RadioParameters* Data Structure

The RadioParameters provides communication equipment (physical) and logical communication information. This is an abstract class, needs technology-aware specialized implementation.

Property	Type	Multiplicity	Description	Note
technology	Technology	1	The technology of the radio parameters.	
antenna	Antenna	1..*	The used antenna parameters.	

Table 21: The RadioParameters data structure

5.14 The *ServiceLevel* Enumeration

The *ServiceLevel* enumeration type specifies service levels.

Property	Description	Note
C2		
STREAM_4K		

...		

Table 22: The Technology enumeration

5.15 The *Technology* Enumeration

The *Technology* enumeration type specifies Communication technologies.

Property	Description	Note
CELL_4G		
CELL_5G		
...		

Table 23: The Technology enumeration

5.16 The *TrajectoryCoverageInformation* Data Structure

The *TrajectoryCoverageInformation* holds an analysis in regards to connectivity coverage for a flight trajectory belonging to an operation plan.

Property	Type	Multiplicity	Description	Note
coverageSummary	CoverageSummaryInfo	1	Overview information about how the requested service level is met for the whole trajectory. If this is FULLY_COVERED or NON_COVERED, then the coverageAtTrjectoryElement elements may be omitted.	
coverageAtTrjectoryElement	GeometryCoverageInformation	0..*	Coverage information corresponding to a certain trajectory element or operation volume.	

Table 24: The TrajectoryCoverageInformation data structure

5.17 The *TrajectoryElement* Data Structure

Note: *TrajectoryElement* is fullly described in a separate Operation Plan service specification.

The *TrajectoryElement* describes a segment of a flight trajectory by providing a four-dimensional point in space-time.

5.18 The *Volume* Data Structure

The *Volume* structure describes a geographic 3D volume in space. These are covered in greater detail in an external Volume specification. Typical volumes are cylinders with a certain radius and height or polyhedrons.

Property	Type	Multiplicity	Description	Note
id	UUID	1	Unique reference.	
type	*enum*	1	The type of volume	
geometry	Geonetry	1	The geometry that describes this volume	

Table 25: The Volume data structure

6 Service Interface Specifications

This chapter describes the details of each service interface. One sub-chapter is provided for each Service Interface.

The Service Interface specification covers only the static design description while the dynamic design (behaviour) is described in a subsequent chapter.

6.1 Network Coverage Service Interface

This Service Interface is the main point of interaction for Service Consumers. It provides methods to fetch volume coverage and conduct operation plan analyzes. It is provided by the Network Coverage Service.

The NetworkCoverageServiceInterface realizes the Request/Response Message Exchange Pattern (MEP), where the Service Consumer calls Operations at the Service Provider and the Service Provider answers synchronously with a result. This MEP is most suitable for the synchronous, 1:1 nature of the included Service Operations.

6.1.1 Operation getVolumeCoverage

The getVolumeCoverage operation produces information about three-dimensional area connectivity conditions for a certain Service Level and a certain Connectivity Provider. It basically answers the question where in three-dimensional space can the requested Service Level be provided by the Connectivity Provider right now. Note that this is only a high-level overview on the connectivity conditions as other significant factors like aircraft speed and orientation are conceptually not available at the time of requesting large area coverage.

Coverage information is transported in 3D buffer CoverageData objects. This operation returns references to such objects for the requested volume. The actual coverage data can then be downloaded via the downloadCoverageData operation.

Parameter Name	Direction	Data Type	Description
volume	Input	Volume	Specifies the 3-dimensional space for which the network coverage shall be determined.
serviceLevel	Input	ServiceLevel	Requested service level.
connectivityProvider	Input	ConnectivityProvider	Requested connectivity provider.

<none>	Return	GeometryCoverageInformation	The return value contains a structure with connectivity information for the requested 3D volume. If network connectivity is not homogeneously covered or not covered for the whole volume, then the result contains a list of references to CoverageData elements, comprising a 3D raster of 3D cells with finer graned coverage information.

Table 26: Payload description of getVolumeCoverage operation

6.1.2 Operation downloadCoverageData

The download CoverageData operation is used to download the actual coverage data for a given CoverageData reference. CoverageData references can be be obtained from the getVolumeCoverage operation or are reported via the volumeCoverageChanged operation in the NetworkCoverageServiceNotificationInterface.

