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Inception Report of the Preliminary Impact Assessment on the Safety of Communications for Unmanned Aerial Systems (UAS)

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Executive Summary

Introduction

This report constitutes the first formal deliverable of the Preliminary Impact Assessment of communications architectures for UAS contract number EASA.2008.C20 (procedure OP.08). This first deliverable, the inception report contains the outline project management plan and the details of the assessment methodology being used to perform the impact assessment. Also included is a description on the progress to date, stakeholder groups and the stakeholders so far identified.

Objectives

Much debate has taken place within the industry (including standardisation groups such as EUROCAE WG-73 and RTCA SC-203) about the architecture of the communications systems that will support the operation of UAVs outside segregated airspace. Although these groups have produced some useful technical work, their role is not to endorse or promote a particular architecture, and consequently there is no consensus on what the architecture should look like.

In creating this project, EASA has initiated a process that will lead to the implementation of policy to permit the use of UAS in non-segregated airspace. The objective of this study is to provide an initial input and guidance for the Regulatory Impact Assessment (RIA) process. This will be achieved through a Preliminary Impact Assessment on the safety and other factors that will be affected by the architecture(s) used for UAS communication systems.

Scope

The scope of this impact assessment is limited to the following communications links:

- An air-ground link between the Ground Control Station (GCS) and the UAV for command and control;
- An air-ground link between ATS/C and the UAV for traffic surveillance (and/or communication) purposes, if assessed as necessary;
- Communication link(s) between the UAS crew and ATS/ATC.

The way these links are implemented may have a considerable impact on aspects of the UAS marketplace. This study will therefore assess the impact of various communications architectures on the topics of Safety, Economy, Social, Spectrum, Global interoperability and European regulation.

Methodology

A six step methodology has been adopted that is compatible with the Eurocontrol Safety Assessment Methodology (SAM) and ESSAR 4 principles:

- Identify potential candidate architectures
- Apply risk analysis to identify set of bounded (safe) architectures
- Impact assessment – on the remaining topics
- Stakeholder engagement (questionnaire/interviews)
- Analysis and Correlation
- Prepare final report

Bounded Architectures

The methodology provided the rationale for the selection of bounded architectures. The following architectures were selected and agreed at the project kick off meeting as the 4 bounded architectures to take forward to assess the remaining impact topics.

AR2 - ATC relay using a networked ground station

This had the lowest overall risk score, required no modification to present day ATC infrastructure and was seen as a logical solution as long as sufficient spectrum was available to permit ATC voice/data to be carried over the C2 datalink.

NR1 - ATC via terrestrial ground station and datalink via non-networked ground station

This had the lowest risk score of the non-ATC relay architectures, and was seen as being a practical and cost effective solution for small UAS operating within a confined geographical area (e.g. radio line of sight).

NR3 - ATC via terrestrial Ground Station and datalink via geostationary satellite

This is the lowest scoring architecture with a satellite communications element and is seen as being cost effective and practical for medium/large UAS that need to operate over longer distances, or where there is no terrestrial C2 ground station coverage. By studying this architecture in more detail it will be possible to explore issues to do with the use of Satellite communications for C2, and the use of a Communication Service provider (CSP) to provide voice/data communications with ATC using ground-based radio equipment.

NR12 - ATC via CSP wired interface and datalink via networked ground station

Although this architecture does not have a particularly low score, it is considered to be a practical solution in the context of the SESAR 2020 timeframe. By studying this architecture in more detail it will be possible to explore issues associated with the use of a CSP managed wired interface to the ATC voice/data network.

Next steps

Impact assessment

The remaining topics (Economy, Social, EM Spectrum, Global interoperability and European regulation) are to be assessed by QinetiQ experts and draft stakeholder questions identified.

Stakeholder Engagement

There are two distinct groups of stakeholders. Group 1 represent the regulatory and safety community. Their role is to review the architectures and draft questions and produce a weighting for the questions based on the regulatory and safety aspects as they relate to each architecture. This will be used to weigh the group 2 stakeholders who represent the operational community and consist of ANSPs, manufacturers, operators etc. Group 2 stakeholders will be surveyed through the use of an on-line survey to ensure as wide a sample as possible.

Analysis and Correlation

The Group 2 stakeholder’s responses will be analysed in conjunction with the weightings determined by the group 1 stakeholders. Group 2 stakeholder’s responses will first be weighted by their role, e.g. an ANSP response to questions about the weight of avionics will have less weight than the manufacturers response. Finally a sensitivity analysis will be conducted.

Prepare final report

The final report will be a pedagogic summary of the process and the results obtained. The report data will be made available to ensure transparency in the process, the results and the conclusions reached. Recommendations where appropriate will be made.

Contents

1 Introduction

This report constitutes the first formal deliverable of the Preliminary Impact Assessment of communications architectures for UAS contract number EASA.2008.C20 (procedure OP.08). This first deliverable, the inception report contains the outline project management plan and the details of the assessment methodology being used to perform the impact assessment. Also included is a description on the progress to date, stakeholder groups and the stakeholders so far identified.

1.1 Background

In recent years considerable interest and effort has been expended world-wide into the development of technologies, procedures and standards that will allow Unmanned Aerial Systems (UAS) to become fully integrated into the Air Traffic Management (ATM) environment. This work is essential to satisfy the safety criteria required for UAS to be operated in non-segregated airspace.

The mission of the European Aviation Safety Agency (EASA) is to promote and maintain the highest common standards of safety and environmental protection for civil aviation in Europe and worldwide. In the near future the Agency will also be responsible for safety regulation of airports and air traffic management systems. QinetiQ recognise it is important therefore for EASA to be pro-active in providing a safe regulatory environment for UAS to operate and at the same time not hinder the emerging UAS market either by over regulation or through delays in providing a regulatory framework in which the UAS can operate safely.

As articulated in the Invitation to Tender (ITT) ‘The Agency therefore needs to prepare itself to progressively develop implementing rules, certification specifications (CS), acceptable means of compliance (AMC) and guidance material (GM) as appropriate, for the UAV/S, their crews and their operations, including their interaction with aerodromes, other airspace users and the Air Traffic Management (ATM) infrastructure that exists both now and in the future.

The communications architectures required to operate UAS will form the foundation upon which many technologies, systems and operational procedures will be based. There are many architecture options available and no single, obvious solution. It is essential that these options are properly assessed and refined to enable the pace of development to be maintained.

1.2 Objectives

Much debate has taken place within the industry (including standardisation groups such as EUROCAE WG-73 and RTCA SC-203) about the architecture of the communications systems that will support the operation of UAVs outside segregated airspace. Although these groups have produced some useful technical work, their role is not to endorse or promote a particular architecture, and consequently there is no consensus on what the architecture should look like.

In creating this project, EASA has initiated a process that will lead to the implementation of policy to permit the use of UAS in non-segregated airspace. The objective of this study is to provide an initial input and guidance for the Regulatory Impact Assessment (RIA) process. This will be achieved through a Preliminary Impact Assessment on the safety and other factors that will be affected by the architecture(s) used for UAS communication systems.

1.3 Scope

The scope of this impact assessment is limited to the following communications links:

- An air-ground link between the Ground Control Station (GCS) and the UAV for command and control;
- An air-ground link between ATS/C and the UAV for traffic surveillance (and/or communication) purposes, if assessed as necessary;
- Communication link(s) between the UAS crew and ATS/ATC.

The way these links are implemented may have a considerable impact on safety and other aspects of the UAS marketplace. This study will therefore assess the impact of various communications architectures on the following topics:

- Safety - including taking into account the availability, integrity and latency of transmitted data
- Economy - including the cost and weight of avionics and of modifying ATC systems
- Social - including the speed of development of the market and its effect on jobs, market penetration
- Electromagnetic Spectrum - including the amount of spectrum required, candidate frequency bands and issues associated with protection of existing users (within the candidate bands)
- Global interoperability – the ability for UAS to be safely operated in different States, and to conduct flights that transit FIR boundaries from one State to another.
- EU Regulation – the compatibility of architectures with SES regulations and future operating concepts and system architectures identified by SESAR

A requirement of the impact assessment is to adequately cover all 27 countries in the EU and to provide possible international comparisons. QinetiQ intends to conduct the main stakeholder engagement primarily through the use of an on-line survey tool. This will be made available to a world wide stakeholder group to ensure that the international input as well as the EU input is as comprehensive as possible.

1.3.1 Use of the outputs

The final report will provide evidence and recommendations to enable EASA to progress the RIA with respect to UAS. Potential policy options, specific SMART objectives will be derived and justified from the data received. This will support EASAs development of a coherent strategy for the development of the safety regulation of UAS communications.

1.4 Structure of the Inception Report

Section 1 – Introduction to the Requirement provides a statement of the customer need and objectives.

Section 2 – Provides a description of the methodology as detailed in the project proposal.

Section 3 – Provides a description of the programme of work, major timescales and deliverables.

Section 4 – Describes how the candidate architectures were developed and common assumptions and requirements identified.

Section 5 - Describes the detailed safety risk analysis that was performed on the candidate architectures and the results, and the rationale for the selection of the 4 bounded architectures for further study.

Section 6 - Provides details of the stakeholder groups and stakeholders who have been identified to date.

Appendix A provides the functional and schematic diagrams for all the candidate architectures

Appendix B provides the detail of the hazard assessment scoring for each candidate architecture.

2 Methodology

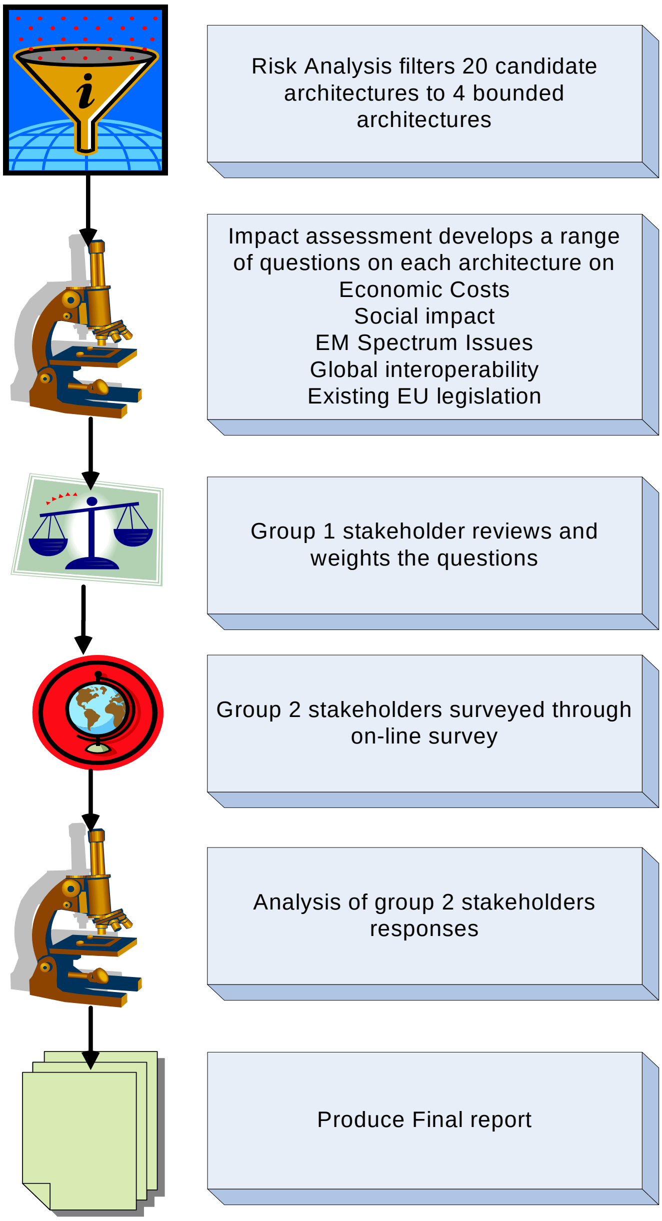
This methodology section was taken from the technical proposal. Section 4 and section 5 describe the implementation of steps1 and 2. The actual implementation may vary slightly. For example, 20 candidate architectures were initially defined and evaluated in step 1 and 2.

The QinetiQ approach recognises the need to find architectures that best satisfy the needs of the UAS industry at large, without compromising on safety performance. This is essentially a 2-part process. The first part identifies up to 4 architectures that will meet safety performance requirements and lists the associated impact issues. In the second part, engagement with a broad cross-section of UAS stakeholders will take place to understand the importance of the impacts associated with the architectures identified. The stakeholder survey will be performed using an on-line survey tool. Participation will be sought throughout the EU and world wide to selected countries with active UAS programmes. An expert body of stakeholders comprising, EASA, other regulators and ANSPs will be used to provide input into determining the weightings to be applied to the stakeholder responses. Furthermore, by asking stakeholders to rate the importance of such issues, it is possible to apply a Multi Criteria Analysis to provide a quantitative assessment of each of the architectures. Finally a sensitivity analysis will be performed to gauge the variation in impact against the weighting applied.

The methodology that will be used for this preliminary assessment is outlined by 6 key steps below:

- Identify potential candidate architectures
- Apply risk analysis to identify set of bounded (safe) architectures
- Impact assessment
- Stakeholder engagement (questionnaire/interviews)
- Analysis and Correlation
- Prepare draft final report

These steps are described in more detail in the following sections.



2.1 Objective

There is no single, obvious architecture for UAS communications that satisfies the underlying needs for equivalence, interoperability and safety. In this age of wideband communications and high speed data networks, many existing technologies and established communications networks have the potential to support UAS communications, to a greater or lesser extent. Using such technologies and systems, any number of architectures could be designed to meet the requirement.

However, not all architectures will be capable of meeting the exacting safety requirements for ATC communications and surveillance, where there is a need for data to be transferred with high availability, high integrity and low latency. Conversely, for some of the architectures that are capable of meeting the safety performance requirements, cost or complexity may be an issue. For example, the cost of required infrastructure may act as a constraint to UAS industry growth, or complexity may mean that the cost of equipment is beyond the reach of most UA operators.

There are two key objectives. The first is to determine which of the many postulated architectures, are capable of satisfying the safety requirements for ATC communications and surveillance. The second is to objectively quantify the merits of the remaining architectures in other key areas (economic, social impact, global interoperability etc). Analysis will then be applied to numerically score the architectures, and rank each in terms of their ability to satisfy regulatory requirements and meet stakeholder expectation.

By applying this impartial and objective approach, it is expected that one or two architectures will have dominant scores. This key work will allow future work by others to focus on a smaller subset of system architectures, and effort can be directed towards refining and developing the optimum system architecture(s). Once these have been developed, it will be possible for EASA to issue Implementing Rules (IR) and Certification Specifications (CS) for the technical systems and infrastructure required.

2.2 Identify Candidate Architectures

From the specifications attached to the ITT, any architecture must include the following communications links:

- An air-ground link between the GCS and the UAV for command and control;
- An air-ground link between ATS/C and the UAV for traffic surveillance (and/or communication) purposes, if assessed as necessary;
- Communication link(s) between the UAS crew and ATS/ATC.

Furthermore, for an architecture to be eligible for consideration it must satisfy certain core tenets to ensure transparency, equivalence and interoperability. Some of these are as follows:

- ATC communications with a UAV pilot should be no different to that for pilots of manned aviation. Fundamentally, voice channels should have good intelligibility, low latency and high reliability.
- Controller-Pilot communications should be available at all times, from the time the aircraft starts moving to the time it comes to a halt at the end of the flight. Even if the UAV/S is fully autonomous, there is a requirement for the UAV pilot to monitor ATC frequencies, and comply with any ATC instructions that are issued whenever operating inside controlled airspace, or accepting a separation service from ATC in other airspace.
- There is a need for accurate UAV position information to be available via the air-ground surveillance link at all times. Furthermore, surveillance systems on the UAV should be standardised to ensure interoperability with other systems (e.g. ATC surveillance and airborne collision avoidance systems).
- Similarly, the UAV pilot is legally responsible for the UAV. There is a requirement to monitor the position and status of the UAV at all times, as there is a duty to comply with aviation law and avoid harm or injury to people, air vehicles or structures through negligence or in the event of a system failure/emergency.

Up to 20 architectures capable of satisfying these core tenets will be identified during this step. To ensure that all credible options are considered, QinetiQ shall organise an internal workshop with communication systems architects and operational experts. A review of WG-73 and SC-203 will also be conducted to ensure that architectures being considered by these expert groups are also included. The following diagrams illustrate two architectures that might be included. Figure 1 shows how a terrestrial base station could be used to provide command, control and ATC communications (C3) between the UAV and the Ground Control Station (GCS) using a proprietary datalink. In this case, ATC voice communications received by a standard ATC radio on the UAV is sent down the datalink to the GCS. Replies to ATC by the UAV pilot are sent up the datalink in the other direction, and fed into the ATC radio. The UAV is also equipped with a SSR transponder which provides surveillance data to the ATC ground system and collision avoidance systems carried by proximate air traffic.

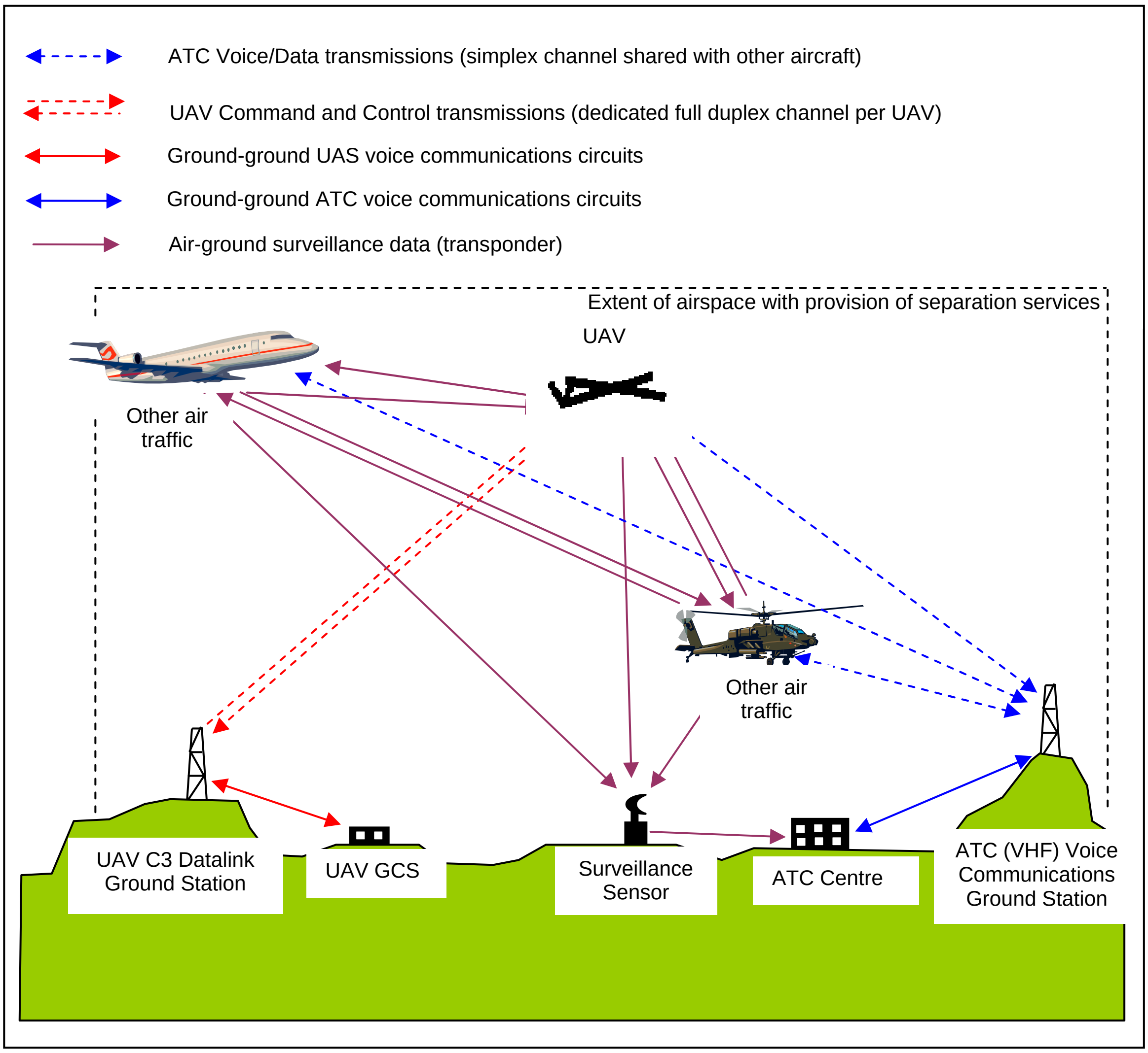


Figure 1 – Terrestrial ground station to provide proprietary C3 datalink communications

Figure 2 illustrates an alternative architecture where datalink communications with the UAV are restricted to command and control. In this case, voice communications with ATC are provided by a 'wired' interface with the ATC centre. By removing ATC voice communications from the datalink, significantly less spectrum would be required for UAS datalink infrastructure, and at the same time, air-ground voice communications would be more reliable, with better speech intelligibility.

However, to avoid having to make multiple connections to the ATC voice switch, access will need to be via a recognised service provider. The service provider would authenticate access to the system, and combine/distribute voice signals amongst the UAVs logged-on to each ATC voice channel.

In a similar vein, surveillance data could conceivably be passed directly to ATC, and superimposed on the radar picture. Position data from on-board sensors on the UAV will be sent down the C2 datalink to the GCS, and then routed onwards to the ATC centre. This might be an attractive option for small UAVs unable to carry a SSR transponder, or those routinely operating at low altitude (e.g. pipeline surveying) where ATC surveillance coverage is unreliable.

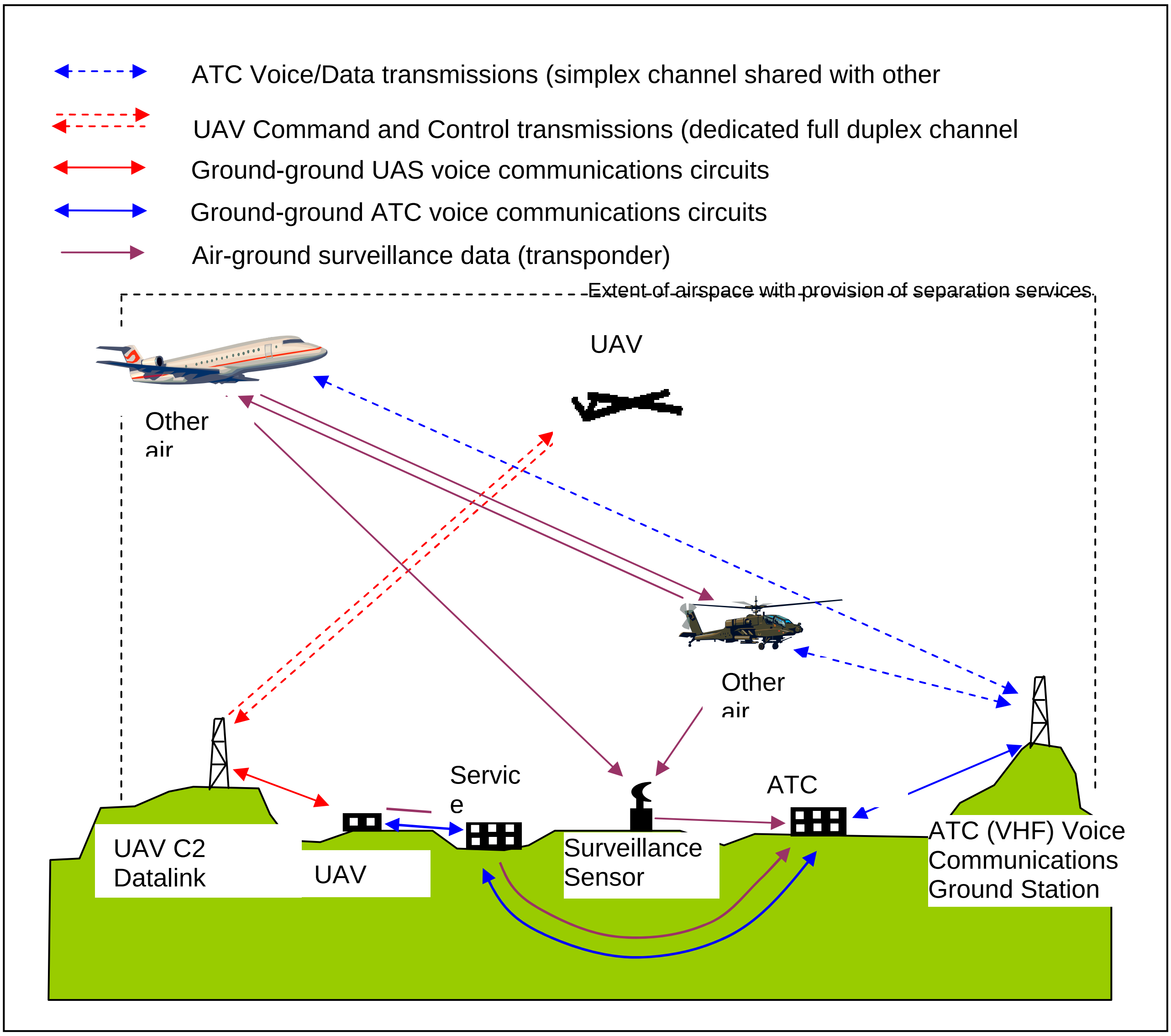


Figure 2 – Terrestrial ground station with wired voice and surveillance input to ATC centre

The above diagrams have illustrated just two of the architectures that will be explored as candidates. During Step 1 of the process up to 18 more candidate architectures will be identified.

2.3 Risk analysis

It is essential that only the architectures identified in Step 1 that are capable of meeting safety requirements for ATC communications and surveillance should be considered for more detailed impact assessment.

Whilst a failure or interruption of any element of the architecture may not constitute a direct safety hazard, such problems can contribute to an operational incident (the so called chain of events). For example, loss of voice communications with a UAV pilot could increase ATC workload, which could lead to a more serious incident (i.e. loss of separation).

When considering the generic safety performance of candidate architectures the following events are considered to be hazardous:

- Loss of voice communications between UAV/S pilot and ATC
- Interruptions to voice communications between UAV pilot and ATC

- Intelligibility and latency of voice communications between UAV pilot and ATC
- Loss of command and control link between UAV and GCS
- Interruption of command and control link between UAV and ATC (due to system reliability or coverage)
- Loss of surveillance information feed to ATC
- Interruption of surveillance information feed to ATC (due to system reliability or coverage)
- Loss of surveillance information to other airspace users
- Interruption of surveillance information to other airspace users (due to system reliability or coverage)

For each of the above categories, a tolerable safety level will be proposed. Once the tolerable levels have been agreed, risk analysis will be conducted on each of the proposed architectures. Only those architectures that meet or exceed the tolerable safety level in all event categories will be considered eligible. These will be referred to as bounded architectures.

A maximum of 4 bounded (safe) architectures will be identified for detailed impact assessment.

2.4 Impact Assessment

The next step in the approach is to assess the impact of implementing each of the bounded architectures.

The impact assessment will identify the issues that are likely to be contentious or high risk, be it for UAV/S manufacturers, UAV/S operators, Air Navigation Service Providers (ANSP) or safety regulators. It is essential that the impact assessment covers a wide range of issues including:

- Investment Costs (to develop suitable avionics equipment and associated ground/space infrastructure)
- Practical limitations (size and weight of equipment)
- Operational Costs
- Operational Limitations

To achieve this, the impact of each bounded architecture will be assessed in detail in the following five areas:

- Economic (cost and weight of the avionics and/or cost of modifications to ATS/ATC systems)
- Social Impact (slower or faster development of EU UAS industry), with a benchmark prediction as to the size of the industry by 2020.
- Use of Electromagnetic Spectrum (estimated total requirement)
- Global Interoperability (ability to operate in different States, and to transit FIR boundaries)
- Impact on other existing EU rules (i.e. compatibility with SESAR regulations and ESARRs)

The impact assessment process shall be qualitative, and will culminate in a list of up to 100 impact topics in total. The positive and negative attributes associated with each topic will be summarised.

There is no need to assess safety aspects in this step as we know from the previous step that all of the bounded architectures will meet or exceed the minimum performance requirements for safety.

2.5 Stakeholder Engagement

Stakeholder engagement is key to the success of the preliminary impact assessment. Consultation with stakeholders will ensure that stakeholder needs are fully recognised and the significance of issues is properly understood.

For the purpose of this study, stakeholders can be formed into two groups:

Group 1 – Safety and ATM (EASA plus selected NSAs and ANSPs)

Group 2 – All stakeholders (UAS manufacturers[1], UAS operators[1], ANSPs, EASA and other safety regulators)

Group 1 stakeholders will quantify the performance of each bounded architecture with respect to the list of impact topics.

Engagement with Group 1 stakeholders will be in the form of a detailed presentation that describes the bounded architectures and the rationale for their selection. They will also be presented with the preliminary results of the impact assessment (Step 3). Group 1 stakeholders will then be asked to quantitatively assess how well each architecture performs with respect to the impact topics.

However, it should be recognised that from a safety/regulatory perspective, some impact topics will be more significant than others. In order to capture this, Group 1 stakeholders will also be asked to assess the significance of each impact topic from a safety/regulatory perspective.

From this information it will be possible to derive an average performance score for each impact topic. A weighting will then be applied during analysis (step 5) to reflect the significance of each impact topic with respect to safety and regulation.

The following table provides an illustrative example of how results from a Group 1 stakeholders might look:

	Safety & Regulatory Significance	Performance (Score 1-5) - unweighted			
		Architecture 1	Architecture 2	Architecture 3	Architecture 4
Impact Topic 1	Medium	5	2	4	3
Impact Topic 2	High	4	4	5	2
Impact Topic 3	Low	3	3	2	5
Impact Topic N	Medium	5	5	4	4

Figure 2-1 Illustrative Group 1 Stakeholder impact table

These results will allow the relative performance of the bounded architectures to be compared in a quantitative way. By aggregating the scores, it will be possible to obtain a consensus as to how well the bounded architectures satisfy safety/regulatory needs.

The list of impact topics will be discussed at the first progress meeting, and will be agreed by the customer before stakeholder engagement takes place.

The purpose of the second phase of stakeholder engagement is to understand the importance of impact issues. For this to be meaningful, it is essential to get responses from a large cross-section of stakeholders involved in all aspects of UAV/S, and from different States. As it will be impractical to have face-to-face meetings with such a large number of stakeholders, the Group 2 stakeholders will be consulted using an on-line survey tool.

Without describing the bounded architecture, the on-line tool will ask stakeholders to score the importance of each impact identified, using a 5-point scoring scheme. For example, some of the architectures may require the UAV to be equipped with datalink radio and antenna equipment that is physically heavy. To identify the importance of this issue, one of the on-line survey questions might ask:

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[1] Manufacturers and operators of UAV with MTOM of 150 kg or more

Please indicate the maximum acceptable weight range for UAV datalink communications equipment:

1. *Equipment weight not an issue*
2. *Up to 50 kg*
3. *Up to 10 kg*
4. *Up to 5 kg*
5. *Up to 1 kg*

Another question the survey might ask is:

What availability is required for the command, control and communications datalink?

1. *No requirement for datalink availability*
2. *The datalink should be available 95% of the time*
3. *The datalink should be available 99.5% of the time*
4. *The datalink availability should be as high as reasonably possible*
5. *Datalink availability should be demonstrated to be comparable with the availability of ATC communications e.g. 1- (1 x* 10^{-7}*)*

The on-line survey tool will provide a reliable and fast means of gathering results from a large group of stakeholders. It should also be easier for stakeholders to complete, and will avoid the need for response sheets to be posted.

The format of the on-line survey will be agreed by the customer at the first progress meeting.

2.6 Analysis and Correlation

In this step, the scores obtained from stakeholder Group 1 that reflect the safety/regulatory performance of each architecture will be correlated with the scores obtained from the Group 2 (assessment of importance) survey.

In very simple terms, a figure of merit for each bounded architecture can be obtained by multiplying the aggregated Group 1 ‘performance’ value with the Group 2 generic ‘importance’ value. The sum of the values obtained for each impact topic then provides a figure of merit for each architecture. Mathematically this can be written as:

$$S_a = \sum_n i_n p_n$$

where

$S_a =$ Figure of merit for architecture.

$i_n =$ aggregate importance (Group 2 stakeholders)

$p_n =$ aggregate performance (Group 1 stakeholders)

As mentioned previously, it is necessary to apply weighting to the performance data obtained from Group 1 stakeholders to take account of the fact that, from a safety and regulatory point of view, some impact topics will be more significant than others.

Similarly for the Group 2 data, it is reasonable to expect different types of stakeholder to provide different scores when assessing the importance of impact issues. In the case of the first example question, we might expect UAV/S manufacturers to be highly concerned about the weight of datalink equipment to be carried by the UAV, whereas this may be of little or no concern to an ANSP. Similarly, we might expect an ANSP or safety regulator to provide higher scores to the question about datalink availability requirements than UAV/S manufacturers or operators might.

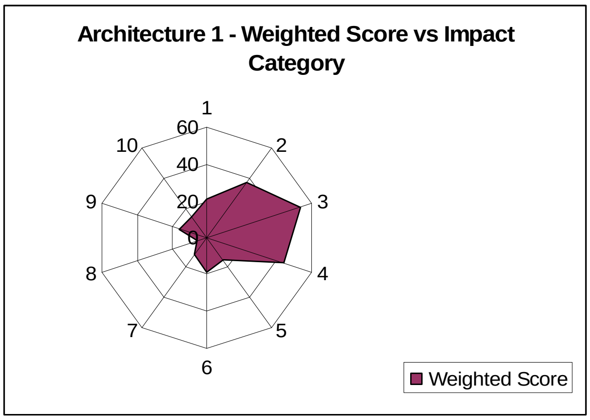
To reflect the fact that some impacts will be more significant or even critical for particular stakeholders, it is necessary to weight the responses to individual questions according to stakeholder type. It is envisaged that weightings would be applied for the following stakeholder types:

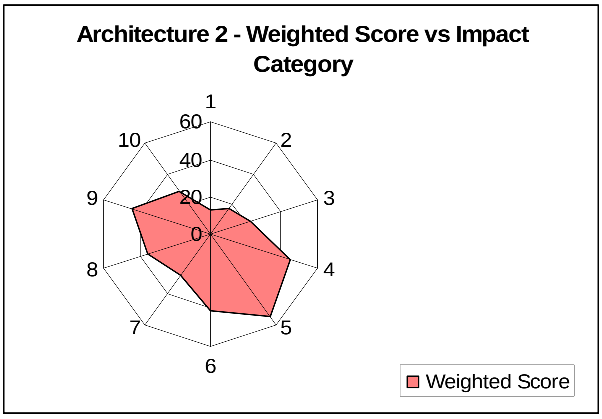
- UAV Manufacturer
- UAV Operator
- Avionics/Payload System Manufacturer
- ANSP/Safety Regulator

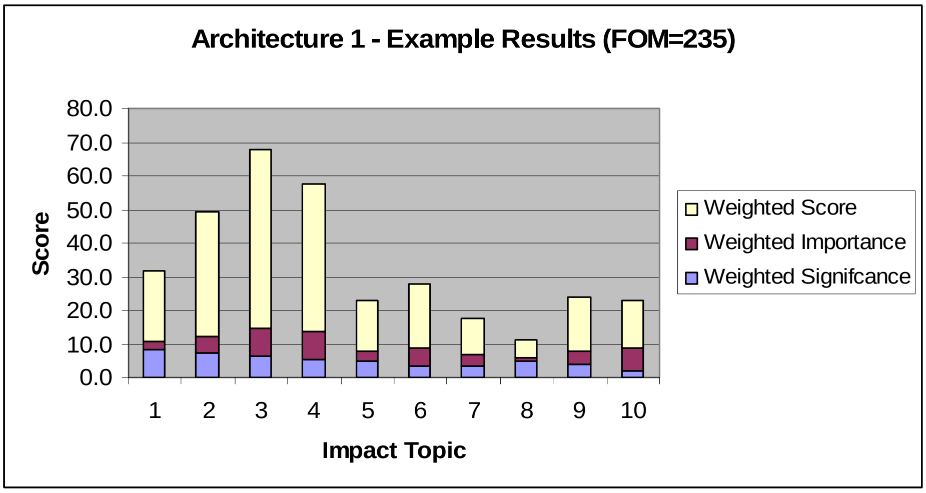
By applying weightings and collating the scores, it will be possible to derive an aggregate score for the overall importance of each impact category. These weighted values for importance and performance will be multiplied together as described above to provide a representative overall figure of merit for each of the bounded architectures.

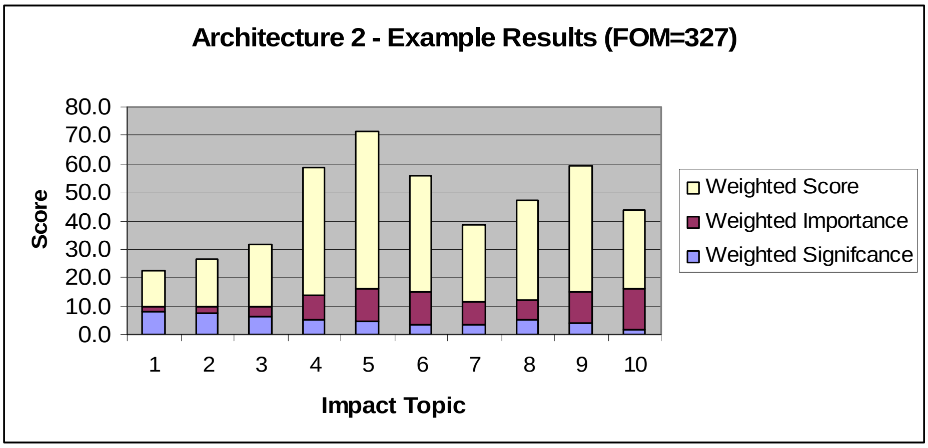
The figure of merit will indicate which of the bounded architectures provides the best solution in terms of safety/regulatory performance and stakeholder expectation.

Results will be illustrated with charts and other graphical techniques. Examples are provided below:









Finally, sensitivity analysis will be conducted. This will be performed by applying a set of low, medium and high weightings to the Group 2 importance data. This will indicate how sensitive the results are to the weightings applied, and the overall significance of the results for each bounded architecture when compared with each other.

2.7 Final Report

The final report will be a pedagogic summary of the process described in the previous 5 steps. The aim of the report will be to explain the selection process used to arrive at the reduced list of bounded architectures, and the method used to obtain figures of merit for the combined performance and importance of each one.

The report will be entirely transparent in the way that it is written, so that there can be no doubt as to the validity of its conclusions. For this reason, it will contain details of scores obtained from stakeholders, and the weightings subsequently applied. This is important so that future effort can focus on the refinement of successful bounded architectures, and the development of appropriate standards and specifications that will enable unconstrained integration of UAS into the future ATM environment.

Finally the report will make recommendations where the data supports that particular actions should be undertaken. This will provide clear guidelines for future detailed studies in order to focus on the most promising architectures and/or to resolve challenges or issues identified in this study. Policy options will be discussed and where appropriate SMART objectives recommended, which can be used to monitor the results of the policies if adopted.

The final report will have the following main section headings:

0.	**Executive Summary**	
1.	**Introduction**	
1.1		Background
1.2		Purpose of the Project
1.3		Overview of the Multi Criteria Analysis Process
2.	**Problem Definition**	
2.1		Introduction
2.2		Civil UAS Context in Europe
2.3		Regulatory Framework
2.4		Objectives of Project
3.	**Essential Requirements for UAS Communications and Surveillance**	
3.1		Communications with ATC
3.2		Surveillance

3 Programme of Work

This section describes the work breakdown for the tasks, and associated deliverables and has been developed to be fully compliant to the requirements of the ITT. It is taken from the technical proposal and updated with actual dates of meetings and milestones. It also contains an up to date Gantt chart.

3.1 Work Breakdown Structure

The work breakdown structure is shown below.

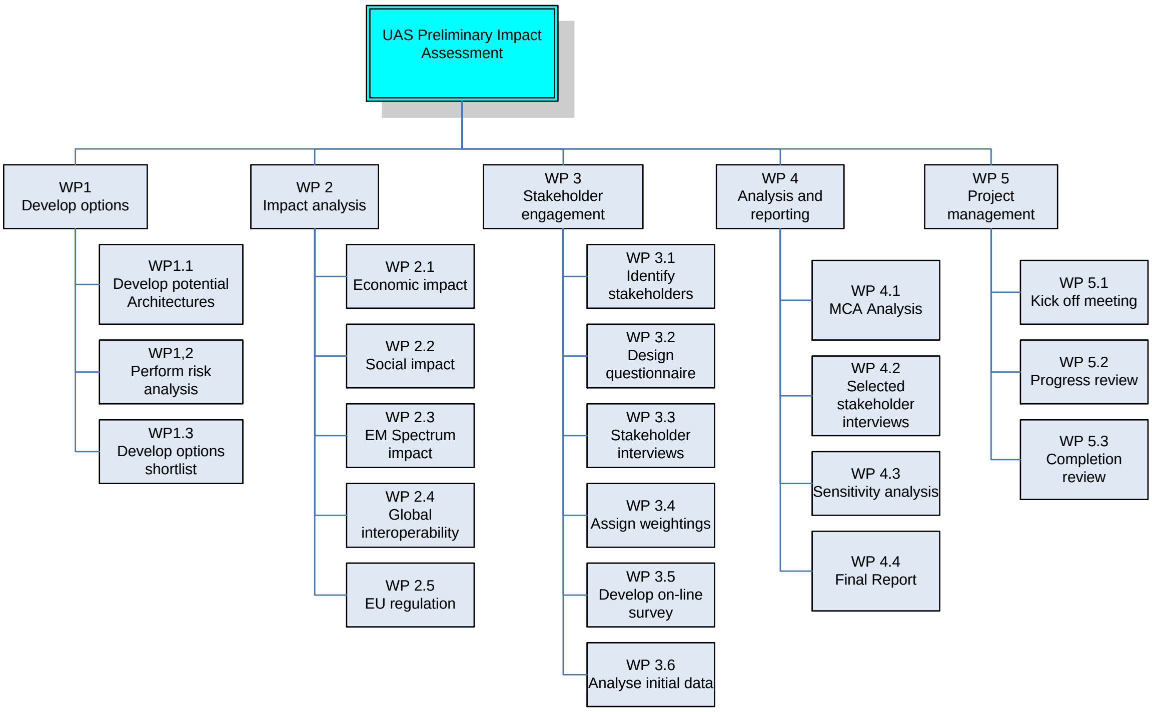


Figure 3-1Work breakdown structure

3.2 WP 1 – Develop Options

3.2.1 Objective

The aim of this work package is to perform a safety analysis on the architecture options to produce bounded (safe) architectures that can be analysed for their social, economic, global interoperability, spectrum usage and regulatory impact on the UAS stakeholders.

3.2.2 Content

The work package consists of the following sub packages:

WP1.1 Develop potential Architectures. This sub package will develop 20 potential architectures to be subject to the risk analysis.

WP1.2 Perform Risk analysis. The risk analysis will be performed by an expert body derived from QinetiQ internal staff who collectively have the combined safety experience and operational expertise to define the hazards and potential safety issues.

WP1.3 Develop Bounded Architectures. As a result of the risk analysis up to 4 architectures that can demonstrate adequate safety performance will go forward for the impact analysis and be subject to the main stakeholder survey.

3.2.3 Inputs

The following are required inputs:

- Agreement with EASA on the candidate architectures to be analysed
- Agreement with EASA on the safety performance requirements
- Agreement with EASA on the set of bounded (safe) architectures

3.2.4 Outputs

The following outputs will be produced

- Description of all options and results of the risk analysis
- Safety performance requirements and rationale for accepting/rejecting architectures
- List of bounded architectures selected

These outputs will form part of the final report.

3.2.5 Dependencies

The following are dependencies on the successful outcome of this work package:

- Agreement on the inputs listed in section 3.2.3.

3.2.6 Benefits

The development of multiple architectures and the analysis will clearly and demonstrably show that all viable options have been evaluated. This approach will ensure that only the architectures considered ‘safe’ will be put forward for more detailed analysis.

3.3 WP 2 – Impact Assessment

3.3.1 Objective

The aim of this work package is to develop the chosen options and elicit issues and potential impacts that may affect the development of the civilian UAS marketplace.

3.3.2 Content

Each architecture will be evaluated by an expert team of professional staff drawn from within QinetiQ specifically with regard to:

- Economic impact
- Social impact
- EM spectrum use impact
- Global interoperability
- EU regulation

3.3.3 Inputs

The following are required inputs:

- Selected bounded architectures form WP 1

3.3.4 Outputs

The following outputs will be produced

- List of issues and ranges for each option against each topic of analysis.
- Common list of impact topics (up to 100)

3.3.5 Dependencies

None

3.3.6 Benefits

This work package will be used to identify the impact topics which are most relevant. It will enable the stakeholder survey questions and the range of possible answers to be designed accordingly.

3.4 WP 3 – Stakeholder Survey

3.4.1 Objective

The aim of this work package is to elicit from a representative range of stakeholders their perceived impact as to what affect the impacts identified will have on them.

3.4.2 Content

The following sub packages will be undertaken:

WP 3.1 Identify stakeholders. Group 1 and Group 2 stakeholders will be identified from a variety of sources.

Group 1 stakeholders will be limited to EASA and a selection of NSA's or ANSPs with experience or an interest in UAS ATM integration. There will be up to 5 stakeholders in this group.

Group 2 stakeholders will cover all relevant groups including manufacturers, maintainers, operators, end users, ATC and regulators. As wide an audience as possible will be selected within the EU and also in the USA and other active countries in order to compare the EU market with the rest of the world.

WP 3.2 Design Questionnaire. Taking as the starting point the outputs from WP 2 the questionnaire will be developed to cover the range and topics identified in the impact assessments associated with the 4 bounded architectures.

WP 3.3 Stakeholder Interviews. Group 1 stakeholders (safety and ATM organisations) will be interviewed to quantify the performance impacts of each of the selected architectures and to assess the significance of each impact topic from a safety/regulatory perspective.

WP 3.4 Assign Weightings. Following the Group 1 stakeholder interviews weightings will be assigned to each of the topics for each of the bounded architecture options.

WP 3.5 Develop on-line Survey. QinetiQ intends to use an on-line survey tool such as SurveyMonkey.com to produce the online survey for the Group 2 stakeholders. This sub package will develop the web site using the host capability provided as part of the service. SurveyMonkey.com is an online survey tool that provides a quick and easy set up of multiple choice questionnaires and surveys. When the design and set-up is complete emails with the web address will be sent to all participants explaining the background to the survey and how to log on and complete the survey. The survey tool has the ability to track and monitor survey respondents that will provide follow up reminders to those who have not yet responded.

WP 3.6 Analyse Initial Data. An initial download of the data will be performed and analysed for inclusion into the interim report.

3.4.3 Inputs

The following inputs are required:

- Risk analysis from WP 1
- Impact Assessment from WP 2
- Stakeholder input and cooperation

3.4.4 Outputs

The following is a list of outputs that will be derived from this work package:

- Example Questionnaire
- Initial responses and analysis – to be included in the Interim report
- Questionnaire – to be included in the Interim report
- Results and analysis of stakeholder input – to be included in the final report

3.4.5 Dependencies

3.4.6 Benefits

The use of an on-line survey will make possible an unlimited number of stakeholders globally to respond to the survey. This world wide capability will provide an excellent basis on which to gauge the impact of the various architectures and to better fit the policy options derived in an international context.

3.5 WP 4 – Analysis and reporting

3.5.1 Objective

The aim of this work package is to determine from the stakeholder responses a number of policy options together with recommendations for more in depth study of those that have possibilities of being acceptable both from a safety/regulatory and industry business perspective.

3.5.2 Content

The following sub packages will be undertaken:

WP 4.1 MCA Analysis. The Group 2 stakeholder data will be subject to the data analysis described in section 2.0 Methodology using the weightings defined by the Group 1 stakeholders.

WP 4.2 Selected Stakeholder Interviews. For the purposes of clarification or obtaining further information selected stakeholder interviews will be conducted, either by telephone or in person as appropriate.

WP 4.3 Sensitivity Analysis. The data analysis will be subject to a sensitivity analysis by varying the weightings applied. This will provide further input to gauge where the issues identified are most sensitive to variation.

WP 4.4 Final Report. From the analysis conclusions and recommendations will be developed and presented in the final report. Key findings will be highlighted and discussed with EASA either prior to or during the final progress review. Comments will be incorporated into the final deliverable.

3.5.3 Inputs

The following inputs are required to perform this work package:

- Bounded architecture descriptions from WP1
- Impact assessments and weightings
- Full data set from stakeholder engagement in WP 3

3.5.4 Outputs

The following outputs will be produced from this work package:

- Complete analysis of the data (figure of merit allocated to each bounded architecture)
- The draft final report for review by EASA
- The final report, incorporating EASA comments

3.5.5 Dependencies

None.

3.5.6 Benefits

The benefits of this approach are the quantitative nature of analysis, and the large stakeholder group. This will ensure that the architectures with the highest score best meet the needs of stakeholders, and are not prejudiced in any way.

3.6 WP 5 – Project Management

3.6.1 Objective

The role of project management is to ensure the effective delivery of the programme deliverables to the customer on time and to the agreed quality standards.

3.6.2 Content

This work package will provide the management and project control activities to undertake the programme to ensure that the deliverables are delivered on time and to the agreed quality standards.

The project manager will manage the project according to the QinetiQ procedures and standards described within the business management system (BMS). A Project Management Plan (PMP) will be produced which will provide descriptions of the work packages, deliverables, milestones, programme schedule, organisation, roles, responsibilities, quality, control systems and risk management. It will form the basis for the management of the programme and will be reviewed and updated as necessary. This will ensure efficiency of effort, cohesion and connectivity across all work packages.

Control and monitoring of progress will be undertaken by regular progress reviews with the team.

3.6.3 Benefits

The customer can be assured that the deliverables will be fit for purpose, will be delivered on time and will meet the agreed quality standards.

3.7 Planned progress meetings

The following table contains a list of progress meetings assumed in this proposal. All progress meetings are expected to take place in Köln.