Parameter Name	Direction	Data Type	Description
coverageDataRef	Input	CoverageDataRef	CoverageData reference, pointing to the coverage data obtained via a different operation (getVolumeCoverage or volumeCoverageChanged).
<none>	Return	CoverateData	The return value contains the detailed coverage information.

Table 27: Payload description of downloadCoverageData operation

6.1.3 Operation analyzeOperationPlan

The analyzeOperationPlan operation answers the question “where on the given flight route is the given Service Level met for a particular Connectivity Provider?” It can also help with route planning by providing the option to alter the route in certain limits for locations so that the complete route fulfils the Service Level requirements.

The Network Coverage Service brokers with the Connectivity Provider or connectivity data provider so that the given flight route is evaluated on their premises. The Network Coverage Service then returns the results to the Consumer.

A “service level” in the context of this interface is an abstract name for a combination of connectivity conditions. For example, a “C2” (command & control) service level might require a certain maximum physical layer latency, whereas a “streaming 4K” service level might require a minimum guaranteed throughput in mbit/s. Additionally, depending on the communication technology, other technical thresholds and limits will be in place for the different service levels (in 4G for example, a minimum RSRP and SINR value). These thresholds and limits are configured on the connectivity provider’s side

and likely be specified by standardization. The aviation user does not need to know these; she only requests the service levels by name that are relevant for the planned mission.

Parameter Name	Direction	Data Type	Description
operationPlan	Input	OperationPlan	An operation plan, including four-dimensional trajectory information and optional contingency planning (i.e., alternative flight locations).
serviceLevel	Input	ServiceLevel	Requested service level.
Connectivity Provider	Input	Connectivity or connectivity data Provider	
<none>	Return	OperationPlanAnalyzeResult	The return value contains a structure with connectivity information for the given operation plan. If network connectivity is not homogeneously covered or not covered for the whole operation plan, then the result contains dedicated coverage information structures for individual trajectory elements and for individual contingency planning elements.

Table 28: Payload description of analyzeOperationPlan operation

6.2 Network Coverage Subscription Interface

This Service Interface provides Subscribe operations to Service Consumers. It is provided by the Network Coverage Service.

The NetworkCoverageSubscriptionInterface and the NetworkCoverageNotificationInterface together realize the Publisher/Subscriber MEP. As the connectivity information in a certain area constantly changes, the notification for such changes is posted to a Publisher/Subscriber topic. Service Consumers can attach to those topics and get asynchronously notified about changes to areas of their interest.

6.2.1 Operation subscribe

The subscribe operation allows a Service Consumer to subscribe to changes in area connectivity coverage.

Whenever the connectivity information for a certain Service Level and Connectivity Provider happens to change, a notification is posted in a dedicated topic. Service Consumers can subscribe to that topic to be notified about those changes.

Parameter Name	Direction	Data Type	Description

serviceLevel	Input	ServiceLevel	Requested service level.
connectivityProvider	Input	ConnectivityProvider	Requested connectivity provider.

Table 29: Payload description of subscribe operation

6.2.2 Operation unsubscribe

As the opposite operation of subscribe, this operation allows a Service Consumer to stop receiving notifications about changes for a certain Service Level and Connectivity Provider.

This removes the service consumer from the list of consumers to be notified.

Parameter Name	Direction	Data Type	Description
serviceLevel	Input	ServiceLevel	Service level for unsubscription.
connectivityProvider	Input	ConnectivityProvider	Connectivity provider for unsubscription.

Table 30: Payload description of unsubscribe operation

6.3 Network Coverage Notification Interface

This Service Interface is provided by and implemented on the service consumer's side. It is called to notify the service consumer about changes it subscribed to via the operations in the NetworkCoverageSubscriptionInterface.

The NetworkCoverageSubscriptionInterface and the NetworkCoverageNotificationInterface together realize the Publisher/Subscriber MEP. As the connectivity information in a certain area constantly changes, the notification for such changes is posted to a Publisher/Subscriber topic. Service consumers can attach to those topics and get asynchronously notified about changes to areas of their interest.

6.3.1 Operation volumeCoverageChanged

This Operation is called on the service consumer's side whenever the coverage information for a certain Service Level and a certain Connectivity Provider changed.

Whenever the connectivity information for a certain Service Level and Connectivity Provider happens to change, a notification is posted in a dedicated topic. If the service consumer subscribed to that topic, it will receive notifications via this operation.