Date	No. of People	Meeting
8 January 2009	2	Kick off Meeting (1 day)
19 May 2009	2	Progress/review meeting (1 day)
14 October 2009	2	Progress/review meeting (1 day)

Figure 3-2 List of planned meetings

3.8 Milestones and Deliverables

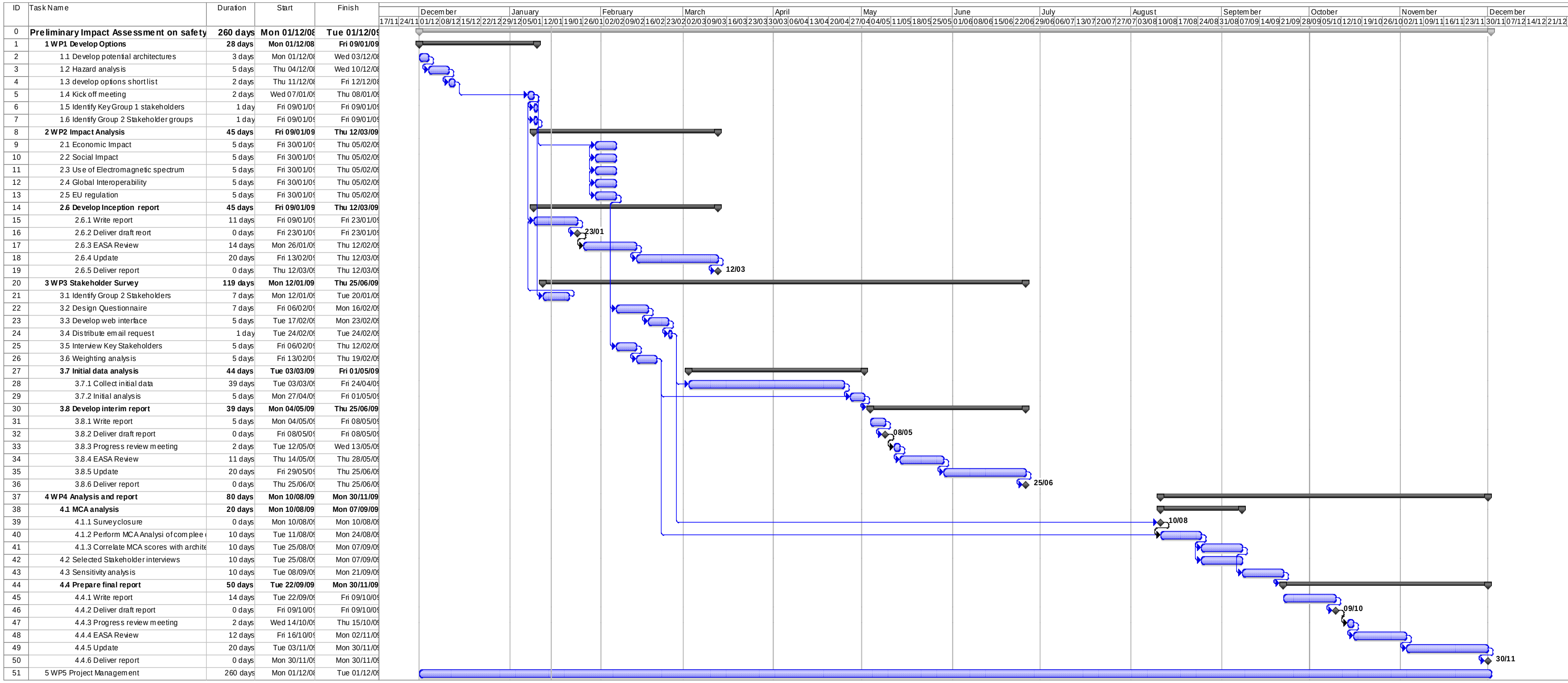
The table below shows the contracted deliverables and due date:

Deliverable no.	Deliverable	Due date
1	Inception report	23 January 2009
2	Interim report	8 May 2009
3	Final Report	8 October 2009

Figure 3-3 List of deliverables and dates

3.9 Gantt Chart

The Gantt chart below shows indicative timescales for each of the workshops and the associated milestones for the delivery of minutes and updates services document. The project start date is 8 December 2008. Delivery dates are referenced to this date.



ID	Task Name	Duration	Start	Finish
0	**Preliminary Impact Assessment on safety**	**260 days**	**Mon 01/12/08**	**Tue 01/12/09**
1	**1 WP1 Develop Options**	**28 days**	**Mon 01/12/08**	**Fri 09/01/09**
2	1.1 Develop potential architectures	3 days	Mon 01/12/08	Wed 03/12/08
3	1.2 Hazard analysis	5 days	Thu 04/12/08	Wed 10/12/08
4	1.3 develop options shortlist	2 days	Thu 11/12/08	Fri 12/12/08
5	1.4 Kick off meeting	2 days	Wed 07/01/09	Thu 08/01/09
6	1.5 Identify Key Group 1 stakeholders	1 day	Fri 09/01/09	Fri 09/01/09
7	1.6 Identify Group 2 Stakeholder groups	1 day	Fri 09/01/09	Fri 09/01/09
8	**2 WP2 Impact Analysis**	**45 days**	**Fri 09/01/09**	**Thu 12/03/09**
9	2.1 Economic Impact	5 days	Fri 30/01/09	Thu 05/02/09
10	2.2 Social Impact	5 days	Fri 30/01/09	Thu 05/02/09
11	2.3 Use of Electromagnetic spectrum	5 days	Fri 30/01/09	Thu 05/02/09
12	2.4 Global Interoperability	5 days	Fri 30/01/09	Thu 05/02/09
13	2.5 EU regulation	5 days	Fri 30/01/09	Thu 05/02/09
14	**2.6 Develop Inception report**	**45 days**	**Fri 09/01/09**	**Thu 12/03/09**
15	2.6.1 Write report	11 days	Fri 09/01/09	Fri 23/01/09
16	2.6.2 Deliver draft reort	0 days	Fri 23/01/09	Fri 23/01/09
17	2.6.3 EASA Review	14 days	Mon 26/01/09	Thu 12/02/09
18	2.6.4 Update	20 days	Fri 13/02/09	Thu 12/03/09
19	2.6.5 Deliver report	0 days	Thu 12/03/09	Thu 12/03/09
20	**3 WP3 Stakeholder Survey**	**119 days**	**Mon 12/01/09**	**Thu 25/06/09**
21	3.1 Identify Group 2 Stakeholders	7 days	Mon 12/01/09	Tue 20/01/09
22	3.2 Design Questionnaire	7 days	Fri 06/02/09	Mon 16/02/09
23	3.3 Develop web interface	5 days	Tue 17/02/09	Mon 23/02/09
24	3.4 Distribute email request	1 day	Tue 24/02/09	Tue 24/02/09
25	3.5 Interview Key Stakeholders	5 days	Fri 06/02/09	Thu 12/02/09
26	3.6 Weighting analysis	5 days	Fri 13/02/09	Thu 19/02/09
27	**3.7 Initial data analysis**	**44 days**	**Tue 03/03/09**	**Fri 01/05/09**
28	3.7.1 Collect initial data	39 days	Tue 03/03/09	Fri 24/04/09
29	3.7.2 Initial analysis	5 days	Mon 27/04/09	Fri 01/05/09
30	**3.8 Develop interim report**	**39 days**	**Mon 04/05/09**	**Thu 25/06/09**
31	3.8.1 Write report	5 days	Mon 04/05/09	Fri 08/05/09
32	3.8.2 Deliver draft report	0 days	Fri 08/05/09	Fri 08/05/09
33	3.8.3 Progress review meeting	2 days	Tue 12/05/09	Wed 13/05/09
34	3.8.4 EASA Review	11 days	Thu 14/05/09	Thu 28/05/09
35	3.8.5 Update	20 days	Fri 29/05/09	Thu 25/06/09
36	3.8.6 Deliver report	0 days	Thu 25/06/09	Thu 25/06/09
37	**4 WP4 Analysis and report**	**80 days**	**Mon 10/08/09**	**Mon 30/11/09**
38	**4.1 MCA analysis**	**20 days**	**Mon 10/08/09**	**Mon 07/09/09**
39	4.1.1 Survey closure	0 days	Mon 10/08/09	Mon 10/08/09
40	4.1.2 Perform MCA Analysi of complee	10 days	Tue 11/08/09	Mon 24/08/09
41	4.1.3 Correlate MCA scores with archite	10 days	Tue 25/08/09	Mon 07/09/09
42	4.2 Selected Stakeholder interviews	10 days	Tue 25/08/09	Mon 07/09/09
43	4.3 Sensitivity analysis	10 days	Tue 08/09/09	Mon 21/09/09
44	**4.4 Prepare final report**	**50 days**	**Tue 22/09/09**	**Mon 30/11/09**
45	4.4.1 Write report	14 days	Tue 22/09/09	Fri 09/10/09
46	4.4.2 Deliver draft report	0 days	Fri 09/10/09	Fri 09/10/09
47	4.4.3 Progress review meeting	2 days	Wed 14/10/09	Thu 15/10/09
48	4.4.4 EASA Review	12 days	Fri 16/10/09	Mon 02/11/09
49	4.4.5 Update	20 days	Tue 03/11/09	Mon 30/11/09
50	4.4.6 Deliver report	0 days	Mon 30/11/09	Mon 30/11/09
51	5 WP5 Project Management	260 days	Mon 01/12/08	Tue 01/12/09

Figure 3-4 Project Gantt chart

4 Identify Potential Architectures

This section describes the first step in the methodology described in section 2 where the candidate architectures are developed. The rationale that was used to determine the architectures is described.

4.1 Basic Principles

In assessing the needs of a UAS communications architecture, the following principles are recognised.

4.1.1 Transparency to ATC (Comms & Surveillance)

- For ATC, the process of monitoring flight progress and issuing instructions to an UAV via voice/data should be no different to that applied to manned aircraft
- A UAV pilot should be able to maintain situational awareness by monitoring voice exchanges between ATC and other aircraft (manned or unmanned)
- Transponders or other surveillance devices (when fitted) should always be physically located on the UAV as they can enable ATC to monitor flight progress independently of the datalink and GCS. Also, the UAV will be able to interact with ACAS (and reduce the risk of mid-air collision).

4.1.2 Reliability and Continuity

- Existing (analogue) ATC voice communications are simple and reliable
- Communications failures are seldom, but when they do occur ATC workload can increase significantly
- UAS communications, particularly for ATC must be reliable

4.1.3 Spectrum

- UAS datalinks will require significant amount of spectrum
- Amount of spectrum required is directly proportional to peak number of UAS operating in a frequency re-use area
- In order to provide good QoS, channel rate will be significantly greater than bit rate
- After video, ATC voice relay has greatest demand for bandwidth

4.1.4 Coverage

The object is to maintain communications with ATC, and for the ground station to be able to maintain datalink communications with the UAV. The mobile nature of a UA means that loss of communications due to the aircraft moving outside coverage is a factor that must be taken account of in each architecture, see Figure 4-1 below.

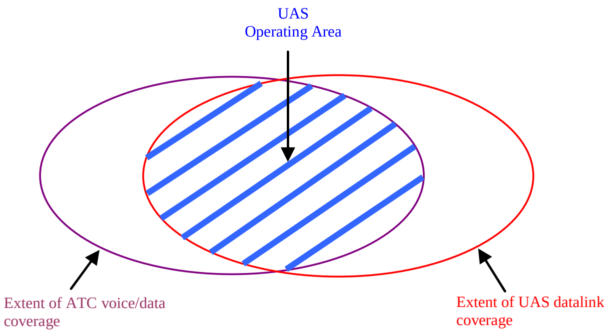


Figure 4-1 Overlapping coverage of UAV datalink and ATC limits the UAV operating area

Clearly, a wired architecture will overcome the finite coverage limitations of the ATC voice/data communications system, and this is one aspect that needs to be taken into consideration by the preliminary risk analysis. Whilst the telecommand and telemetry datalink will always have finite coverage, a cellular system employing network of ground stations with overlapping coverage will have superior performance than a single dedicated ground station.

When considering coverage requirements, the following issues must be taken into account:

- The UAV remains within datalink coverage for entire flight
- Terrestrial coverage impaired by curvature of Earth and terrain shadowing
- Satellite provides coverage down to the ground but introduces latency
- LEO provides better coverage than GEO and requires less gain/power per unit bandwidth to achieve link margin

4.2 Candidate Architectures

Candidate architectures were developed according to specific rules in order to develop a comprehensive set of architectures that would encompass as wide a variety and combinations of capabilities as possible. Three overriding variables became the key to developing the architecture matrix:

- ATC relay/ non ATC relay – Whereby the ATC communications with the pilot is through the UAV or direct.
- Dedicated wired interface or single approved interface communications service provider. Logically the ATC relay cannot have a wired interface and this set therefore does not exist.
- Command and Control (C2) implementation using either:
    - Dedicated terrestrial ground station
    - Networked terrestrial ground station(s)
    - Geostationary (GEO) satellite
    - Low Earth Orbit (LEO) satellite
    - High Altitude Platform (HAP)

This gives rise to the matrices in the following paragraphs.

4.2.1 ATC relay architectures

The following architectures represent those where the ATC communications with the pilot is relayed through the UAV.

	Dedicated terrestrial GS	Networked Terrestrial GS	GEO satellite	LEO satellite	HAP
ATC Relay	AR1	AR2	AR3	AR4	AR5

Table 4-1 ATC relay type candidate architectures

4.2.2 Non-ATC relay architectures

The following architectures represent those where the ATC communications with the pilot is direct either through a terrestrial ATC radio, a dedicated wired connection, or a wired connection through a communication service provider (CSP).

Non ATC relay	Dedicated terrestrial GS	Networked Terrestrial GS	GEO satellite	LEO satellite	HAP
Terrestrial GS (Radio)	NR1	NR2	NR3	NR4	NR5
Dedicated Wired Interface	NR6	NR7	NR8	NR9	NR10
CSP Wired Interface	NR11	NR12	NR13	NR14	NR15

Table 4-2 Non-ATC candidate architectures

Detailed diagrams and schematics can be found in appendix A. These candidate architectures were the subject of a preliminary risk analysis as described in the following section.

5 Preliminary Safety Hazard Assessment

The second step in the overall methodology described in section 2 is to analyse the candidate architectures using a risk analysis that will be used to rank the architectures with respect to their inherent safety and reliability of operation. The purpose of doing this is to select 4 architectures that score best for safety and provide sufficient variety such that the remaining topics can be explored.

This section describes the risk analysis process, the assumptions that underpin the analysis, the scores that were obtained and finally the rationale for selection of the 4 bounded architectures.

5.1 Safety Hazard Assessment Process

A hazard identification and analysis workshop was convened with subject matter experts from QinetiQ's Air Traffic Management, Unmanned Aerial Systems and System Safety. The meeting attendees are listed in Figure 5-1 Hazard assessment team of Experts. The aim of the workshop was to identify and record the functional hazards arising from each of the 20 architectures, and a brainstorming approach was used to elicit this from the expert judgements.

Team Member	Speciality
Simon Brown	Safety expert/ facilitator
Adrian Clough	UAS expert/ Project Technical Leader
Phil Platt	Communications expert
Sarah Hunt	Mathematician and analyst
Phil Richards	UAV communications and spectrum specialist
Mike Ainley	Project Manager

Figure 5-1 Hazard assessment team of Experts

The risk analysis was based on the EUROCONTROL Safety Assessment Methodology (SAM) preliminary Hazard assessment (PHA) process. This methodology uses a set of severity categories to quantify the risk to ATC. The same categories are also found in ESARR 4.

The candidate architectures were presented to the team as a set of functional diagrams. All architectures were also portrayed as a schematic diagram, showing the system level elements. These diagrams were agreed by the team members to be a reasonable high level abstraction of the critical functions for the architecture.

A risk analysis was conducted on the candidate architectures using the SAM impact categories. Using the risk scheme described below the architectures were ranked with respect to their perceived safety.

5.2 Risk Classification Scheme

The SAM/ESARR 4 classification scheme is reproduced below in Figure 5-2 Hazard Classification table. The scheme is qualitative, with the severity classifications defined below in Figure 5-3 Table of hazard severity. Frequency of occurrence is divided into five categories between 'HIGH' or category 5, the most likely to occur and 'LOW' or category 1, the least likely to occur. A measure of likely risk, the risk index, is obtained by multiplying severity by frequency. Thus the highest risk would have a risk index of 25. Risk indexes shown in green indicate a level of risk considered to be acceptable by the team subject matter experts. Risk indexes in red were considered to indicate architectures that may be difficult to engineer to be acceptably safe.

Severity Class	**5 [Most Severe]**	**4**	**3**	**2**	**1**
Effect on Operations	**Accidents**	**Serious incidents**	**Major incidents**	**Significant incidents**	**No immediate effect on safety**
Examples of effects on operations	☐ one or more catastrophic accidents, ☐ one or more mid-air collisions ☐ one or more collisions on the ground between two aircraft ☐ one or more Controlled Flight Into Terrain ☐ total loss of flight control. No independent source of recovery mechanism, such as surveillance or ATC and/or flight crew procedures can reasonably be expected to prevent the accident(s).	☐ large reduction in separation (e.g., a separation of less than half the separation minima), without crew or ATC fully controlling the situation or able to recover from the situation. ☐ one or more aircraft deviating from their intended clearance, so that abrupt manoeuvre is required to avoid collision with another aircraft or with terrain (or when an avoidance action would be appropriate).	☐ large reduction (e.g., a separation of less than half the separation minima) in separation with crew or ATC controlling the situation and able to recover from the situation. ☐ **minor** reduction (e.g., a separation of more than half the separation minima) in separation without crew or ATC fully controlling the situation, hence jeopardising the ability to recover from the situation (without the use of collision or terrain avoidance manoeuvres	☐ increasing workload of the air traffic controller or aircraft flight crew, or slightly degrading the functional capability of the enabling CNS system. ☐ **minor** reduction (e.g., a separation of more than half the separation minima) in separation with crew or ATC controlling the situation and fully able to recover from the situation.	No hazardous condition i.e. no immediate direct or indirect impact on the operations **.**

Figure 5-2 Hazard Classification table

Severity Class		5	4	3	2	1
Likelihood		Accidents	Serious Incidents	Major Incidents	Significant Incidents	No immediate effect
High	5	25	20	15	10	5
Medium/H	4	20	16	12	8	4
Medium	3	15	12	9	6	3
Low/Med	2	10	8	6	4	2
Low	1	5	4	3	2	1

Figure 5-3 Table of hazard severity

5.3 Analysis Technique

A top level functional hazard assessment was conducted using keyword prompts to engender discussion between members and to elicit potential plausible hazards. Keywords were selected from the SAM according to ESARR 4. Assumptions made about each candidate architecture are listed at Paragraph 5.5 below. The results from the risk analysis were compiled into a series of worksheets, one worksheet for each proposed architecture. The worksheets are shown in appendix B

The worksheets were used to record, for each keyword, any plausible hazard, the potential cause of the hazard, the team's evaluation of likelihood of occurrence and severity for each hazard, the resulting risk index and any mitigations that may reduce the hazard risk.

A further weighted score was added to the worksheets to account for potential multiple occurrences of the same hazard within different functional blocks. This score assumed that the functional blocks could be considered to be in series. Thus the risk index for the recurring hazard in each block was a cumulative value; that is risk index multiplied by number of occurrences.

In order to rank the candidate architectures all the risk indexes and weighted indexes for the hazards identified on the worksheets were totalled. These totalled scores, together with the unweighted risk totals and other non-safety technical criteria, were used to select the most suitable bounded architectures on which to conduct more detailed analysis.

5.4 Kick Off Meeting

Subsequent to the risk assessment and tentative selection, the project kick-off meeting was held. In attendance at this meeting was the EASA focal point Mr F Tomasello and representatives of the Project Steering Group (PSC). The following paragraphs on assumptions, rankings and approved selection for the architectures reflect the comments at the kick off meeting.

5.5 Assumptions

During the course of the risk assessments the following assumptions were identified.

Assumption 1	The UAV has no independent means of providing sense and avoid.
Detail	The UAV is assumed to have no independent means of autonomously maintaining separation from other aircraft, terrain or hazardous weather.
Rationale	Whilst in the future, many unmanned aircraft are likely to be equipped with certified systems capable of independently performing sense and avoid functions, this capability cannot be assumed to exist for all unmanned aircraft. Operation of the UAV is therefore assumed to be reliant on the provision of an ATC separation service or the pilot. Refers to a UAS that would be restricted to operate only inside controlled airspace

Assumption 2	A UAS will do what it is instructed to do by ATC.
Detail	A UAS being operated under an Air Traffic Control Service will comply with ATC instructions in a timely manner. ATC instructions may require the UAV to climb, descend, turn or adjust speed.
Rationale	For a UAS to be able to operate outside segregated airspace amongst other air traffic, it must be able to respond to ATC instructions and react in a timely manner.

Assumption 3	If the UAV loses communications it will continue on its planned route.
Detail	If the UAV loses communications with ATC or its GCS, then it will continue on its planned route at its planned flight level. Note: It is recognised that different UAVs are programmed to do different things in the event of a communications failure, and there is currently no standard

	procedure.
Rationale	This is what a manned aircraft will do, and procedures exist to enable ATC to continue to provide separation.

Assumption 4	The UAS datalink communications system has the ability to detect errors.
Detail	The integrity requirements of the data paths will ensure that undetected errors cannot arise.
Rationale	This is a reasonable expectation for a certified flight safety system.

Assumption 5	No redundancy in sub-system elements
Detail	Regardless of the safety performance requirement, all sub-system elements are assumed to be non-redundant. For example, a communications path between two nodes will be assumed to have a single mode of failure even though it will have been engineered to meet availability requirements.
Rationale	It is not possible to provide an accurate assessment of sub-system elements, and it is therefore necessary to make some general assumptions at this stage.

Assumption 6	A UAV carrying ATC voice/data radios can tune to any valid frequency.
Detail	ATC voice/data radios installed on a UAV can be remotely tuned from the GCS by sending commands over the C2 datalink. Tuning of ATC voice/data radios could be remotely controlled via the C2 datalink
Rationale	There would be no point having an ATC voice/data radio that could not be remotely tuned.

Assumption 7	One UAV per GCS
Detail	All architectures assume only one UAV per GCS.
Rationale	Whilst it may be technically possible to control more than one UAV from a GCS, there are various legal, operational and human factor issues to be addressed before such operation is likely to be approved. There is no justifiable reason to consider architectures capable of supporting more than one UAV per GCS at this point in time.

Assumption 8	C2 and ATC communications channels always ‘open’
Detail	It shall be assumed that C2 and ATC voice/data communications

	channels are ‘open’ for the duration of the flight. Whilst private virtual circuits may be used, it is assumed that channels are continuously open, and any information sent to or from the UAS is passed through the communications channel in near real time.
Rationale	In order to comply with ATC instructions in a timely manner, both the ATC voice/data and C2 datalink channels must be continuously open. ATC instructions may require the UAV to climb, descend, turn or adjust speed.

Assumption 9	UAVs do not require ‘stick’ input control
Detail	It is assumed that all UAVs capable of operating outside segregated airspace do not require constant control input in order to maintain flight. In other words, autopilot systems will ensure that attitude, roll angle and yaw control inputs are generated to maintain the desired flight path trajectory. (Linked with Assumption 3).
Rationale	Technology required for simple flight control is readily available (i.e. 3-axis autopilot).

Assumption 10	Satcom on UAVs requires a directional antenna
Detail	It is not uncommon for broadband satellite terminals to require a directional antenna. This can be due to the need to avoid interference to/from other satellites, or to ensure enough signal power over a long propagation path. Maintenance of the link from a moving platform (i.e. UAV) is dependent on the ability of automatic antenna steering systems to continuously track the satellite, and this is considered to be a potential mode of intermittent failure. ESA should be included as a stakeholder to ensure that UAS requirements for ATM communications are captured by Iris project.
Rationale	Whilst not all Satcom terminals will require a directional antenna, for the purpose of the PHA it has been assumed that GEO and LEO Satcom terminals will include a directional antenna.

Assumption 11	The UAV will always be within coverage of one satellite.
Detail	The coverage footprints of GEO satellites and orbit paths of LEO satellites are complex and will vary according to each network/constellation. The only safe assumption is to assume that the UAV is only within coverage of a single satellite.
Rationale	It cannot be assumed that other satellites will be within coverage of the UAV. If communications via the satellite fail, no redundancy can be assumed to be available from other satellites.

Assumption 12	All UAVs will be equipped with a Mode S transponder

Detail	A Mode S transponder will provide surveillance information to ATC ground radar systems and is compatible with collision avoidance systems (ACAS II) carried by turbine-powered civil aircraft of 5,700 kg or more.
Rationale	Due to the safety benefits transponder carriage brings, aircraft operating in controlled airspace will be required to carry a transponder, so it is not unreasonable to assume that UAVs will also be required to do so. This is common across all architectures and in a similar approach to the risk analysis where there is commonality across all architectures it is discounted on the basis that this assumption is made a requirement of obtaining an airworthiness certificate. This will be the subject of a survey questionnaire to gauge stakeholder reaction and opinion on the practicality of this assumption.

Assumption 13	Latency in Network Management Centres
Detail	Latency in the ATC voice/data communication path or C2 datalink is a potential problem as it can impede the ability for a UAV pilot to comply with ATC instructions. Where signals pass through a network management centre, there is potential for additional latency due to the amount of signal routing and processing that takes place. For this reason, any network management centre shall be assumed to be a source of latency.
Rationale	Where signals pass through a network management centre, there is potential for additional latency due to the amount of signal routing and processing that takes place. For this reason, any network management centre shall be assumed to be a source of latency.

Assumption 14	Latency in Satellite Communications
Detail	Latency in the ATC voice/data communication path or C2 datalink is a potential problem as it can impede the ability for a UAV pilot to comply with ATC instructions. Where signals are routed via a geostationary satellite, at least a quarter of a second of additional latency will be introduced. For low earth orbit satellites, propagation paths can be of similar length due to the need to route feeder signals via several intermediate satellites (if a satellite earth station is not within coverage of the satellite being used). For this reason, any satellite communications path shall be assumed to be a source of latency.
Rationale	Where signals are routed via a satellite, there is potential for additional latency due to the length of propagation paths involved. For this reason, any satellite communications path is assumed to be a source of latency.

Assumption 15	Only UAS with MTOM of 150kg or more shall be considered
Detail	This assumption underlies the scope of the project to limit considerations to UAV with a MTOM of greater than 150kg.

Rationale	EASA's remit only covers UAV of 150 kg or more.

Assumption 16	Architectures considered are only applicable for UAS operations conducted beyond visual line of sight.
Detail	The architectures considered are applicable for UAS operations that extend to a range of more than 500 m, or a height of more than 400 ft (150 m) from the UAV operator. In such cases, it is not considered practical or safe for the UAV operator to control the flight by visual observation techniques.
Rationale	Very short range UAS operations can be safely conducted as long as the UAV operator has good visual awareness of the UAV, and its proximity to other objects (buildings, people etc). For a UAV that is operated beyond visual line of sight the operator will rely on electronic systems (either on the UAV or on the ground), to sense and avoid nearby objects. See assumption 1.

Assumption 17	All ground control stations power supplies will be safe.
Detail	Ground control station power supplies are common to all architectures.
Rationale	The safety effect on the scoring can be ignored for comparison purposes providing this assumption is made and it becomes a requirement that can be demonstrated in practise during the air worthiness certification process.

Assumption 18	Architectures will be suitable for implementation within a SESAR concept environment
Detail	When considering the cost aspects associated with the bounded architectures, it was important to consider what is likely to exist in the 2020 timeframe (i.e. with SESAR concepts and related architectures already in place).
Rationale	The fact that current regulations prevent a type of activity taking place should not necessarily mean that future regulations will prevent it taking place. If there is a good reason for changing existing regulations, then they can be changed, through the appropriate procedures.

5.6 Risk Assessment Scores

The following table shows the results of the analysis.

		Risk Score			
Architecture	Description	Weighted	plain	Red Risks	Yellow
AR1	ATC relay: non-networked GS	110	41	1	
AR2	ATC relay: networked GS	69	27	0	
AR3	ATC relay: GEO satellite	171	49	0	1
AR4	ATC relay: LEO satellite	140	40	0	
AR5	ATC relay: HAP	142	44	0	
NR1	ATC via terrestrial GS + DL via non-networked GS	92	33	1	
NR2	ATC via terrestrial GS + DL via networked GS	129	31	0	
NR3	ATC via terrestrial GS + DL via GEO satellite	152	34	0	
NR4	ATC via terrestrial GS + DL via LEO satellite	154	32	0	
NR5	ATC via terrestrial GS + DL via HAP	153	36	0	
NR6	ATC via dedicated wired i/f + DL via non-networked GS	91	35	1	
NR7	ATC via dedicated wired i/f + DL via networked GS	126	40	0	1
NR8	ATC via dedicated wired i/f + DL via GEO satellite	146	38	0	
NR9	ATC via dedicated wired i/f + DL via LEO satellite	146	38	0	
NR10	ATC via dedicated wired i/f + DL via HAP	146	42	0	
NR11	ATC via CSP wired i/f + DL via non-networked GS	101	37	1	
NR12	ATC via CSP wired i/f + DL via networked GS	128	38	0	1
NR13	ATC via CSP wired i/f + DL via GEO satellite	161	38	0	
NR14	ATC via CSP wired i/f + DL via LEO satellite	161	38	0	
NR15	ATC via CSP wired i/f + DL via HAP	353	58	0	2

Figure 5-4 Table of hazard assessment scores

5.7 Bounded Architecture Selection

As a result of the risk analysis the following architectures have been selected for further study and impact assessment.

5.7.1 AR2 - ATC relay: networked GS

This had the lowest overall risk score, required no modification to present day ATC infrastructure and was seen as a logical solution as long as sufficient spectrum was available to permit ATC voice/data to be carried over the C2 datalink.

5.7.2 NR1 - ATC via terrestrial GS + DL via non-networked GS

This had the lowest risk score of the non-ATC relay architectures, and was seen as being a practical and cost effective solution for small UAS operating within a confined geographical area (e.g. radio line of sight).

5.7.3 NR3 - ATC via terrestrial GS + DL via GEO satellite

This is the lowest scoring architecture with a satellite communications element and is seen as being cost effective and practical for medium/large UAS that need to operate over longer distances, or where there is no terrestrial C2 ground station coverage. By studying this architecture in more detail it will be possible to explore issues to do with the use of Satellite communications for C2, and the use of a Communication Service provider (CSP) to provide voice/data communications with ATC using ground-based radio equipment.

5.7.4 NR12 - ATC via CSP wired i/f + DL via networked GS

Although this architecture does not have a particularly low score, it is considered to be a practical solution in the context of the SESAR 2020 timeframe. By studying this architecture in more detail it will be possible to explore issues associated with the use of a CSP managed wired interface to the ATC voice/data network.

6 Stakeholder Engagement

This section provides details determined to date in the stakeholder selection process.

Stakeholders are divided into two groups:

- Group 1 represent safety and regulatory bodies
- Group 2 represent industry stakeholders

The two groups have a different role in the process as described in the methodology in section 2.

6.1 Group 1 Stakeholders

Group 1 stakeholders are those who have a vested interest in regulation or safety aspects of UAS operation. They will be used as a reference group to weight the questions as to their safety or regulatory importance.

At the Kick off meeting it was agreed to invite the following to be members of Group 1:

- Members of the PSC
- Peter Hotham, SESAR Chief Architect
- Franco Ongaro, Iris Programme Manager, ESA
- Ron van de Leijgraaf (Chairman of JARUS)
- ANSP representatives from FR-DGAC, DFS and NATS (plus any others wishing to participate)

6.2 Group 2 Stakeholders

Group 2 stakeholders will cover all relevant groups including manufacturers, maintainers, operators, end users, ATC and regulators. As wide an audience as possible will be selected within the EU and also in the USA and other active countries in order to compare the EU market with the rest of the world.

It was agreed that the following individuals or groups should be included in Group 2:

- EASA Advisory Group of National Authorities (AGNA)
- EASA Safety Standards Consultative Committee (SSCC)
- SES Industry Consultation Body (ICB)
- CANSO (relevant WG's)
- UVS International members
- AUVSI members
- EUROCAE WG-73
- RTCA SC-203
- European Aviation Research Partnership Group

The above is not an exhaustive list and other stakeholders may be added as the project progresses. An accreditation letter will be included with the stakeholder communications.

A Appendix A – Candidate architectures Diagrams

The following diagrams represent the 20 candidate architectures and their equivalent schematic diagrams

A.1 Definitions

The following definitions are used in the functional and schematic diagrams.

UA	Unmanned Aircraft
UAS	Unmanned Aircraft System (comprises the UA the GCS and the radio link for command and control between the two).
ATC Relay	An architecture where the ATC voice and/or data communications path is relayed via the UA.
Non-ATC Relay	An architecture where the ATC voice and/or data communications path is not relayed via the UA.
DL	Datalink (used for either ATC voice/data, and/or UA command and control)
GS	(radio) Ground Station (facility used to support either ATC voice/data, and/or UA command and control communications equipment)
GCS	Ground Control Station (from where the UAS pilot governs the flight of the UAV) and associated UAV monitoring/control systems
CSP	Communications Service Provider (used to provide voice/data communications between two specified points – independent of national ATC system).
DLSP	Datalink Service Provider (used to provide aeronautical data communications between ATC and aircraft)
SCSP	Satellite Communications Service Provider. This includes routing signals to/from satellite earth stations, along satellite feeder links and transmission/reception of signals by satellites.
Direct Communications	Where there is a direct communications path between the UA or GCS with ATC (i.e. not routed via a third party voice or data communications network).
Non-Direct Communications	Where the communications path between the UA or GCS with ATC is routed via third party voice or data communications network.
ATC-N	Air Traffic Control – part of a national networked ATC system.
ATC-I	Air Traffic Control – independent service provider without connection to the national networked ATC system.

A.2 Conventions

The following conventions apply to all candidate architectures in this paper:

Colour coding on functional diagrams

- RF links are denoted by dashed lines
- Wired links are denoted by solid lines

- Single line = half duplex channel
- Parallel line = full duplex channel
- Colour shading (on schematic diagrams):
- Light blue denotes systems physically installed on the unmanned aircraft
- Orange shapes are current and future ATC systems
- Magenta lines represent ATC voice/data
- Blue lines represent telecommand links
- Green lines represent telemetry links
- Black lines represent a combined ATC communications, telecommand and telemetry

A mnemonic is used to reference each of the architectures.

- The first letter categorises the architecture in terms of having ATC relay (R) or non-ATC relay (N).
- The second letter defines whether the architecture has a dedicated (D) or networked (N) communications path to ATC.
- The third letter defines whether the architecture has radio (R) or wired (W) connection to ATC.
- Where there is more than one path in the architecture, a second mnemonic block is used.

A.2.1 Functional Diagram

The purpose of the functional diagram is to show the signal path(s) for ATC voice/data, telecommand and telemetry components, which constitute the command and control or C2 link. To aid clarity, the functional diagram does not show other aircraft or UAS. Similarly, it does not show the system elements or institutional aspects of each architecture.

A.2.2 Schematic Diagram

The schematic diagram provides a more detailed breakdown of the communications paths used for ATC voice/data, telecommand and telemetry. It identifies the systems used, the means of connectivity between systems, and in broad terms, who has responsibility for each system element.

To maintain clarity and to enable maximum flexibility in the functional risk analysis process, the attributes of each system (i.e. availability, integrity, likelihood of failure etc) are not specified.

Key to Schematic diagram

T – Potential to result in total failure of UAS communications

M – Potential for a fault to result in communications being misheard by ATC or the UAV pilot

P – Potential to result in a partial failure of UAS communications

D – Potential for communications to be misdirected (to the wrong aircraft, ground station or ATC unit)

L – Potential for system element to introduce significant latency

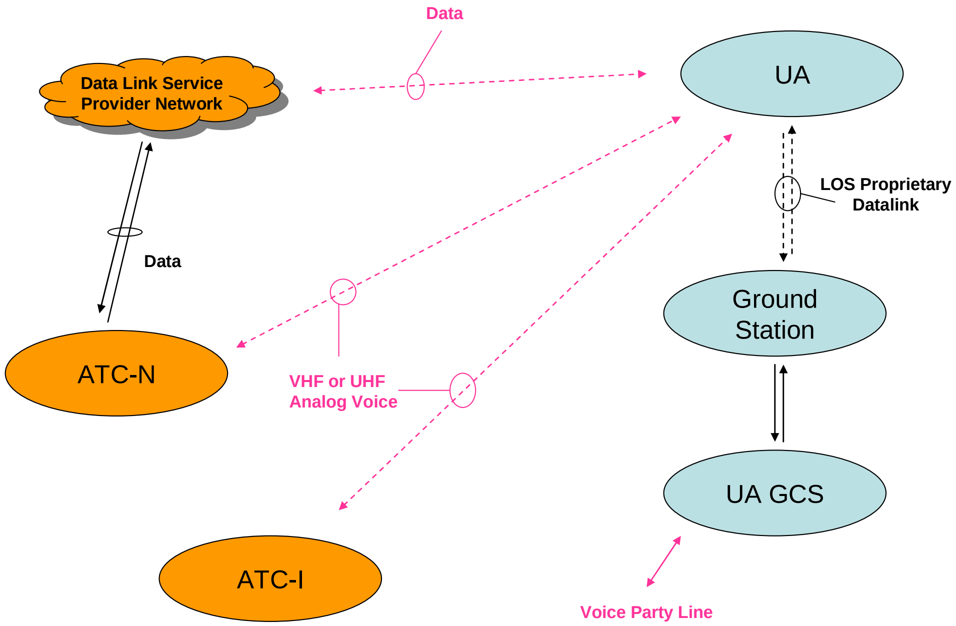
I – Potential for system element to be intermittent

S – Potential for system element to fail through loss of synchronisation with other system elements

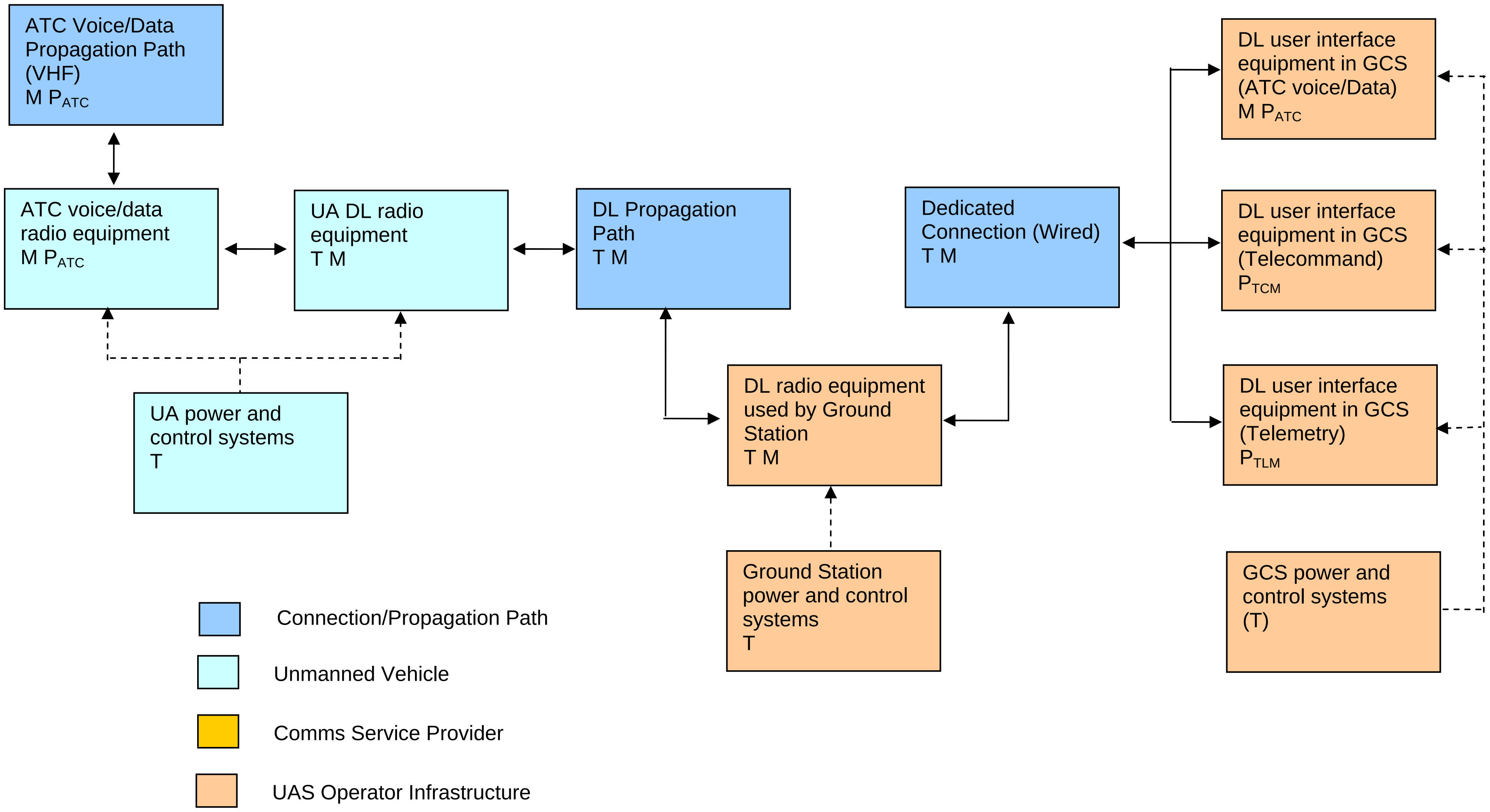
A.3 ATC Relay Architectures

A.3.1 AR1 – ATC Voice/Data, TLM & TCM Communications via Dedicated Radio (ADR)

AR1 – Functional Diagram



AR1 – Schematic Diagram



ATC Voice/Data Propagation Path (VHF)
M P_{ATC}

ATC voice/data radio equipment
M P_{ATC}

UA DL radio equipment
T M

DL Propagation Path
T M

Dedicated Connection (Wired)
T M

DL user interface equipment in GCS (ATC voice/Data)
M P_{ATC}

DL user interface equipment in GCS (Telecommand)
P_{TCM}

DL user interface equipment in GCS (Telemetry)
P_{TLM}

UA power and control systems
T

DL radio equipment used by Ground Station
T M

Ground Station power and control systems
T

GCS power and control systems
(T)

🟦 Connection/Propagation Path

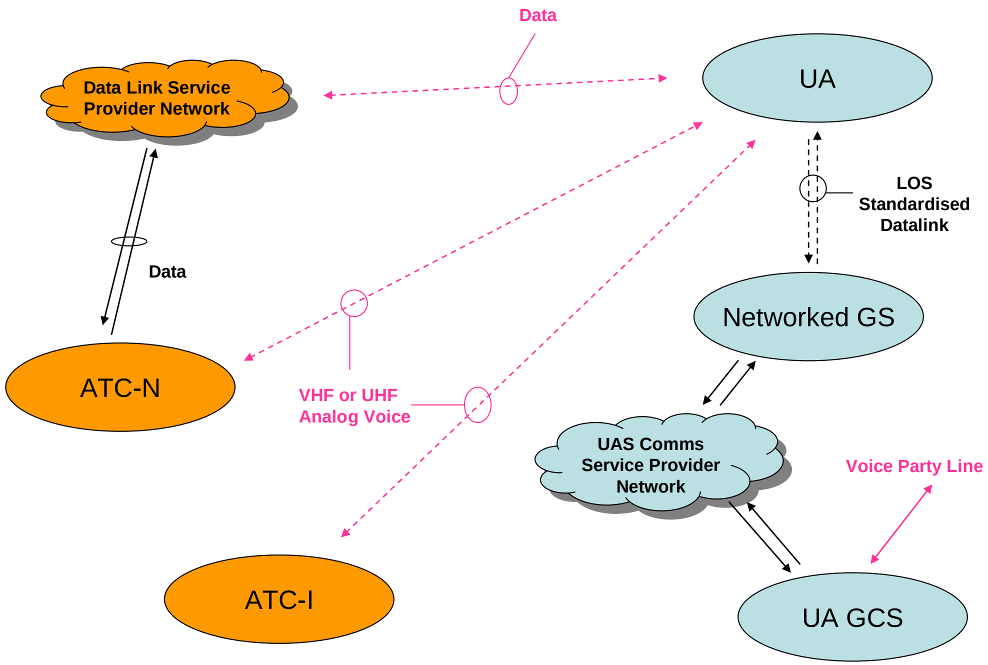
⬜ Unmanned Vehicle

🟨 Comms Service Provider

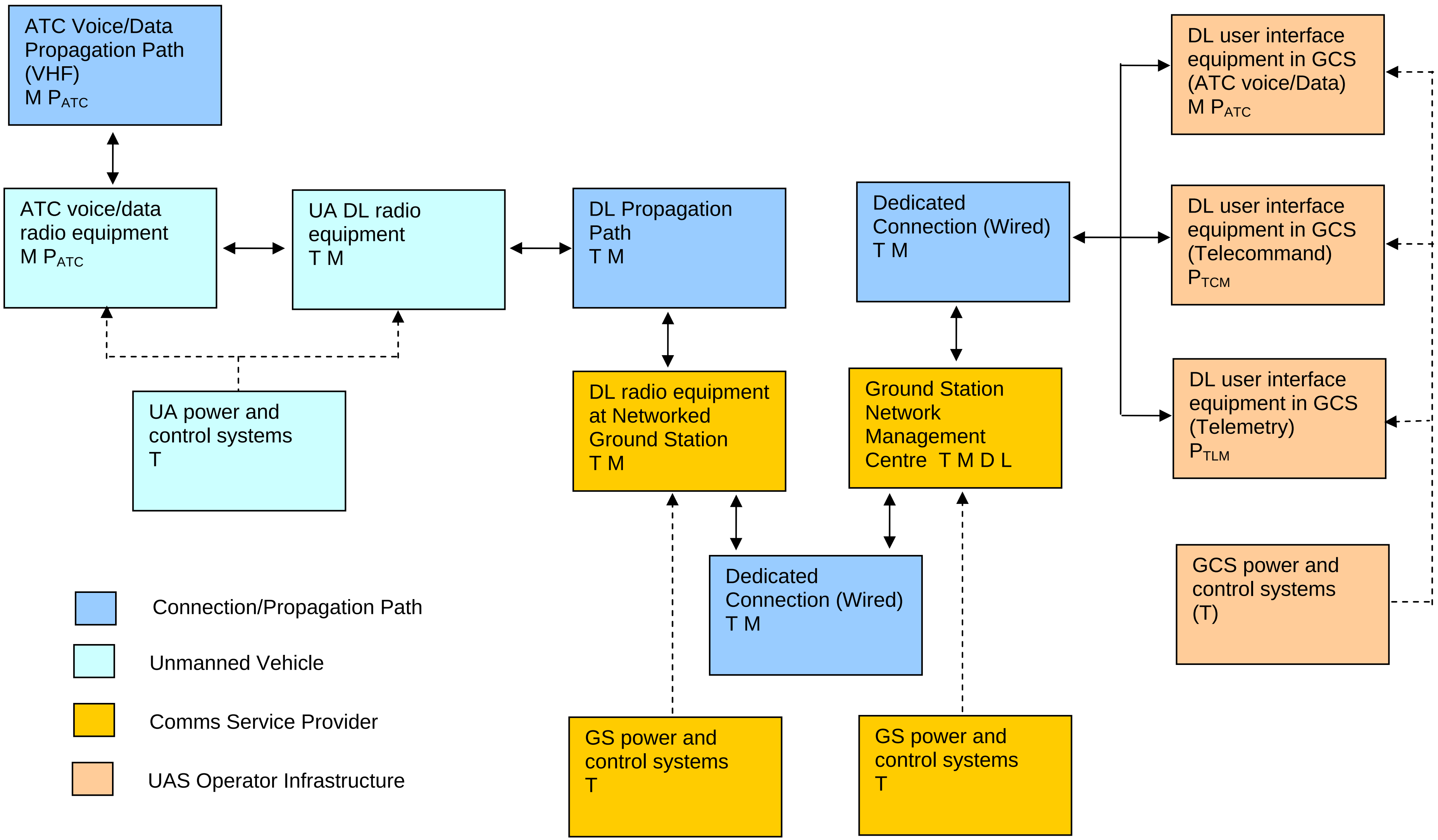
🟧 UAS Operator Infrastructure

A.3.2 AR2 – ATC Voice/Data Communications, TLM & TCM via Networked Terrestrial Radio (ANTR)

AR2 – Functional Diagram



AR2 – Schematic Diagram



ATC Voice/Data Propagation Path (VHF)
M P_{ATC}

ATC voice/data radio equipment
M P_{ATC}

UA DL radio equipment
T M

UA power and control systems
T

DL Propagation Path
T M

DL radio equipment at Networked Ground Station
T M

Dedicated Connection (Wired)
T M

Ground Station Network Management Centre T M D L

Dedicated Connection (Wired)
T M

GS power and control systems
T

GS power and control systems
T

DL user interface equipment in GCS (ATC voice/Data)
M P_{ATC}

DL user interface equipment in GCS (Telecommand)
P_{TCM}

DL user interface equipment in GCS (Telemetry)
P_{TLM}

GCS power and control systems
(T)