Parameter Name	Direction	Data Type	Description
serviceLevel	Input	ServiceLevel	Service level for which the coverage changed.
connectivityProvider	Input	ConnectivityProvider	Connectivity provider for which the coverage changed.

coverageInfo	Return	GeometryCoverageInformation	Details with connectivity information for the 3D volume in which the connectivity changed. If network connectivity is not homogeneously covered or not covered for the whole volume, then the coverageInfo contains a list of references to CoverageData elements, comprising a 3D raster of 3D cells with finer graned coverage information.

Table 31: Payload description of getVolumeCoverage operation

7 Service Dynamic Behaviour

The following diagrams describe examples for the dynamic behavior of the NetworkCoverageService.

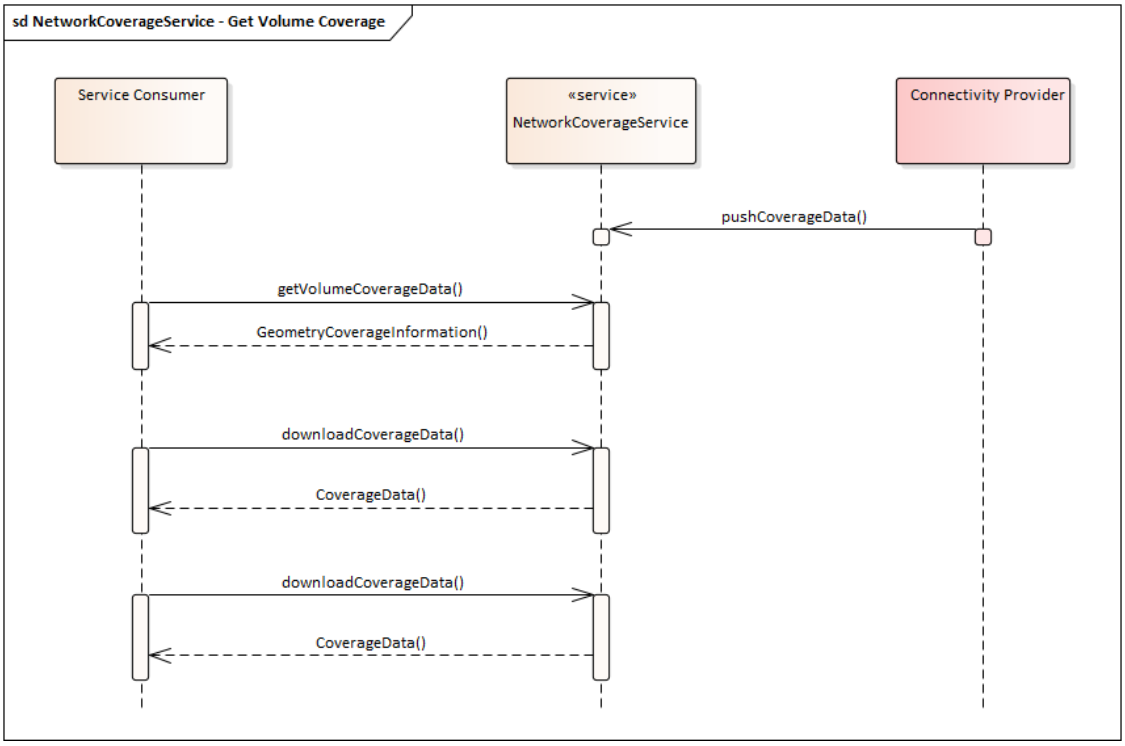

Figure 4: Network Coverage Service Operation Sequence Diagram – Get area coverage