Connection/Propagation Path

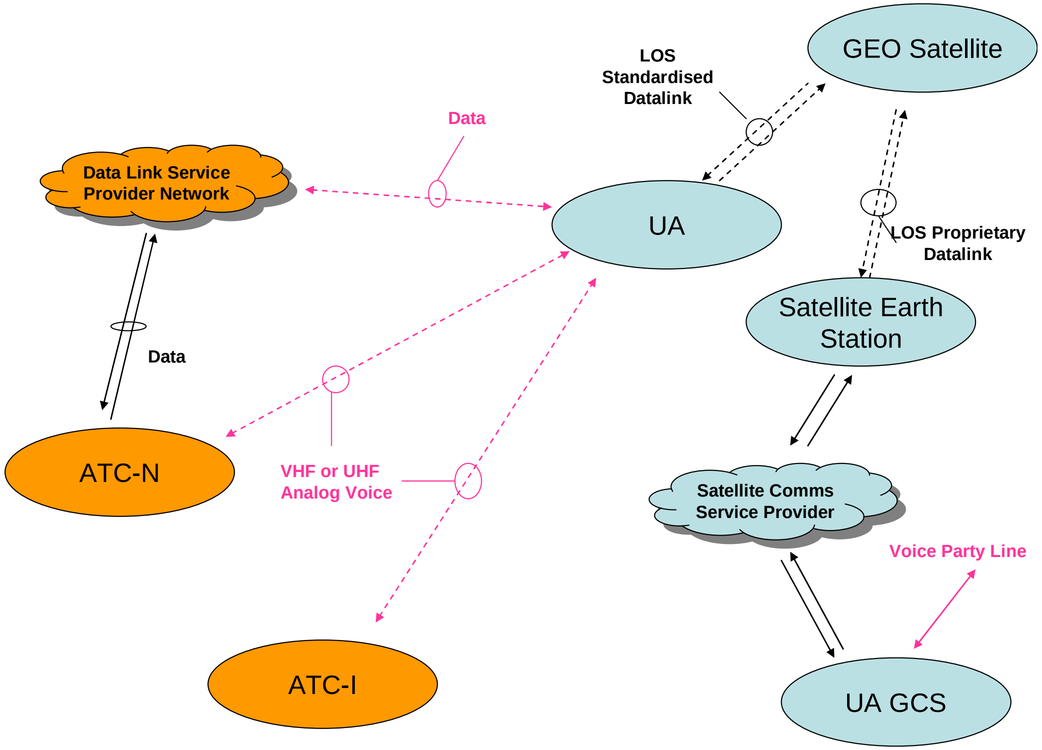
Unmanned Vehicle

Comms Service Provider

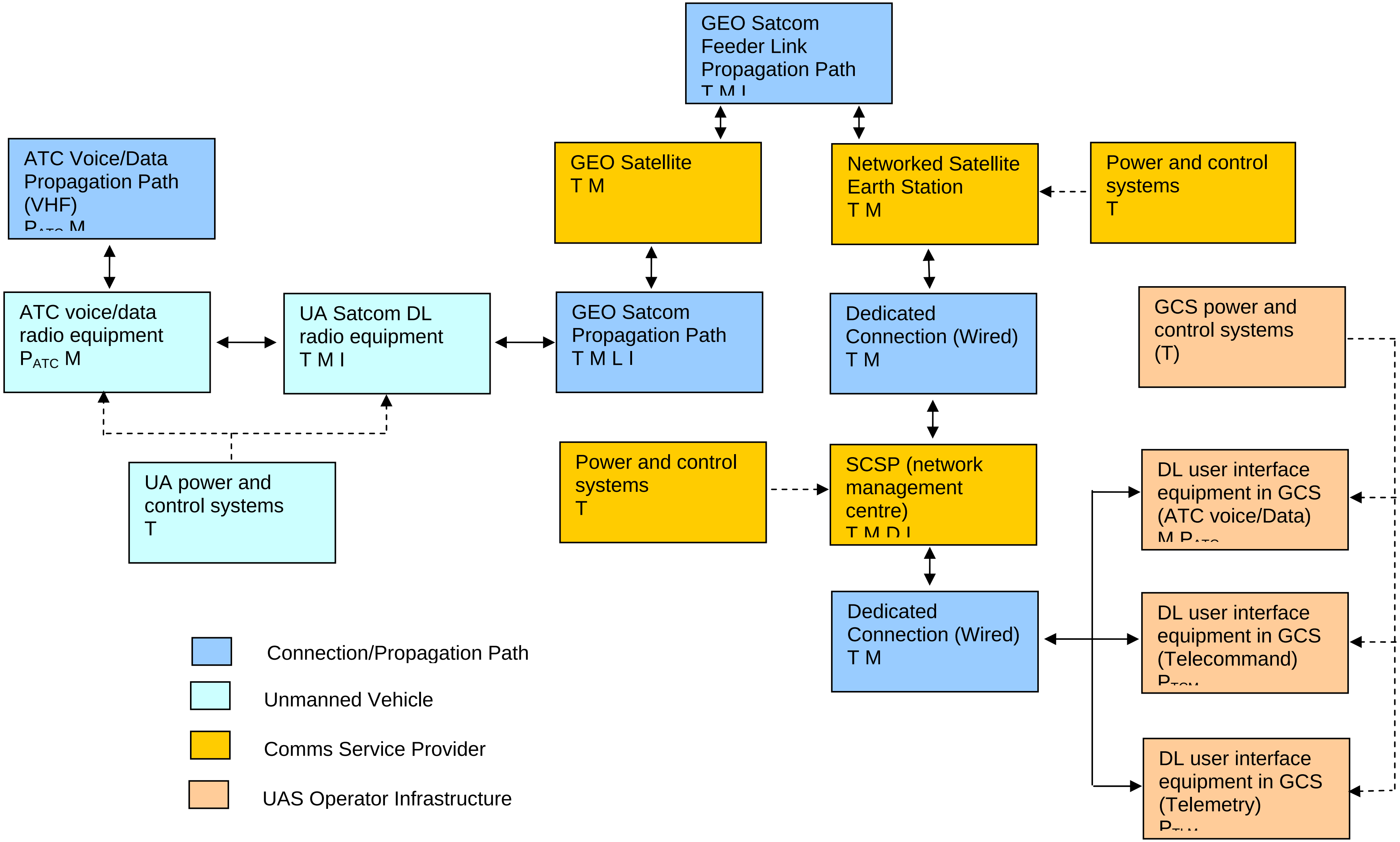
UAS Operator Infrastructure

A.3.3 AR3 – ATC Voice/Data Communications, TLM & TCM via Networked Geostationary Satellite Radio (ANGSR)

AR3 – Functional Diagram



AR3 – Schematic Diagram



GEO Satcom
Feeder Link
Propagation Path
T M I

ATC Voice/Data
Propagation Path
(VHF)
P_{ATC} M

GEO Satellite
T M

Networked Satellite
Earth Station
T M

Power and control
systems
T

ATC voice/data
radio equipment
P_{ATC} M

UA Satcom DL
radio equipment
T M I

GEO Satcom
Propagation Path
T M L I

Dedicated
Connection (Wired)
T M

GCS power and
control systems
(T)

UA power and
control systems
T

Power and control
systems
T

SCSP (network
management
centre)
T M D I

DL user interface
equipment in GCS
(ATC voice/Data)
M P_{ATC}

Dedicated
Connection (Wired)
T M

DL user interface
equipment in GCS
(Telecommand)
P_{TCM}

DL user interface
equipment in GCS
(Telemetry)
P_{TLM}

🟦 Connection/Propagation Path

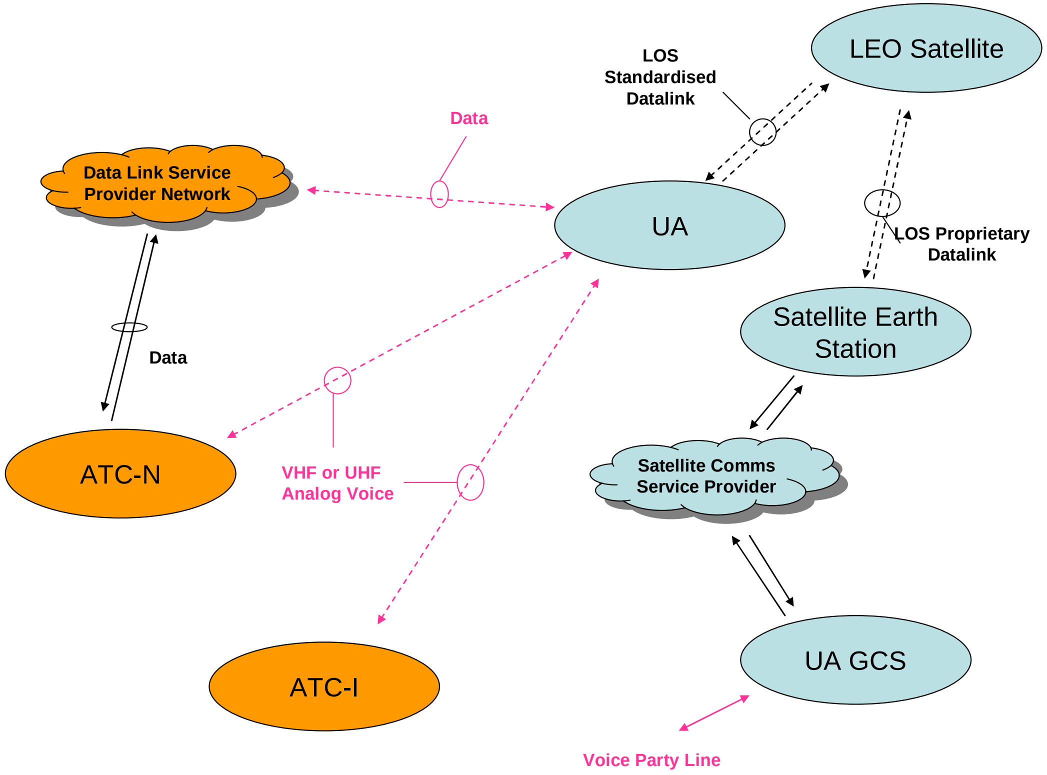
⬜ Unmanned Vehicle

🟨 Comms Service Provider

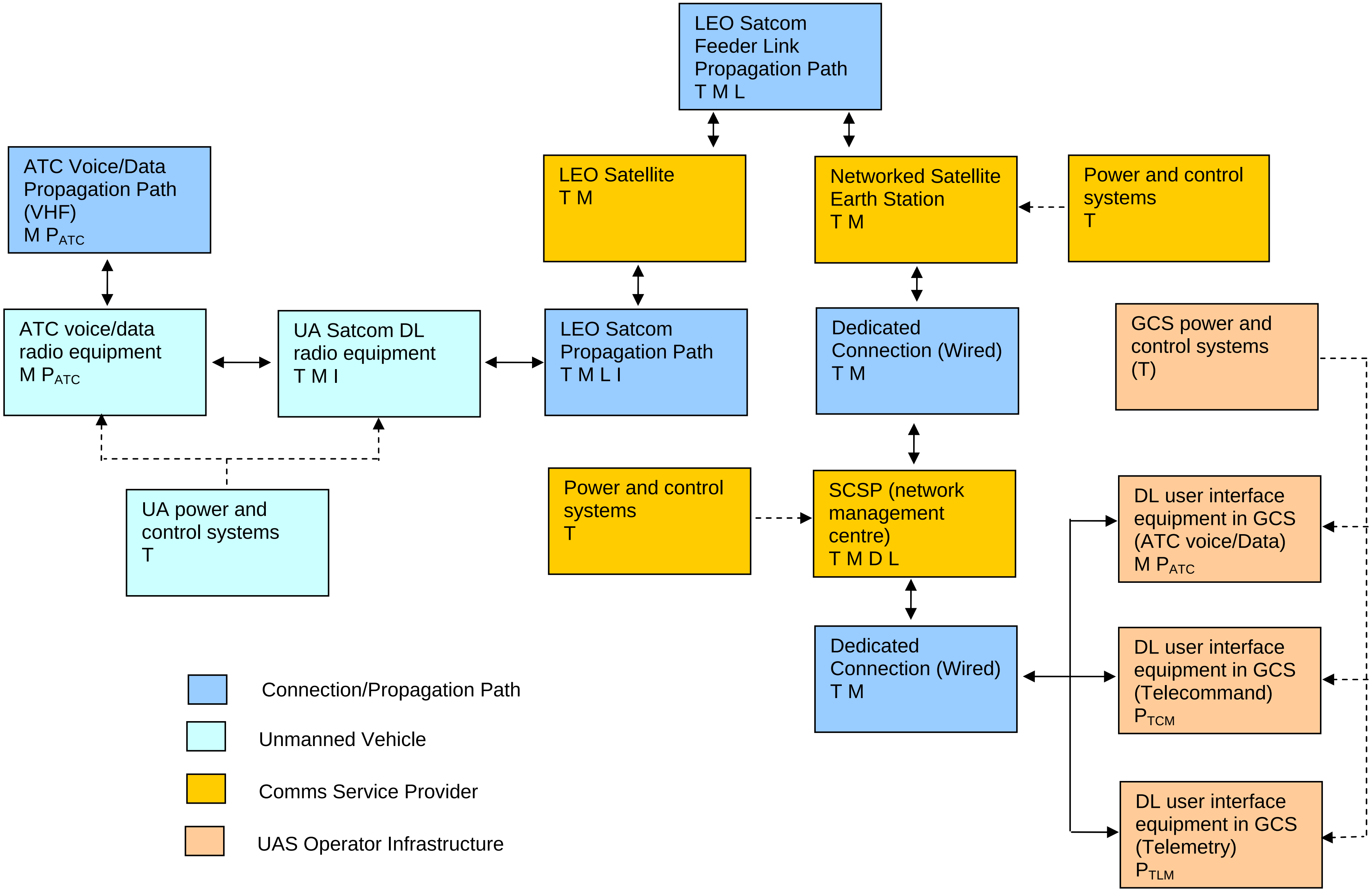
🟧 UAS Operator Infrastructure

AR4 – ATC Voice/Data Communications, TLM & TCM via Networked Low Earth Orbit Satellite Radio (ANLSR)

AR4 – Functional Diagram



AR4 – Schematic Diagram



LEO Satcom Feeder Link Propagation Path
T M L

ATC Voice/Data Propagation Path (VHF)
M P_{ATC}

LEO Satellite
T M

Networked Satellite Earth Station
T M

Power and control systems
T

ATC voice/data radio equipment
M P_{ATC}

UA Satcom DL radio equipment
T M I

LEO Satcom Propagation Path
T M L I

Dedicated Connection (Wired)
T M

GCS power and control systems
(T)

UA power and control systems
T

Power and control systems
T

SCSP (network management centre)
T M D L

DL user interface equipment in GCS (ATC voice/Data)
M P_{ATC}

Dedicated Connection (Wired)
T M

DL user interface equipment in GCS (Telecommand)
P_{TCM}

DL user interface equipment in GCS (Telemetry)
P_{TLM}

🟦 Connection/Propagation Path

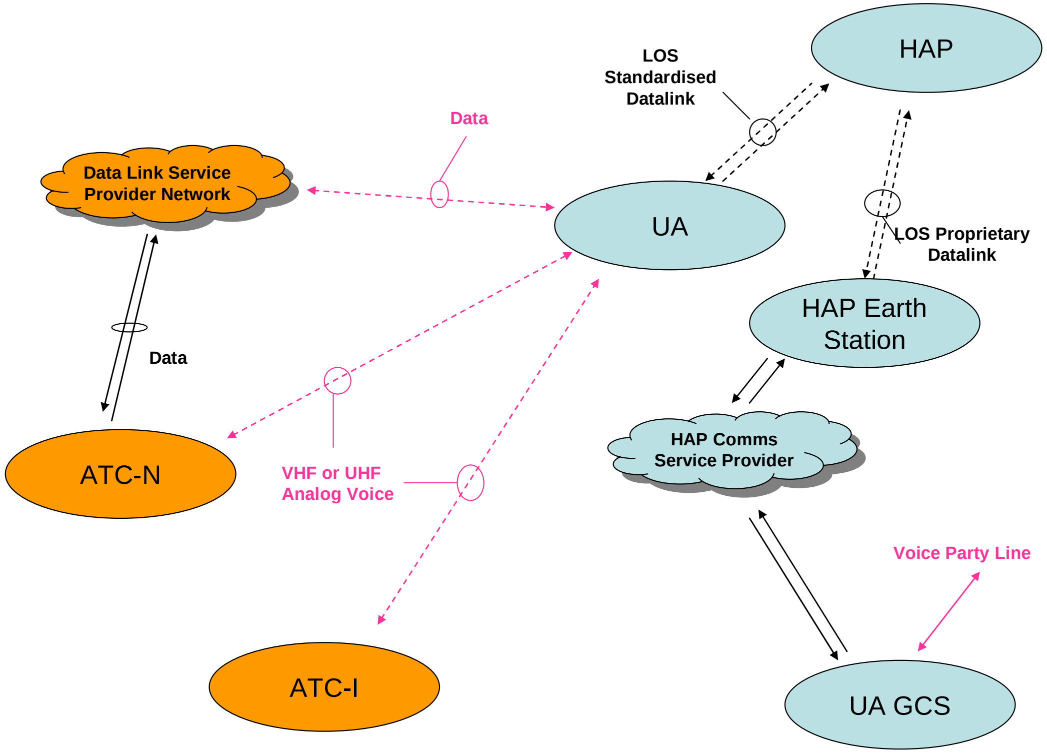
▢ Unmanned Vehicle

🟨 Comms Service Provider

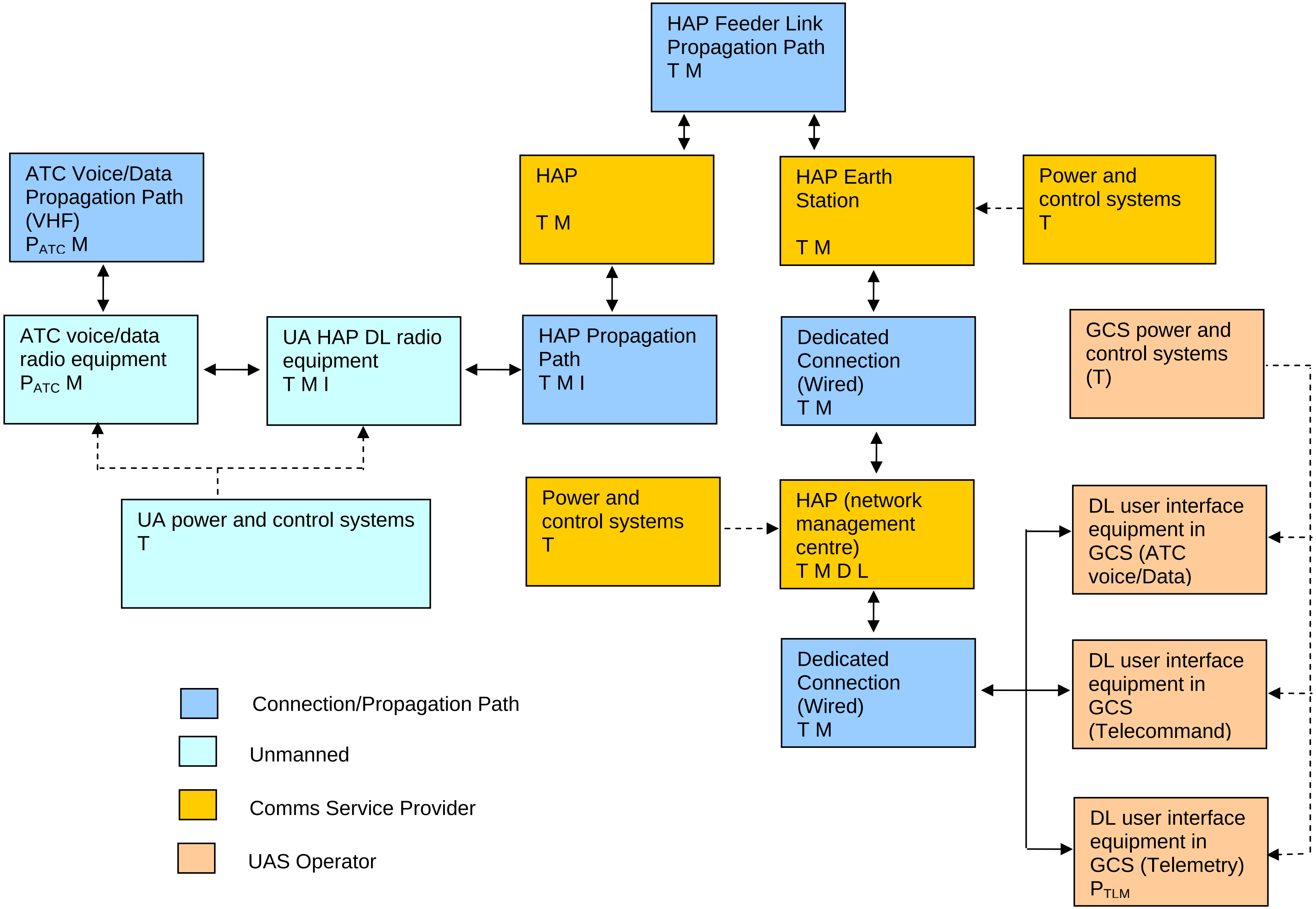
🟧 UAS Operator Infrastructure

A.3.4 AR5 – ATC Voice/Data Communications, TLM & TCM via Networked High Altitude Platform Radio (ANHR)

AR5 – Functional Diagram



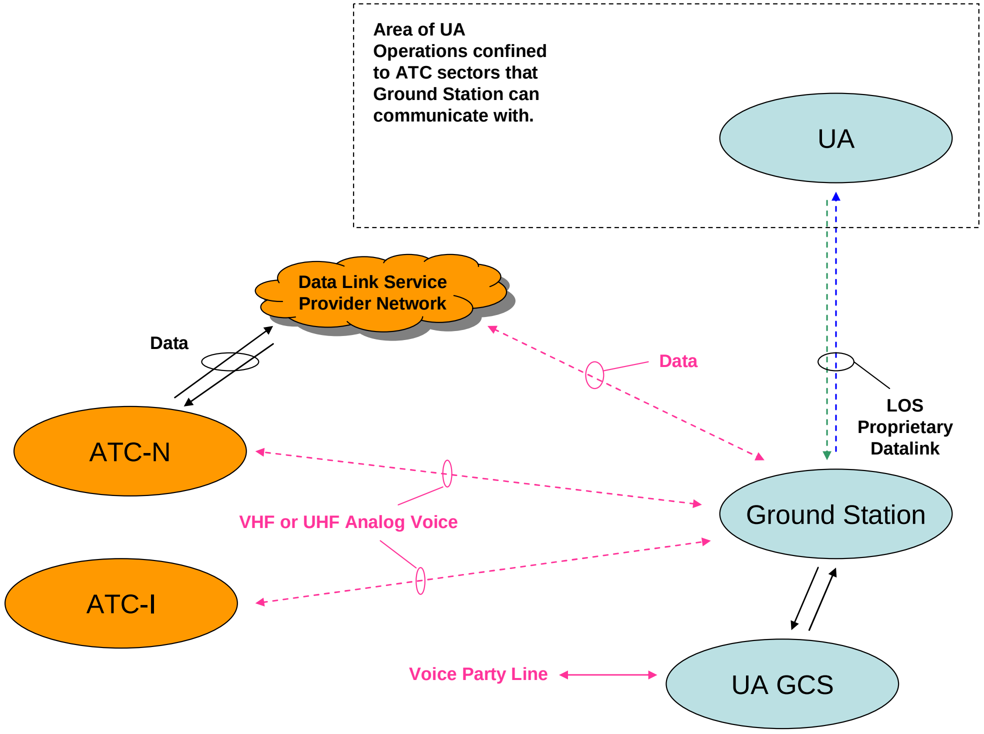
AR5 – Schematic Diagram



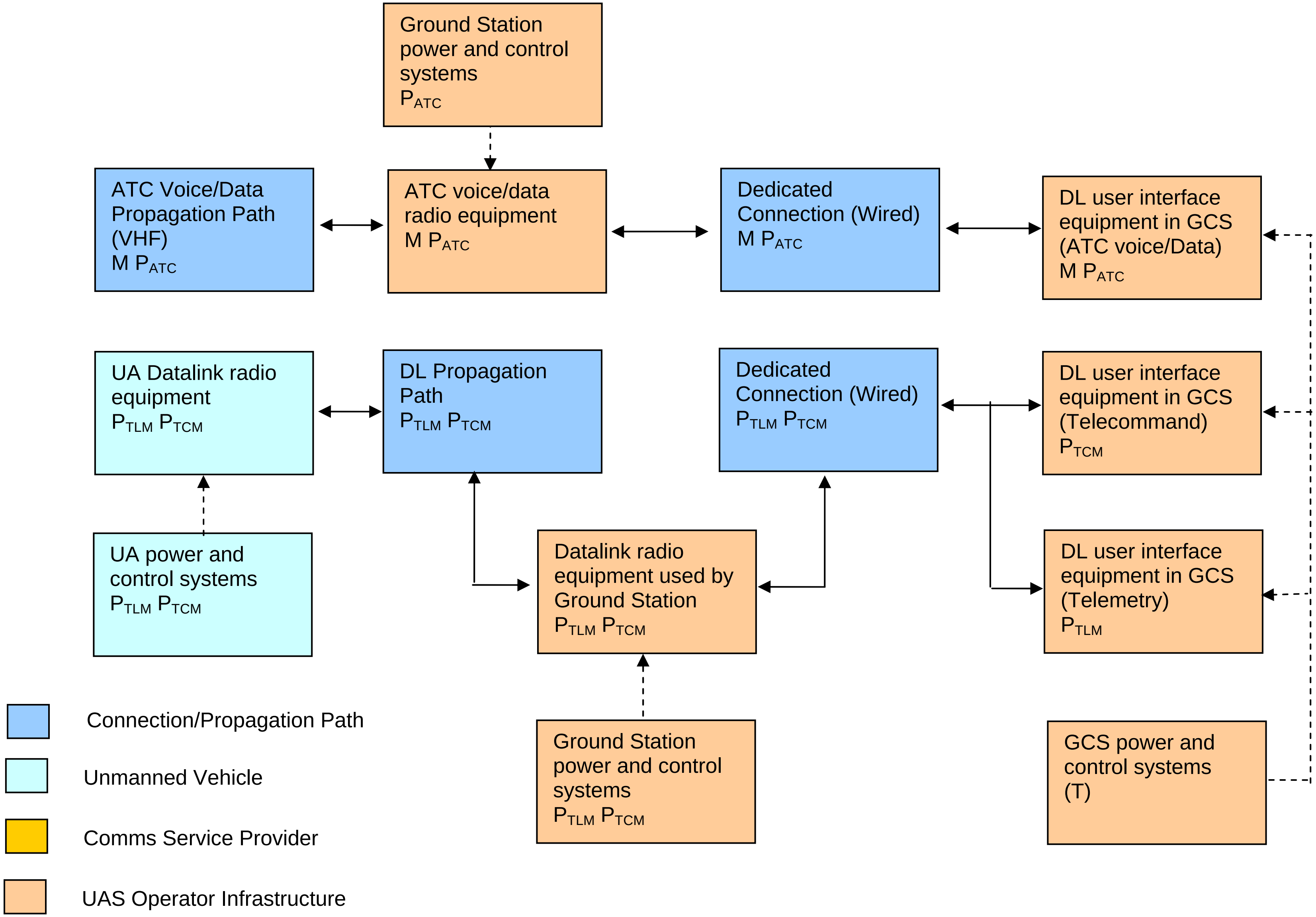
A.4Non-ATC Relay Architectures

A.4.1 NR1 – ATC Voice/Data Communications via Dedicated Ground-based ATC Radio, TCM & TLM via Dedicated Terrestrial Datalink (NDGR-DTD)

NR1 – Functional Diagram

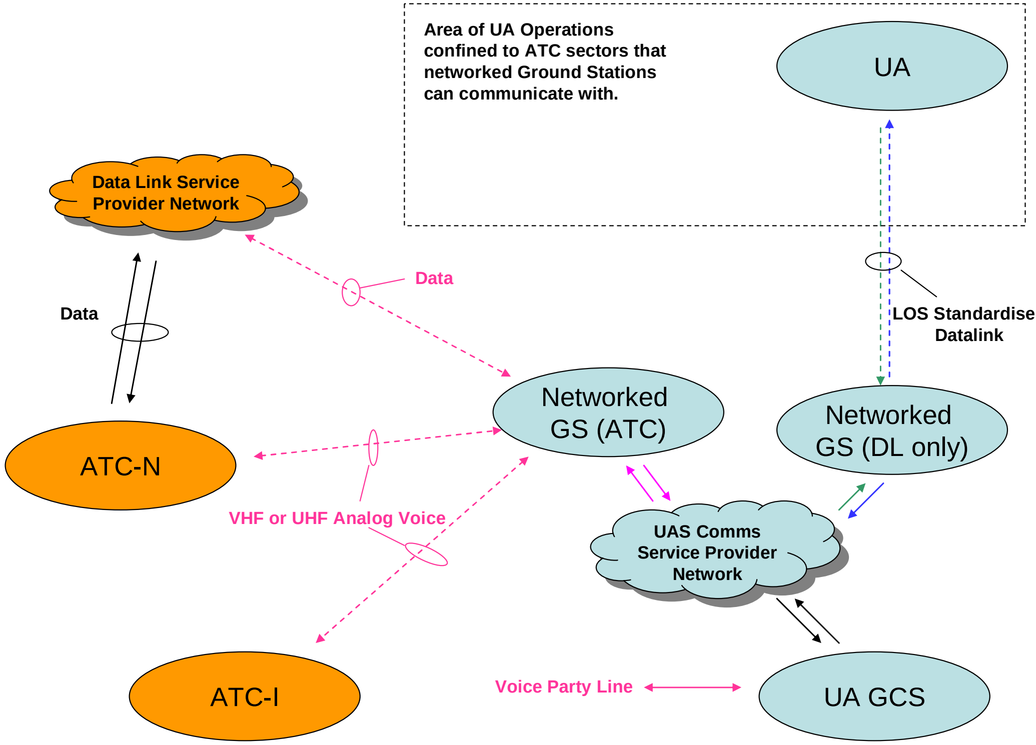


NR1 – Schematic Diagram

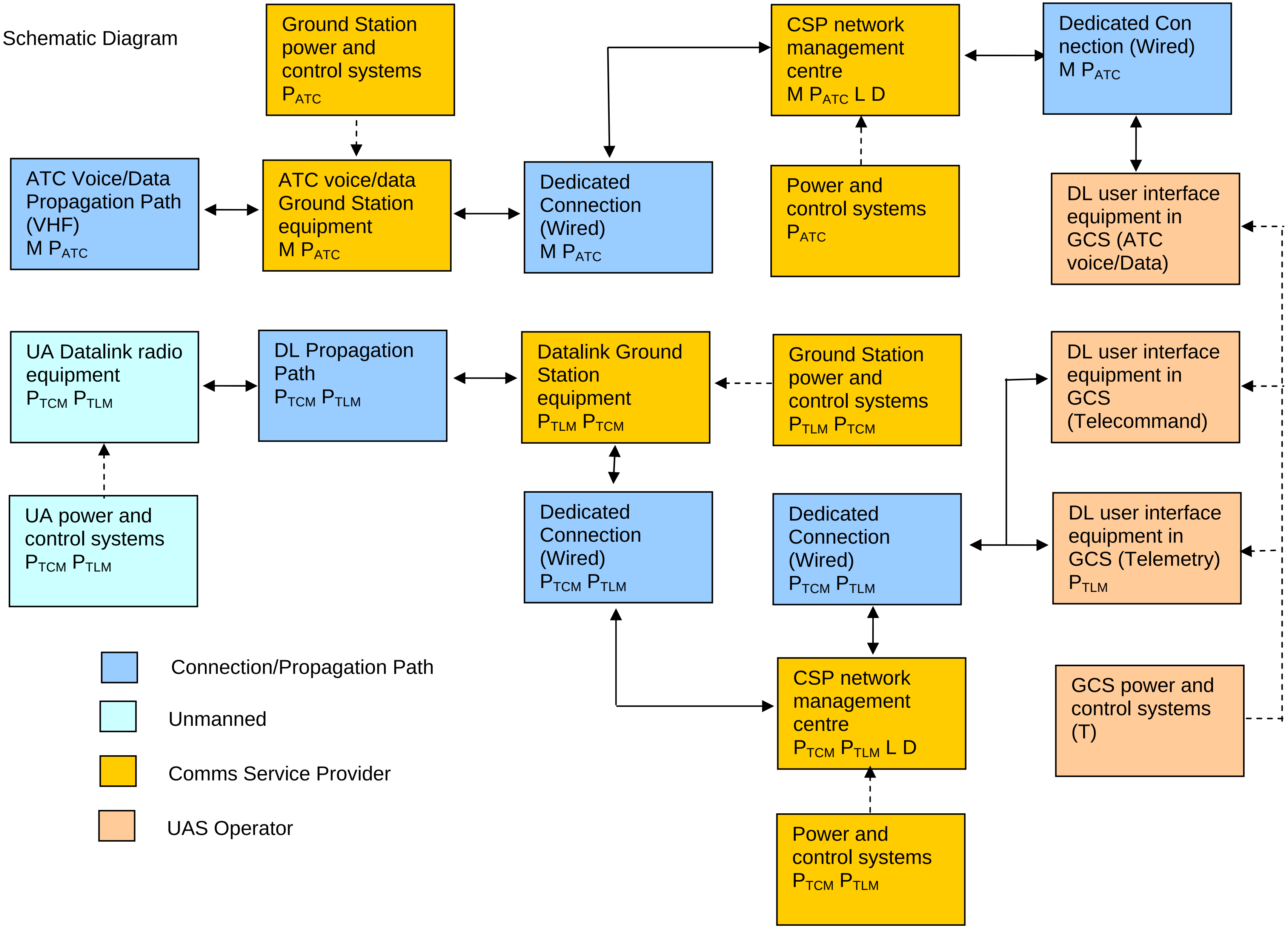


A.4.2 NR2 – ATC Voice/Data Communications via Networked Ground-based ATC Radio, TLM & TLC via Networked Terrestrial Datalink (NNGR-NTD)

NR2 – Functional Diagram



NR2 – Schematic Diagram



Ground Station power and control systems P_{ATC}

CSP network management centre M P_{ATC} L D

Dedicated Connection (Wired) M P_{ATC}

ATC Voice/Data Propagation Path (VHF) M P_{ATC}

ATC voice/data Ground Station equipment M P_{ATC}

Dedicated Connection (Wired) M P_{ATC}

Power and control systems P_{ATC}

DL user interface equipment in GCS (ATC voice/Data)

UA Datalink radio equipment P_{TCM} P_{TLM}

DL Propagation Path P_{TCM} P_{TLM}

Datalink Ground Station equipment P_{TLM} P_{TCM}

Ground Station power and control systems P_{TLM} P_{TCM}

DL user interface equipment in GCS (Telecommand)

UA power and control systems P_{TCM} P_{TLM}

Dedicated Connection (Wired) P_{TCM} P_{TLM}

Dedicated Connection (Wired) P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telemetry) P_{TLM}

CSP network management centre P_{TCM} P_{TLM} L D

GCS power and control systems (T)

Power and control systems P_{TCM} P_{TLM}

🟦 Connection/Propagation Path

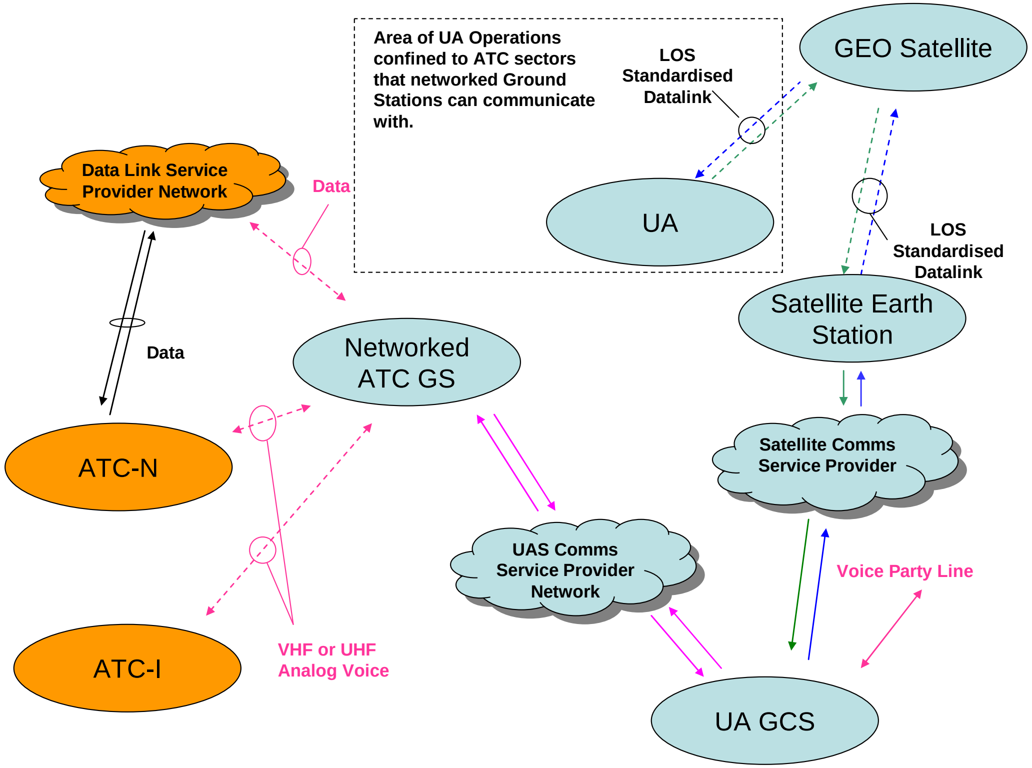
⬜ Unmanned

🟨 Comms Service Provider

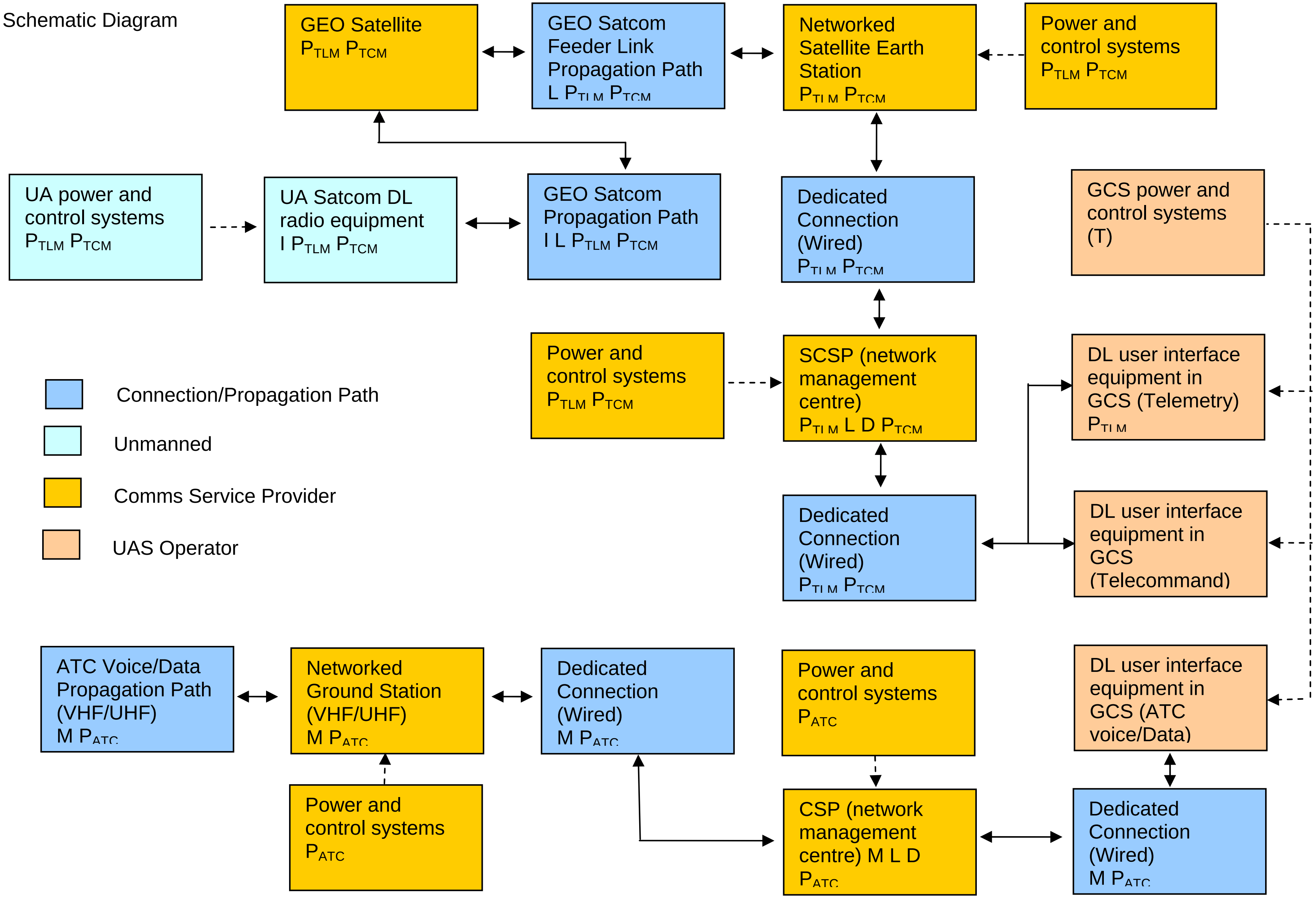
🟧 UAS Operator

A.4.3 NR3 – ATC Voice/Data Communications via Networked Ground-based ATC Radio, TLM & TLC via Geostationary Satellite Datalink (NNGR-GSD)

NR3 – Functional Diagram



NR3 – Schematic Diagram



GEO Satellite
P_{TLM} P_{TCM}

GEO Satcom Feeder Link Propagation Path
L P_{TLM} P_{TCM}

Networked Satellite Earth Station
P_{TLM} P_{TCM}

Power and control systems
P_{TLM} P_{TCM}

UA power and control systems
P_{TLM} P_{TCM}

UA Satcom DL radio equipment
I P_{TLM} P_{TCM}

GEO Satcom Propagation Path
I L P_{TLM} P_{TCM}

Dedicated Connection (Wired)
P_{TLM} P_{TCM}

GCS power and control systems
(T)

Power and control systems
P_{TLM} P_{TCM}

SCSP (network management centre)
P_{TLM} L D P_{TCM}

DL user interface equipment in GCS (Telemetry)
P_{TLM}

Dedicated Connection (Wired)
P_{TLM} P_{TCM}

DL user interface equipment in GCS (Telecommand)

🟦 Connection/Propagation Path

⬜ Unmanned

🟨 Comms Service Provider

🟧 UAS Operator

ATC Voice/Data Propagation Path (VHF/UHF)
M P_{ATC}

Networked Ground Station (VHF/UHF)
M P_{ATC}

Dedicated Connection (Wired)
M P_{ATC}

Power and control systems
P_{ATC}

DL user interface equipment in GCS (ATC voice/Data)

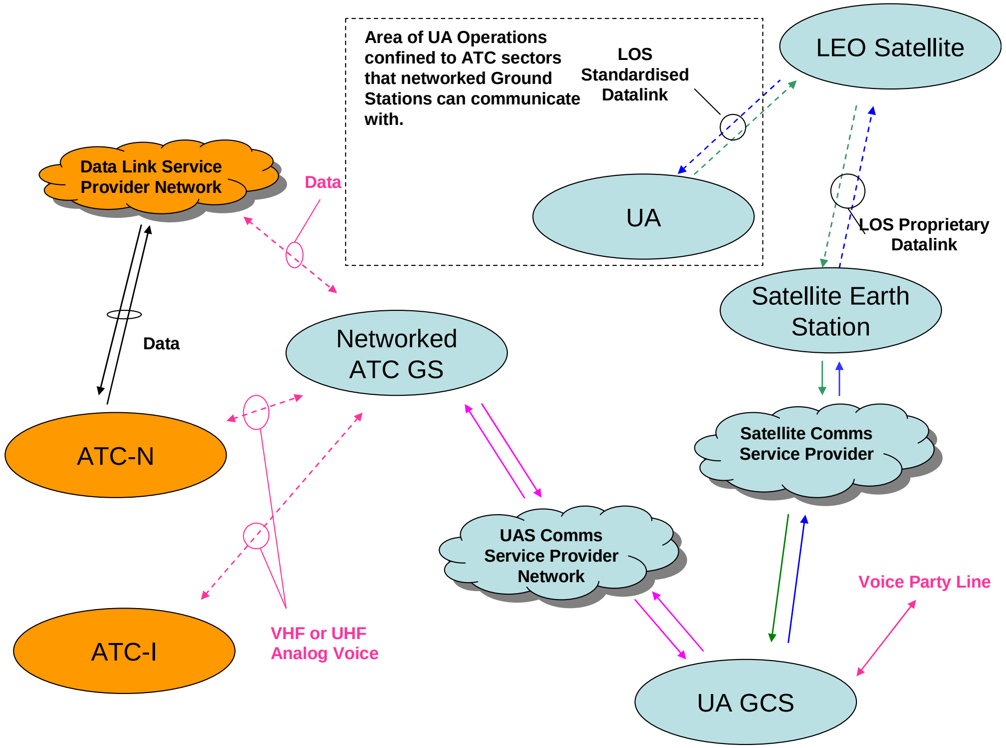
Power and control systems
P_{ATC}

CSP (network management centre) M L D
P_{ATC}

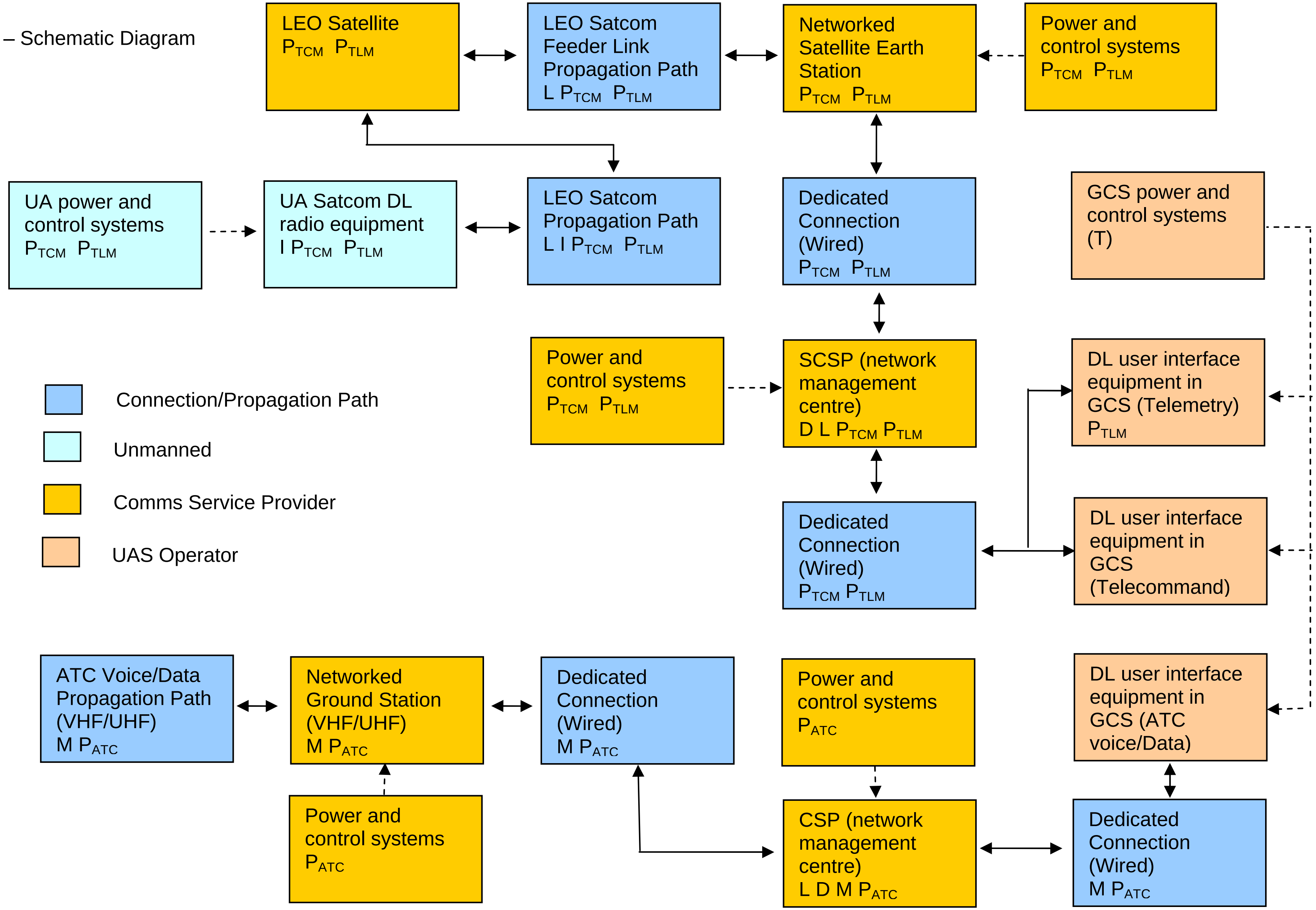
Dedicated Connection (Wired)
M P_{ATC}

A.4.4 NR4 – ATC Voice/Data Communications via Networked Ground-based ATC Radio, TLM & TLC via Low Earth Orbit Satellite Datalink (NNGR-LSD)

NR4 – Functional Diagram



NR4 – Schematic Diagram



LEO Satellite
P_{TCM} P_{TLM}

LEO Satcom Feeder Link Propagation Path
L P_{TCM} P_{TLM}

Networked Satellite Earth Station
P_{TCM} P_{TLM}

Power and control systems
P_{TCM} P_{TLM}

UA power and control systems
P_{TCM} P_{TLM}

UA Satcom DL radio equipment
I P_{TCM} P_{TLM}

LEO Satcom Propagation Path
L I P_{TCM} P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

GCS power and control systems (T)

Power and control systems
P_{TCM} P_{TLM}

SCSP (network management centre)
D L P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telemetry)
P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telecommand)

ATC Voice/Data Propagation Path (VHF/UHF)
M P_{ATC}

Networked Ground Station (VHF/UHF)
M P_{ATC}

Dedicated Connection (Wired)
M P_{ATC}

Power and control systems
P_{ATC}

DL user interface equipment in GCS (ATC voice/Data)