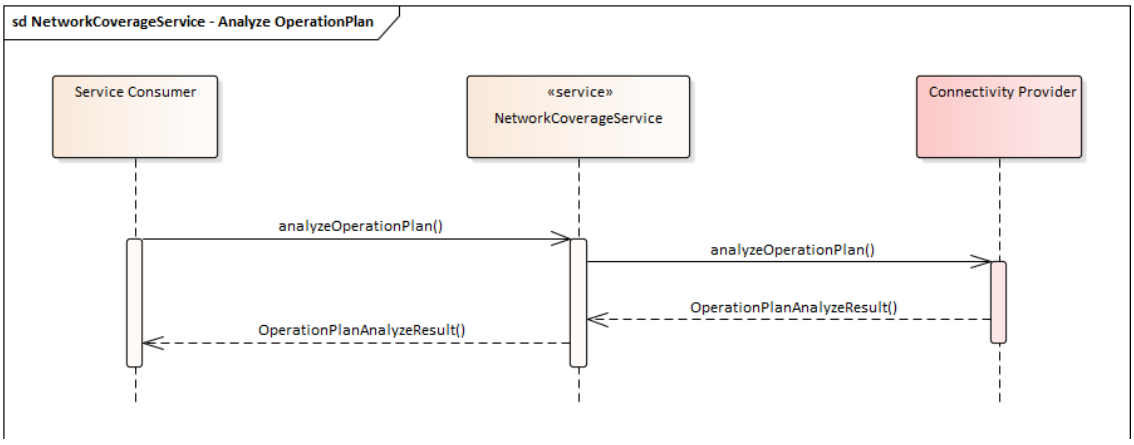

Figure 5: Network Coverage Service Operation Sequence Diagram – Analyze Operation Plan

Please note that the interface between the Connectivity Provider and the NetworkCoverage Service are out of scope of this document, however to indicate the dynamic behavior they are shown here.

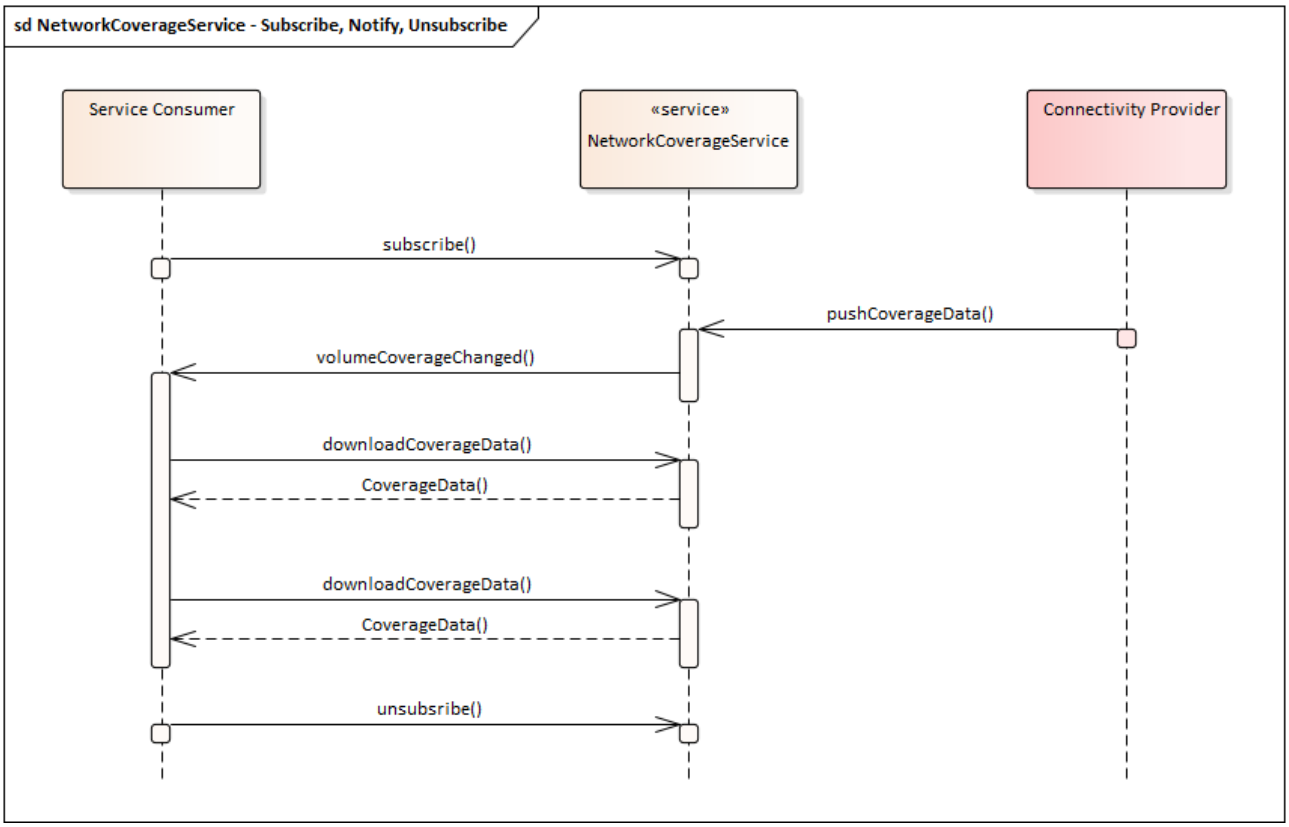

Figure 6: Network Coverage Service Operation Sequence Diagram – subscription, notification and unsubscription

8 Service Provisioning

Left Empty.