Power and control systems
P_{ATC}

CSP (network management centre)
L D M P_{ATC}

Dedicated Connection (Wired)
M P_{ATC}

🟦 Connection/Propagation Path

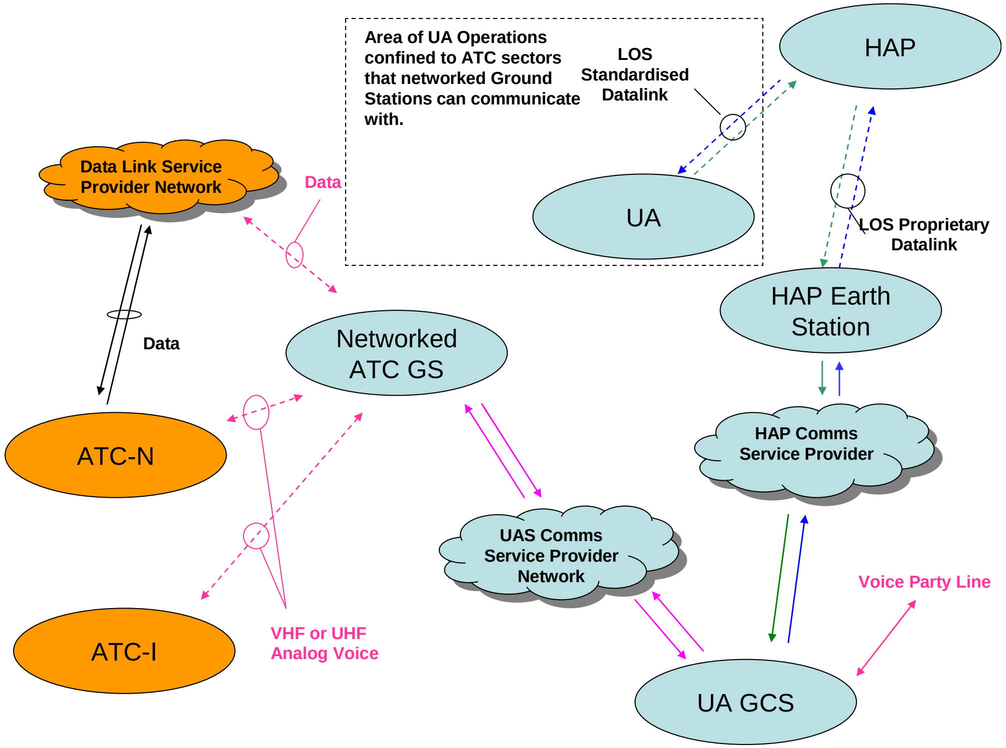
⬜ Unmanned

🟨 Comms Service Provider

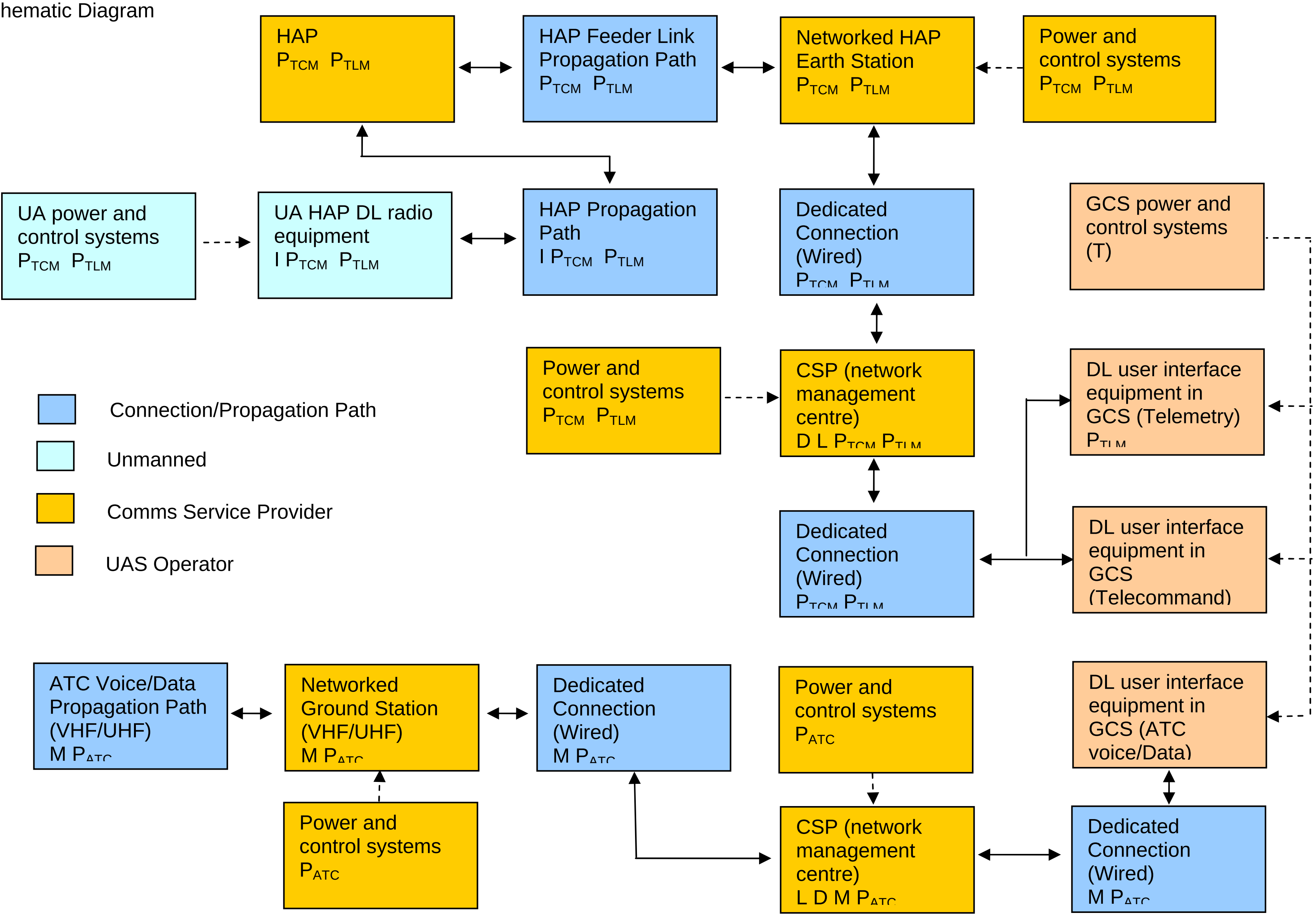
🟧 UAS Operator

A.4.5 NR5 – ATC Voice/Data Communications via Networked Ground-based ATC Radio, TLM & TLC via Low Earth Orbit Satellite Datalink (NNGR-LSD)

NR5 – Functional Diagram



NR5 – Schematic Diagram



HAP
P_{TCM} P_{TLM}

HAP Feeder Link Propagation Path
P_{TCM} P_{TLM}

Networked HAP Earth Station
P_{TCM} P_{TLM}

Power and control systems
P_{TCM} P_{TLM}

UA power and control systems
P_{TCM} P_{TLM}

UA HAP DL radio equipment
I P_{TCM} P_{TLM}

HAP Propagation Path
I P_{TCM} P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

GCS power and control systems (T)

Power and control systems
P_{TCM} P_{TLM}

CSP (network management centre)
D L P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telemetry)
P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telecommand)

ATC Voice/Data Propagation Path (VHF/UHF)
M P_{ATC}

Networked Ground Station (VHF/UHF)
M P_{ATC}

Dedicated Connection (Wired)
M P_{ATC}

Power and control systems
P_{ATC}

DL user interface equipment in GCS (ATC voice/Data)

Power and control systems
P_{ATC}

CSP (network management centre)
L D M P_{ATC}

Dedicated Connection (Wired)
M P_{ATC}

🟦 Connection/Propagation Path

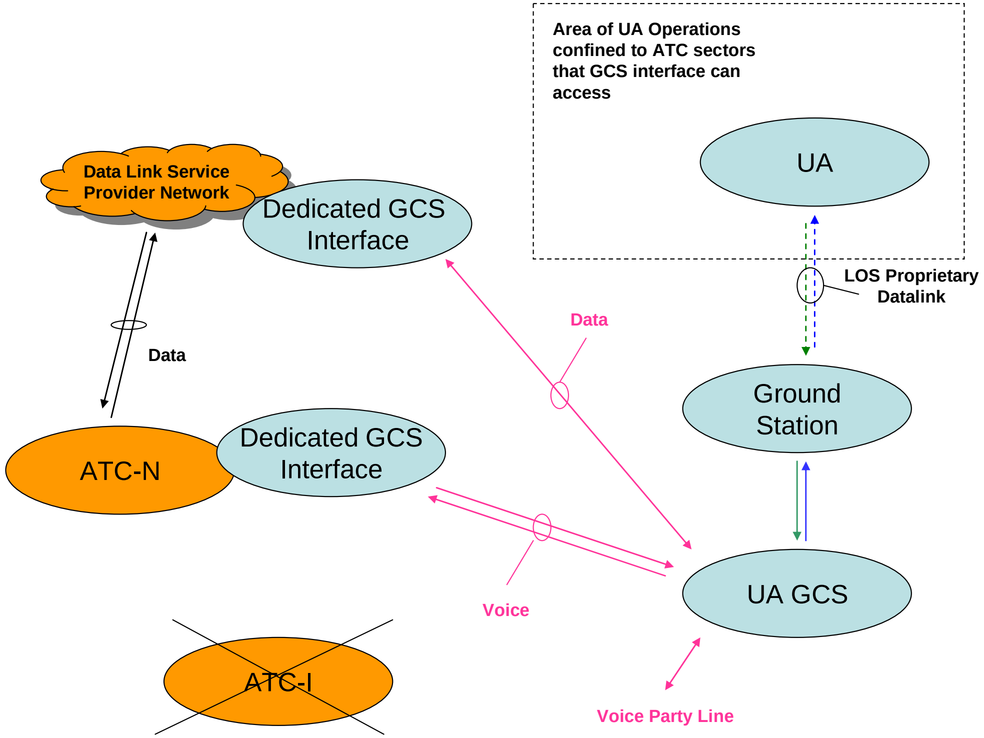
⬜ Unmanned

🟨 Comms Service Provider

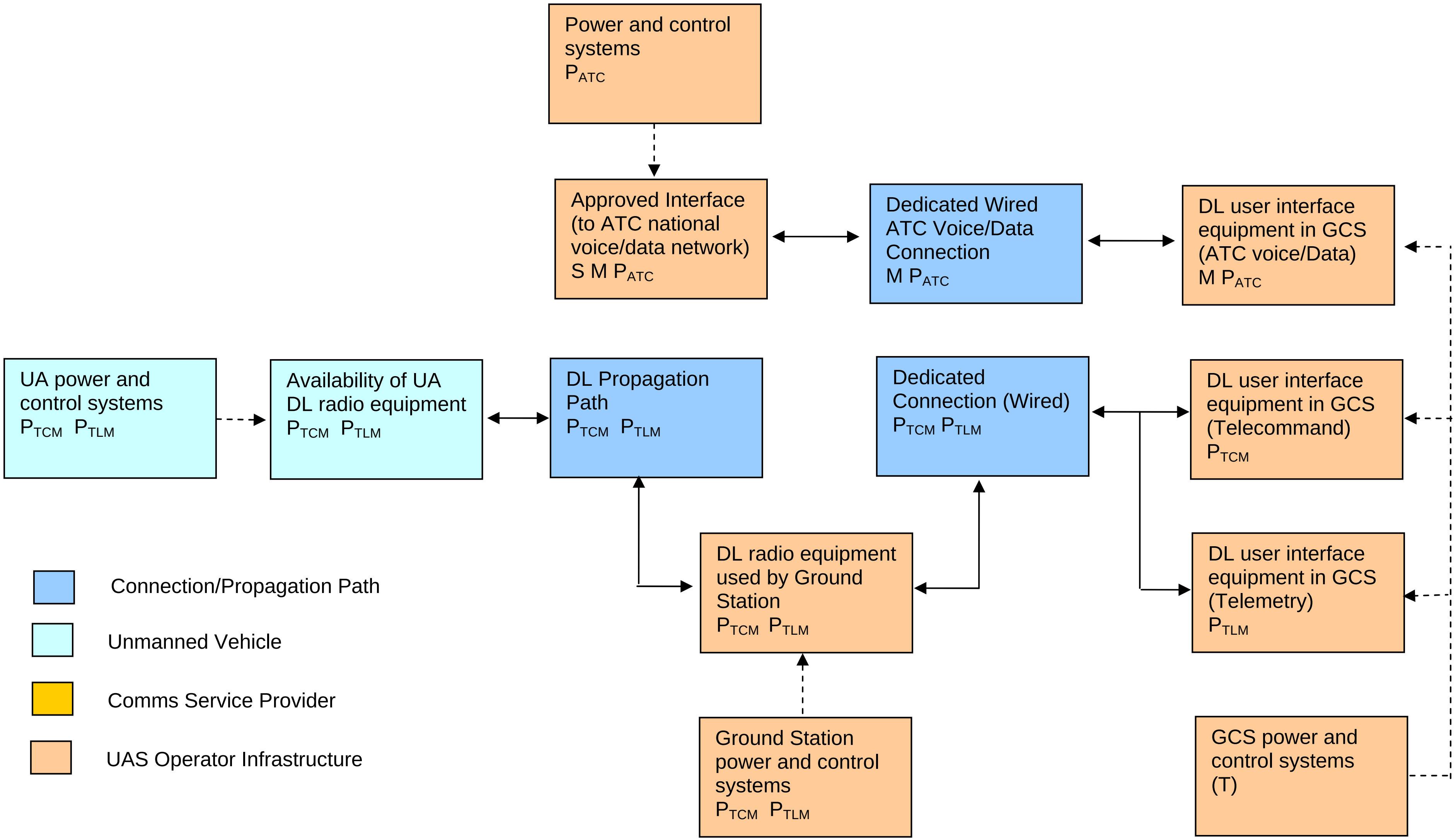
🟧 UAS Operator

A.4.6 NR6 – ATC Voice/Data Communications via Dedicated Wired Interface, TLM & TLC via Dedicated Terrestrial Datalink (NDW-DTD)

NR6 – Functional Diagram



NR6 – Schematic Diagram



Power and control systems P_{ATC}

Approved Interface (to ATC national voice/data network) S M P_{ATC}

Dedicated Wired ATC Voice/Data Connection M P_{ATC}

DL user interface equipment in GCS (ATC voice/Data) M P_{ATC}

UA power and control systems P_{TCM} P_{TLM}

Availability of UA DL radio equipment P_{TCM} P_{TLM}

DL Propagation Path P_{TCM} P_{TLM}

Dedicated Connection (Wired) P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telecommand) P_{TCM}

DL radio equipment used by Ground Station P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telemetry) P_{TLM}

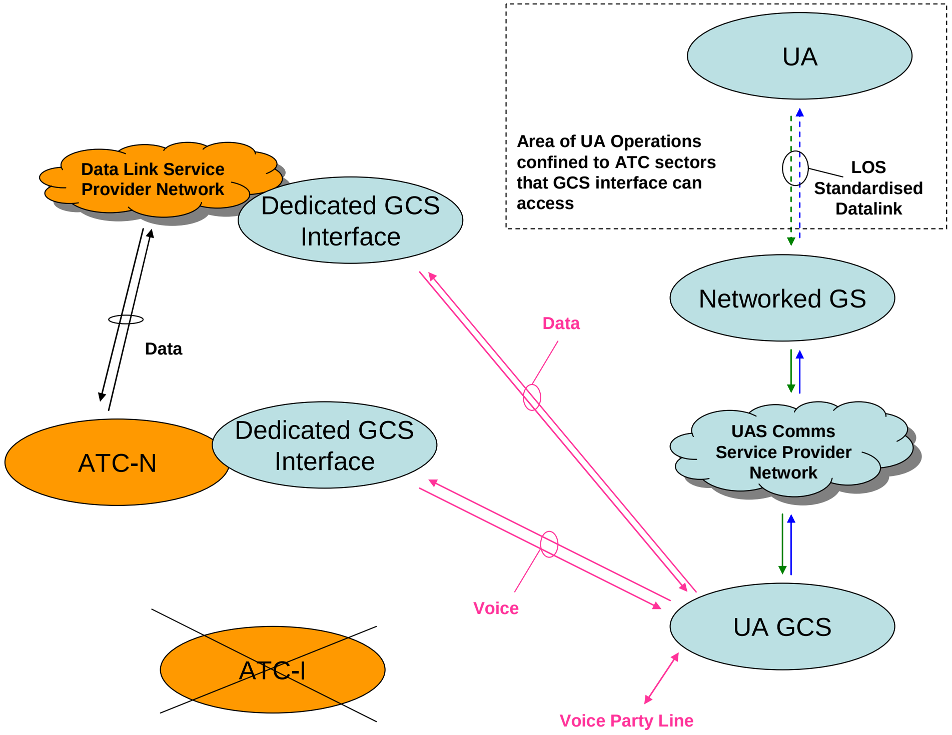
Ground Station power and control systems P_{TCM} P_{TLM}

GCS power and control systems (T)

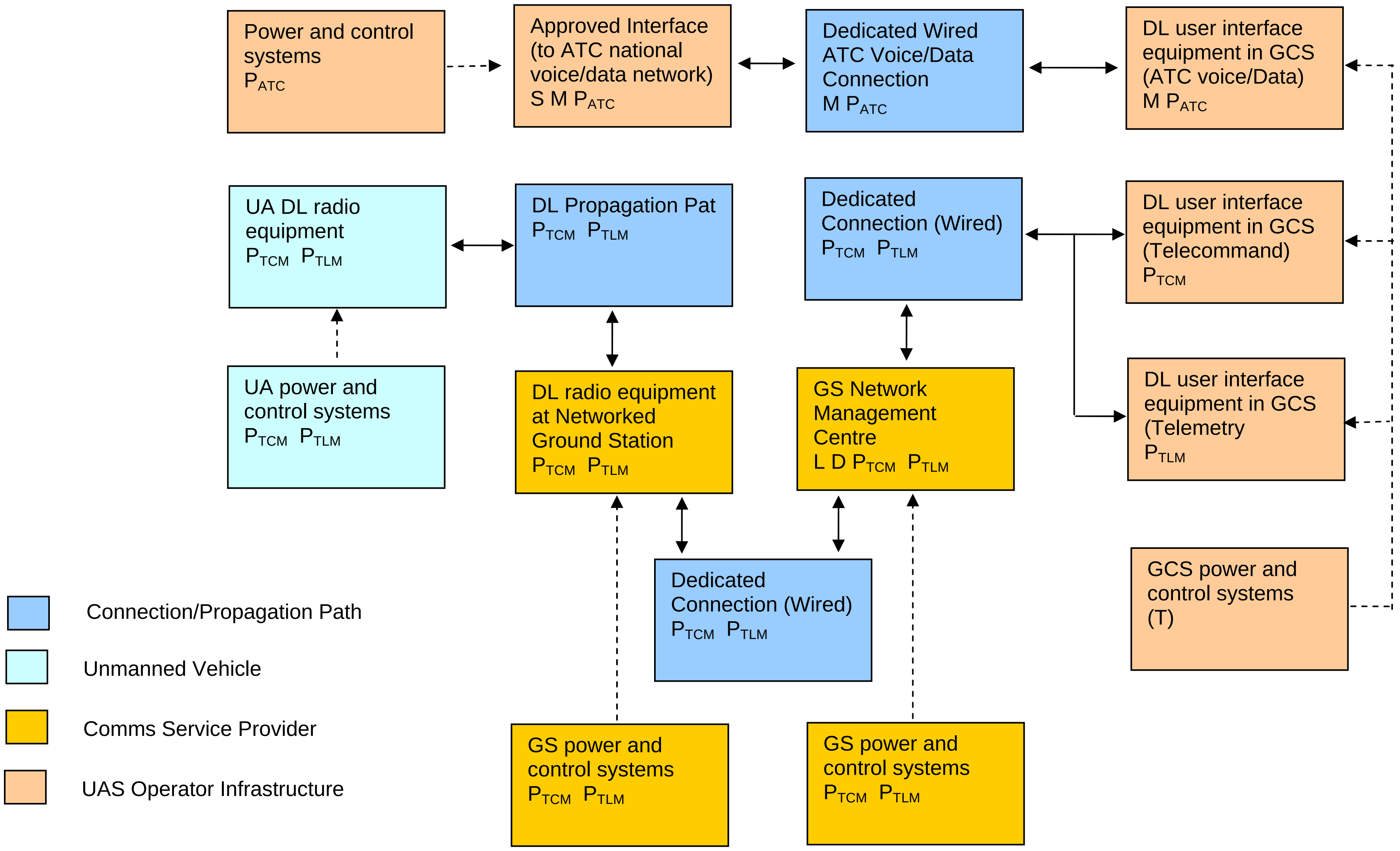
- 🟦 Connection/Propagation Path
- ▢ Unmanned Vehicle
- 🟨 Comms Service Provider
- 🟧 UAS Operator Infrastructure

A.4.7 NR7 – ATC Voice/Data Communications via Dedicated Wired Interface, TLM & TLC via Networked Terrestrial Datalink (NDW-NTD)

NR7 – Functional Diagram



NR7 – Schematic Diagram



Power and control systems P_{ATC}

Approved Interface (to ATC national voice/data network) S M P_{ATC}

Dedicated Wired ATC Voice/Data Connection M P_{ATC}

DL user interface equipment in GCS (ATC voice/Data) M P_{ATC}

UA DL radio equipment P_{TCM} P_{TLM}

DL Propagation Pat P_{TCM} P_{TLM}

Dedicated Connection (Wired) P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telecommand) P_{TCM}

UA power and control systems P_{TCM} P_{TLM}

DL radio equipment at Networked Ground Station P_{TCM} P_{TLM}

GS Network Management Centre L D P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telemetry P_{TLM}

Dedicated Connection (Wired) P_{TCM} P_{TLM}

GCS power and control systems (T)

GS power and control systems P_{TCM} P_{TLM}

GS power and control systems P_{TCM} P_{TLM}

🟦 Connection/Propagation Path

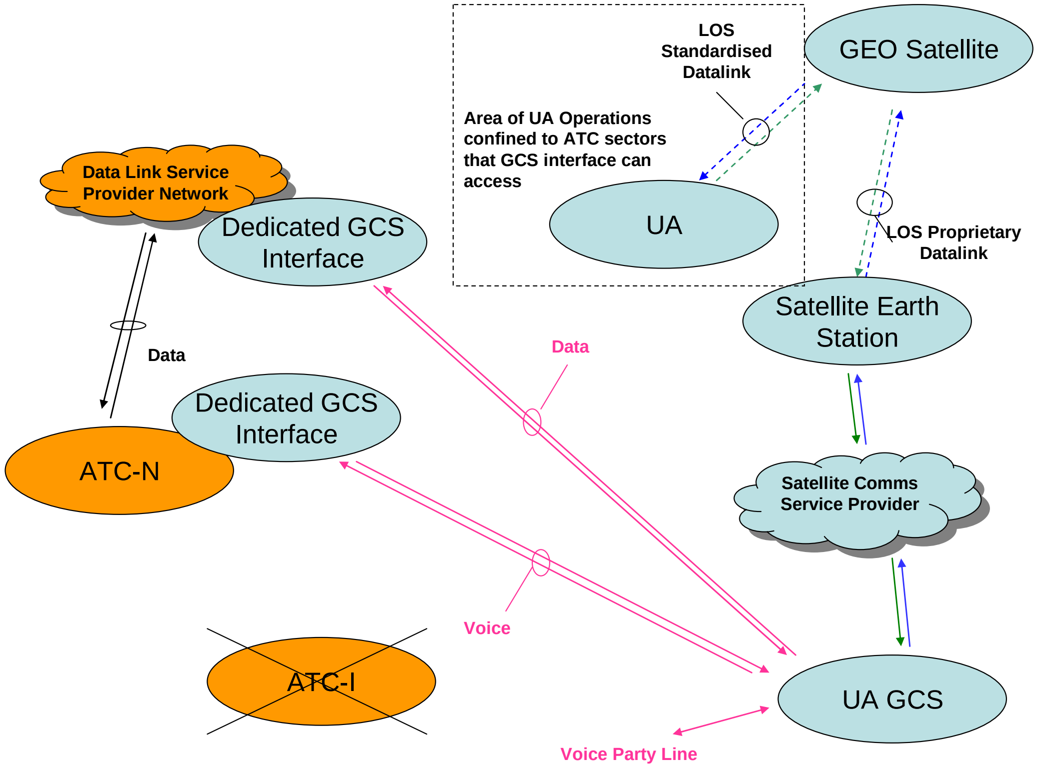
⬜ Unmanned Vehicle

🟨 Comms Service Provider

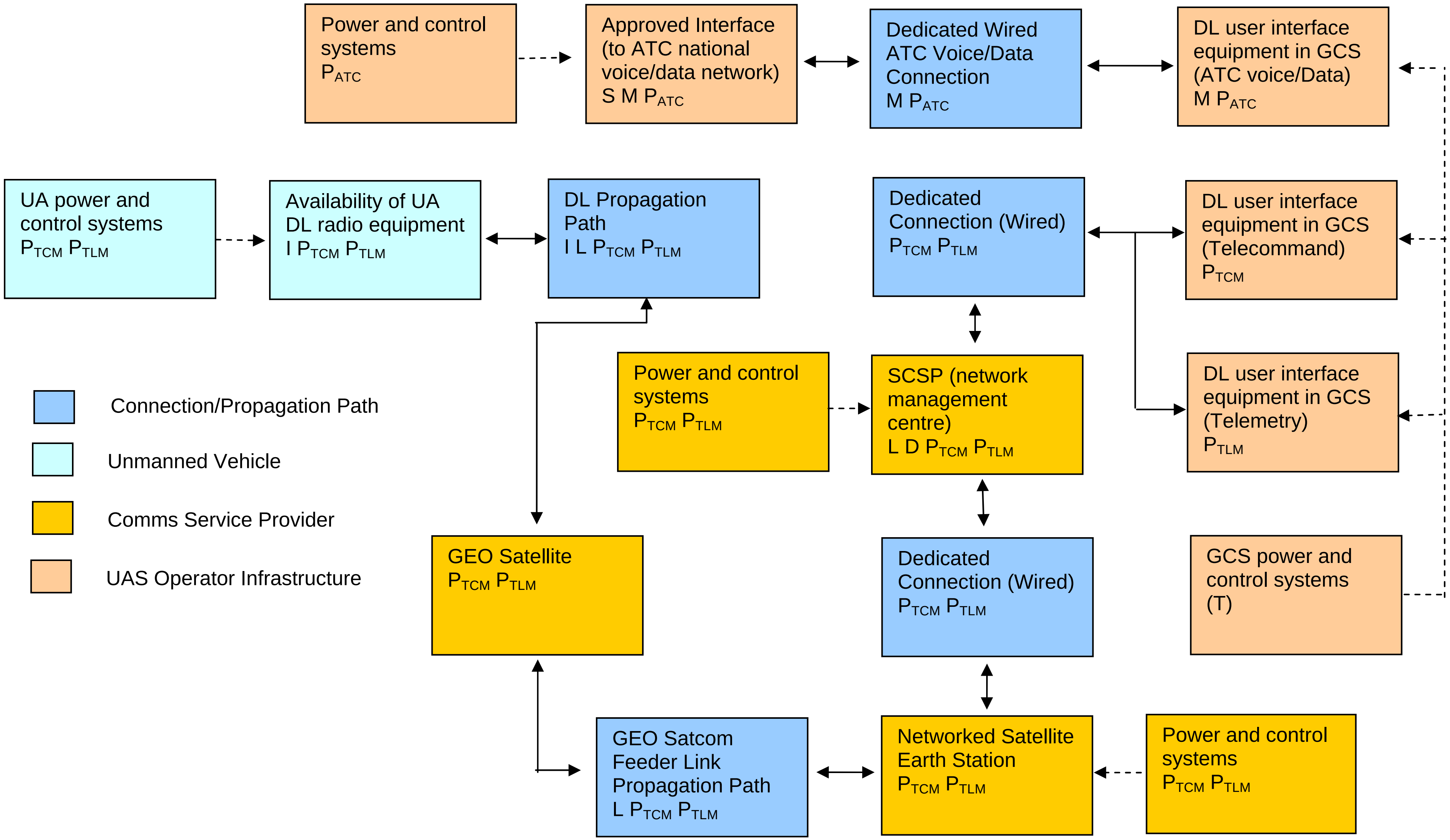
🟧 UAS Operator Infrastructure

A.4.8 NR8 – ATC Voice/Data Communications via Dedicated Wired Interface, TLM & TLC via Geostationary Satellite Datalink (NDW-GSD)