9 References

[1] 3GPP – "Enhanced LTE support for aerial vehicles", RR 35.777, Release 15, 2019, "http://www.3gpp.org" www.3gpp.org

[2] CORUS – SESAR "Concept of Operations for U-Space", https://www.sesarju.eu/node/3411

[3] 5G!Drones, "Initial Definition of the trial controller architecture, mechanisms and APIs", 2020 https://5gdrones.eu/wp-content/uploads/2020/06/D2.1-Initial-definition-of-the-trial-controller-architecture-mechanisms-and-APIs_v1.1.pdf

[4] SESAR – SWIM Profiles, 2015, https://www.sesarju.eu/sites/default/files/SESAR-Factsheet-2015-SWIM-Profiles.pdf

[5] DroC2om – Drone Critical Communications Project, including C2 for U-Space via combined cellular and satellite systems, https://www.droc2om.eu/

[6] U-Space DREAMS (Drones European Aims Study) Final Project Results Report, 2019, https://www.u-spacedreams.eu/wp-content/uploads/ER-DREAMS-D2.2-U-space-Final-Project-Results-Report_1.1.pdf

[7] FAA – UAS Identification and Tracking – Aviation Rulemaking Committee (ARC) Final Report, 2017,https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/UAS%20ID%20ARC%20Final%20Report%20with%20Appendices.pdf

[8] European Commission, "SESAR Standardisation Roadmap 2020", 2019, https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5c9ec6a75&appId=PPGMS

[9] SESAR - "GOF USPACE - Successful demonstration of UTM in international validations, applying SWIM principles to connect 2 air navigation service providers and 3 U-space service provider", 2019 https://www.sesarju.eu/node/3387

[10] ICAO, "International work on high level standardisation of information exchange", https://www.icao.int/APAC/Pages/swim.aspx

[11] EU Commission – "IMPETUS (Information Management Portal to Enable the Integration of Unmanned Systems) - Architecture and Technical Requirements", 2019, https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5c1c8fa04&appId=PPGMS

[12] SESAR - EMPHASIS, "Empowering heterogeneous aviation through cellular signals", 2020, https://www.sesarju.eu/node/3109

[13] SESAR – "Consolidated Report on SESAR U-Space Research and Innovations Results", Nov 2020, https://www.sesarju.eu/node/3691

[14] ICAO – "Technology Workshop ICAO RPAS MANUAL C2 Link and Communications", 2015, https://www.icao.int/Meetings/RPAS/RPASSymposiumPresentation/Day%202%20Workshop%205%20Technology%20Michael%20Neale%20-%20ICAO%20RPAS%20Manual%20C2%20Link%20and%20Communications.pdf

[15] Open Geospatial Consortium, "OGC GeoTIFF standard", http://docs.opengeospatial.org/is/19-008r4/19-008r4.html

[16] FAA, UTM Concept of Operations v2.0, March 2020, https://www.faa.gov/uas/research_development/traffic_management/media/UTM_ConOps_v2.pdf

[17] European Commission, Annex to EASA Opinion No 01/2020, "Commission Implementing Regulation (EU), DRAFT", Oct 2020, https://www.easa.europa.eu/sites/default/files/dfu/Draft%20COMMISSION%20IMPLEMENTING%20REGULATION%20on%20a%20high-level%20regulatory%20fram....pdf

[18] ASTM F3411-19, "Standard Specification for Remote ID and Tracking", Committee F38 on Unmanned Aircraft Systems, https://www.astm.org/COMMITTEE/F38.htm

[19] RTCA DO-377, "Minimum Aviation System Performance Standards for C2 Link Systems Supporting Operations of Unmanned Aircraft Systems in U.S. Airspace", https://standards.globalspec.com/std/13301563/rtca-do-377, March 2019

[20] EUROCAE ED-269, "Minimum Operational Performance Standard for Geofencing", www.eurocae.net, June 2020

[21] ACJA, "NetworkCoverage Service Definition 1.0", published by GSMA and GUTMA, February 2021, https://www.gsma.com/iot/resources/acja-wt2-interface-for-data-exchange-between-mnos-and-the-utm-ecosystem/

[22] EUROCAE ER 012, Command, Control and ATC Communications Operational Concept (C3 CONOPS) for Remotely Piloted Aircraft