NR8 – Functional Diagram



NR8 – Schematic Diagram



Power and control systems
P_{ATC}

Approved Interface (to ATC national voice/data network)
S M P_{ATC}

Dedicated Wired ATC Voice/Data Connection
M P_{ATC}

DL user interface equipment in GCS (ATC voice/Data)
M P_{ATC}

UA power and control systems
P_{TCM} P_{TLM}

Availability of UA DL radio equipment
I P_{TCM} P_{TLM}

DL Propagation Path
I L P_{TCM} P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telecommand)
P_{TCM}

Power and control systems
P_{TCM} P_{TLM}

SCSP (network management centre)
L D P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telemetry)
P_{TLM}

GEO Satellite
P_{TCM} P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

GCS power and control systems
(T)

GEO Satcom Feeder Link Propagation Path
L P_{TCM} P_{TLM}

Networked Satellite Earth Station
P_{TCM} P_{TLM}

Power and control systems
P_{TCM} P_{TLM}

🟦 Connection/Propagation Path

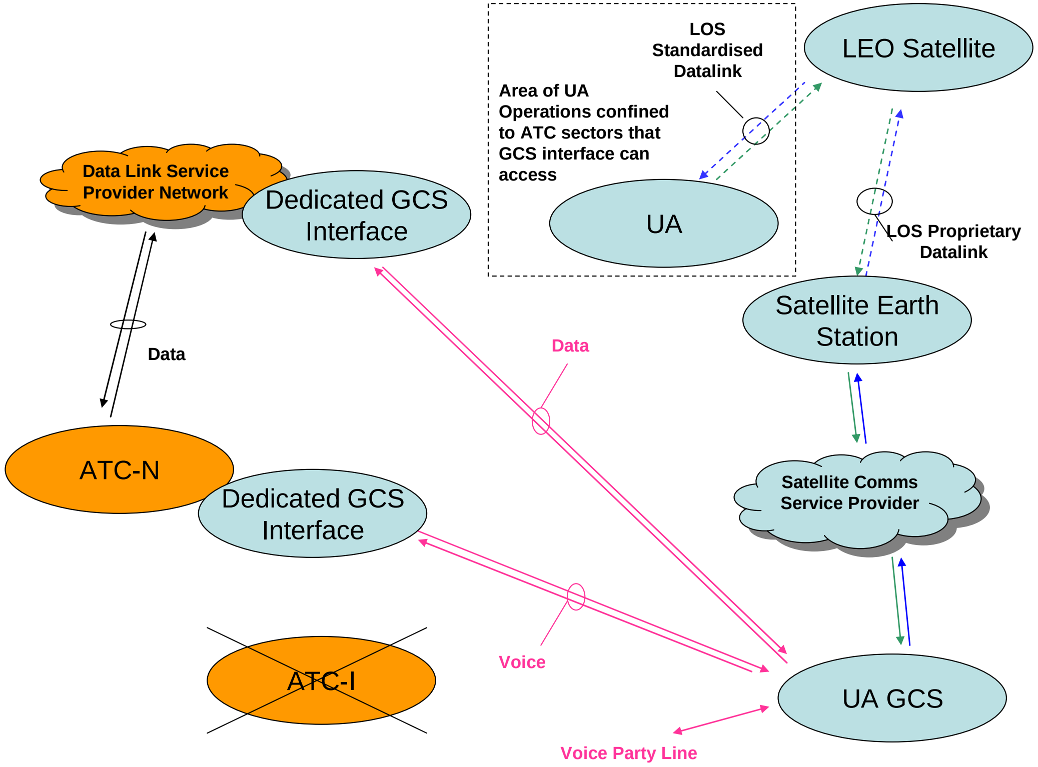
⬜ Unmanned Vehicle

🟨 Comms Service Provider

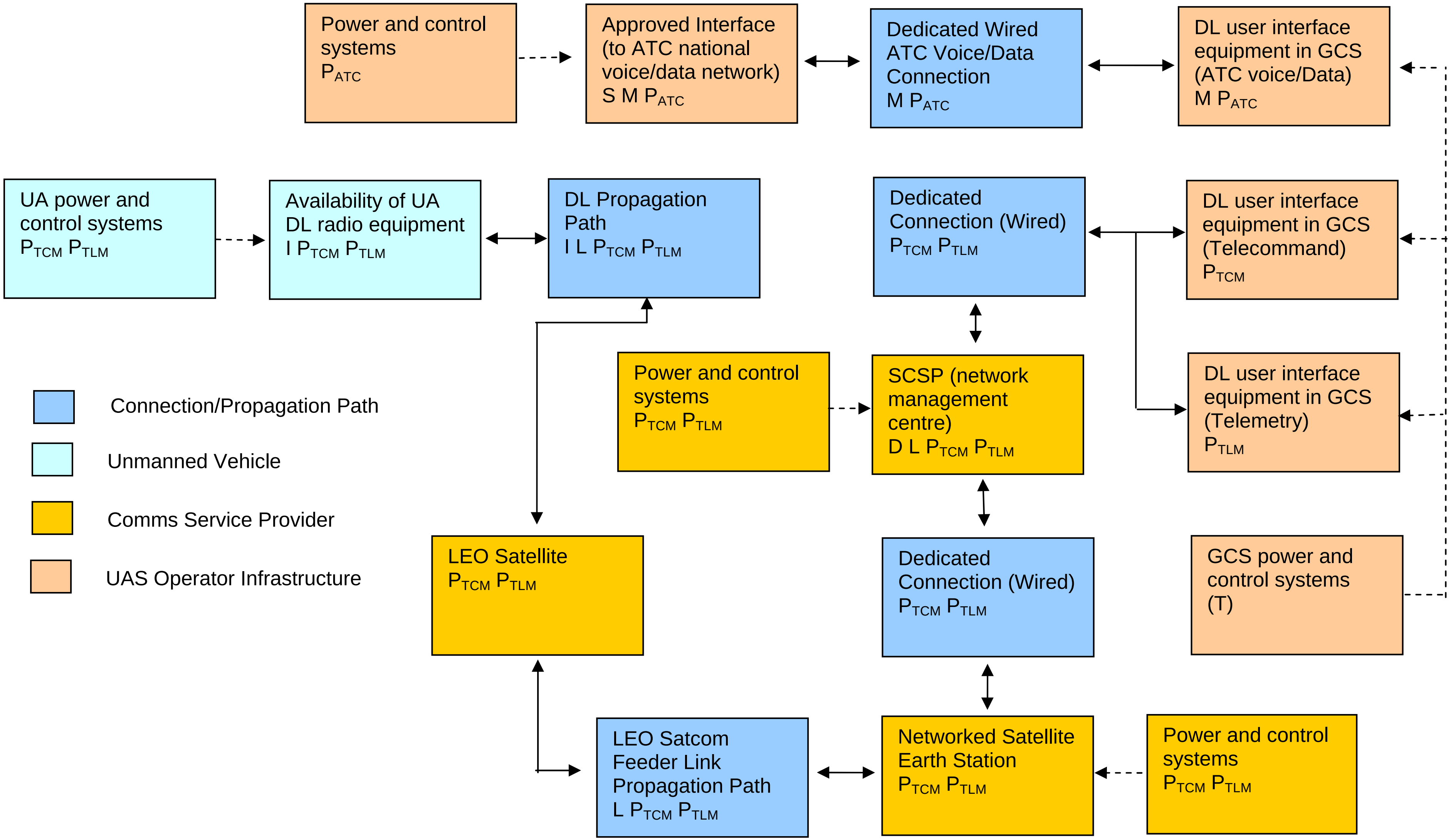
🟧 UAS Operator Infrastructure

A.4.9 NR9 – ATC Voice/Data Communications via Dedicated Wired Interface, TLM & TLC via Low Earth Orbit Satellite Datalink (NDW-LSD)

NR9 – Functional Diagram



NR9 – Schematic Diagram



Power and control systems P_{ATC}

Approved Interface (to ATC national voice/data network) S M P_{ATC}

Dedicated Wired ATC Voice/Data Connection M P_{ATC}

DL user interface equipment in GCS (ATC voice/Data) M P_{ATC}

UA power and control systems P_{TCM} P_{TLM}

Availability of UA DL radio equipment I P_{TCM} P_{TLM}

DL Propagation Path I L P_{TCM} P_{TLM}

Dedicated Connection (Wired) P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telecommand) P_{TCM}

Power and control systems P_{TCM} P_{TLM}

SCSP (network management centre) D L P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telemetry) P_{TLM}

LEO Satellite P_{TCM} P_{TLM}

Dedicated Connection (Wired) P_{TCM} P_{TLM}

GCS power and control systems (T)

LEO Satcom Feeder Link Propagation Path L P_{TCM} P_{TLM}

Networked Satellite Earth Station P_{TCM} P_{TLM}

Power and control systems P_{TCM} P_{TLM}

🟦 Connection/Propagation Path

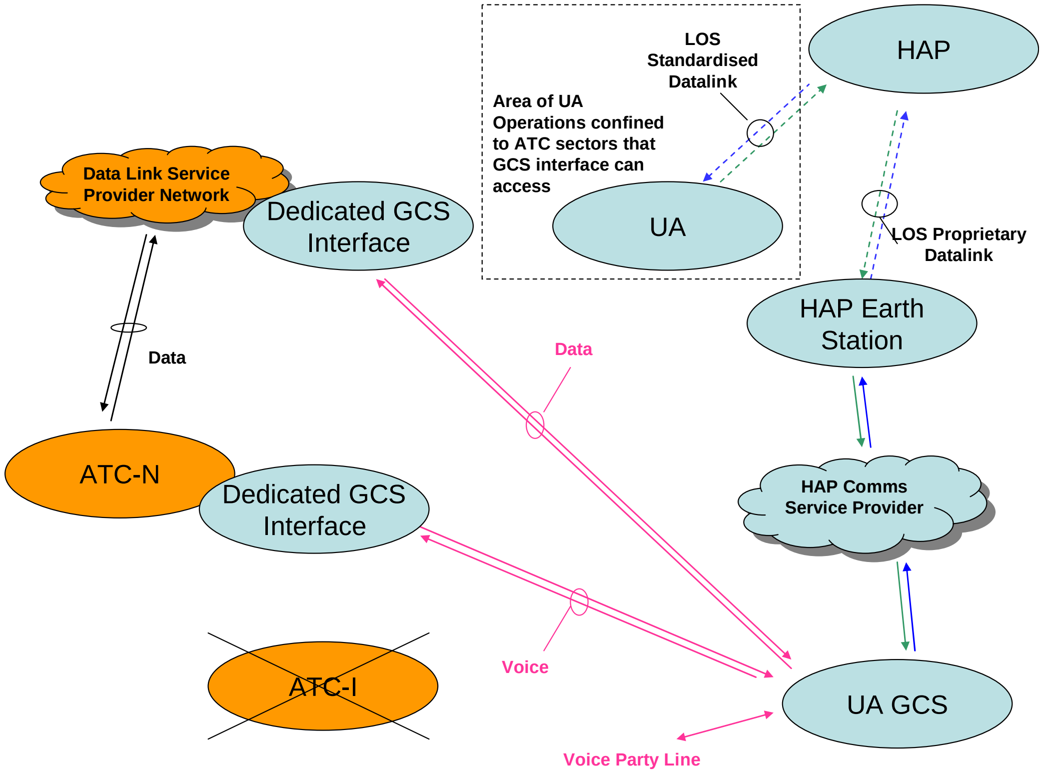
◻ Unmanned Vehicle

🟨 Comms Service Provider

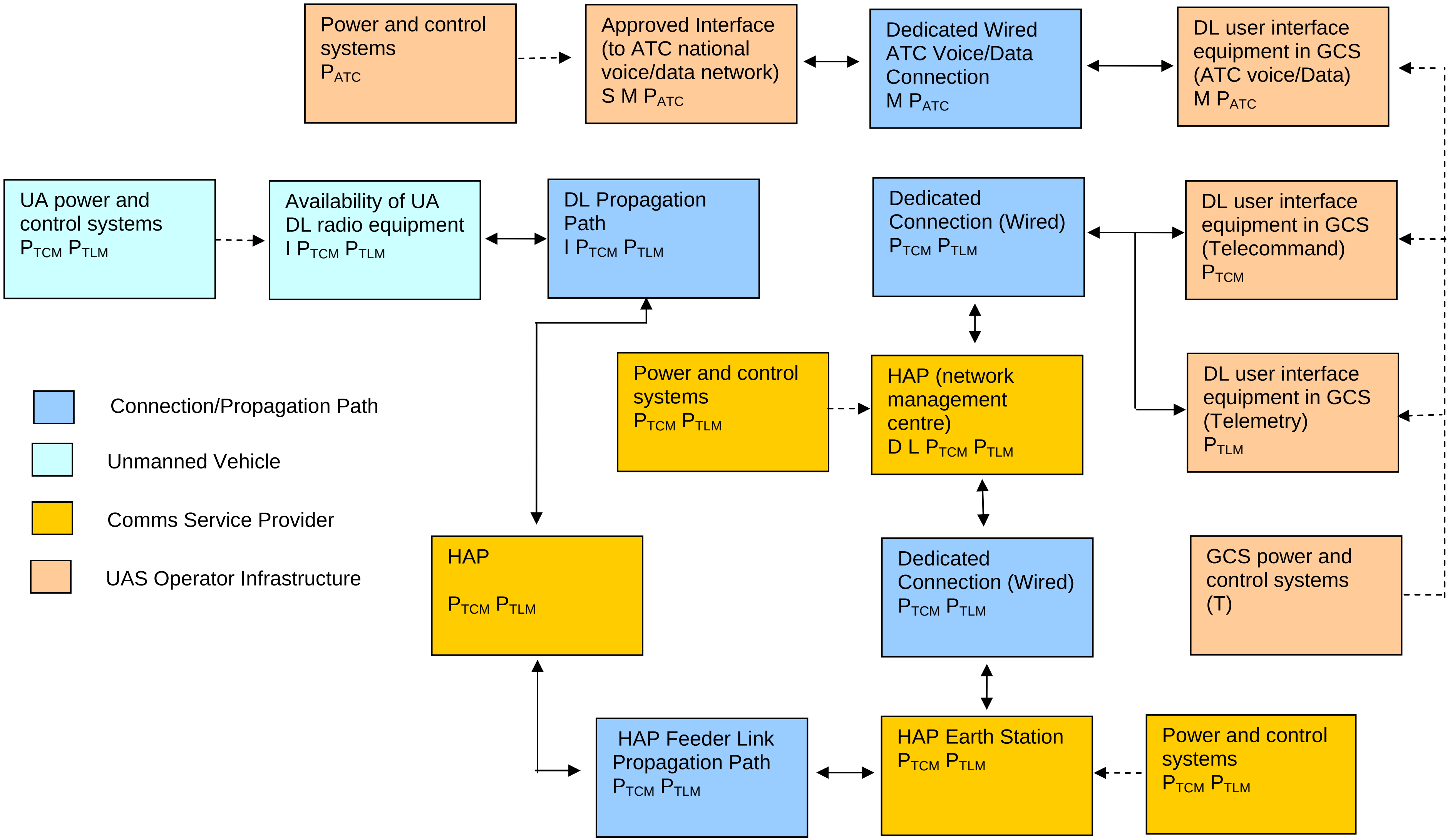
🟧 UAS Operator Infrastructure

A.4.10 NR10 – ATC Voice/Data Communications via Dedicated Wired Interface, TLM & TLC via High Altitude Platform Datalink (NDW-HD)

NR10 – Functional Diagram

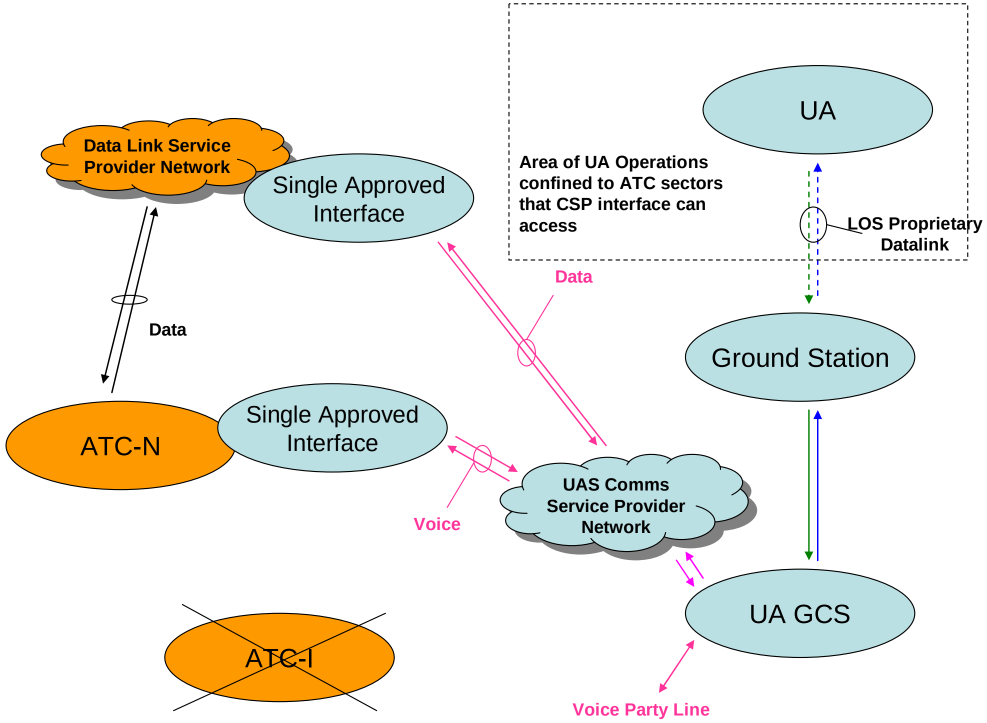


NR10 – Schematic Diagram

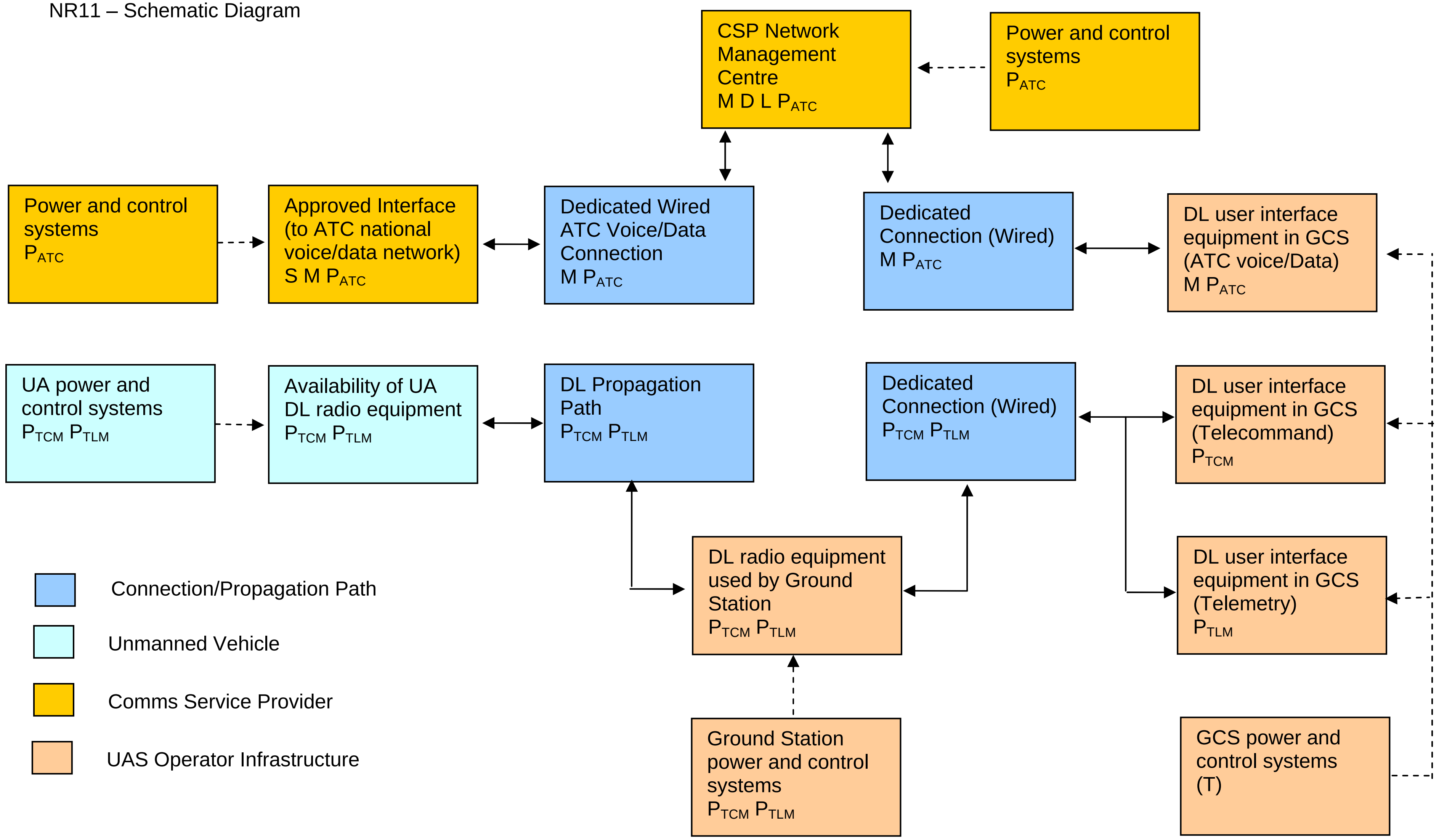


A.4.11 NR11 – ATC Voice/Data Communications via Networked Wired Interface, TLM & TLC via Dedicated Terrestrial Datalink (NNW-DTD)

NR11 – Functional Diagram

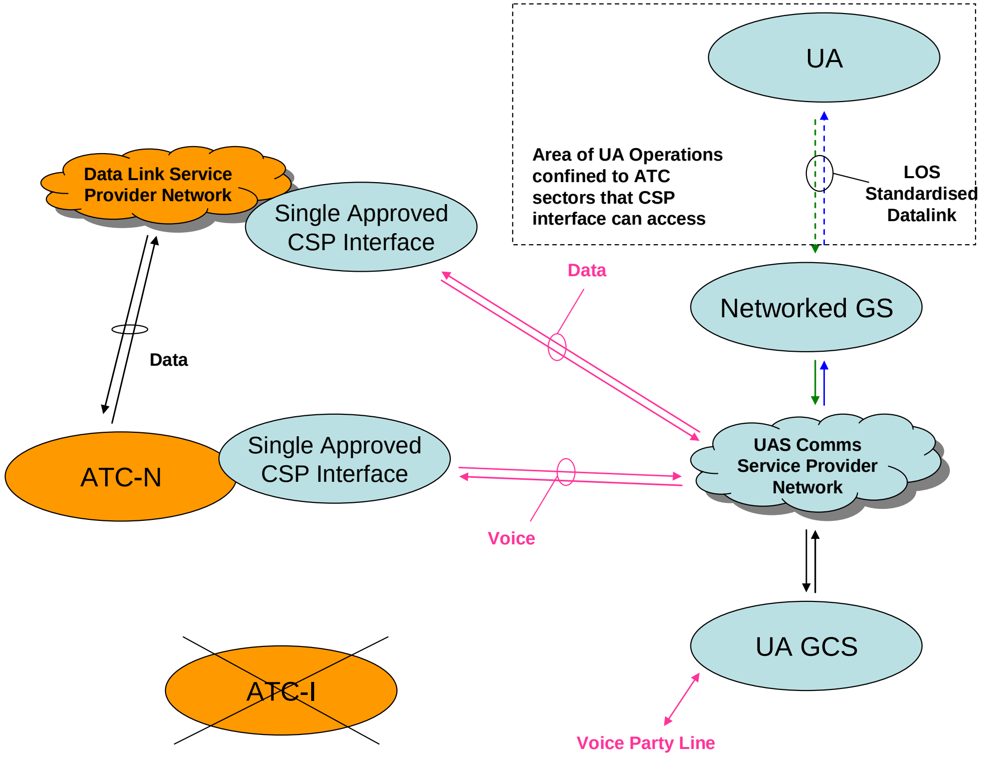


NR11 – Schematic Diagram

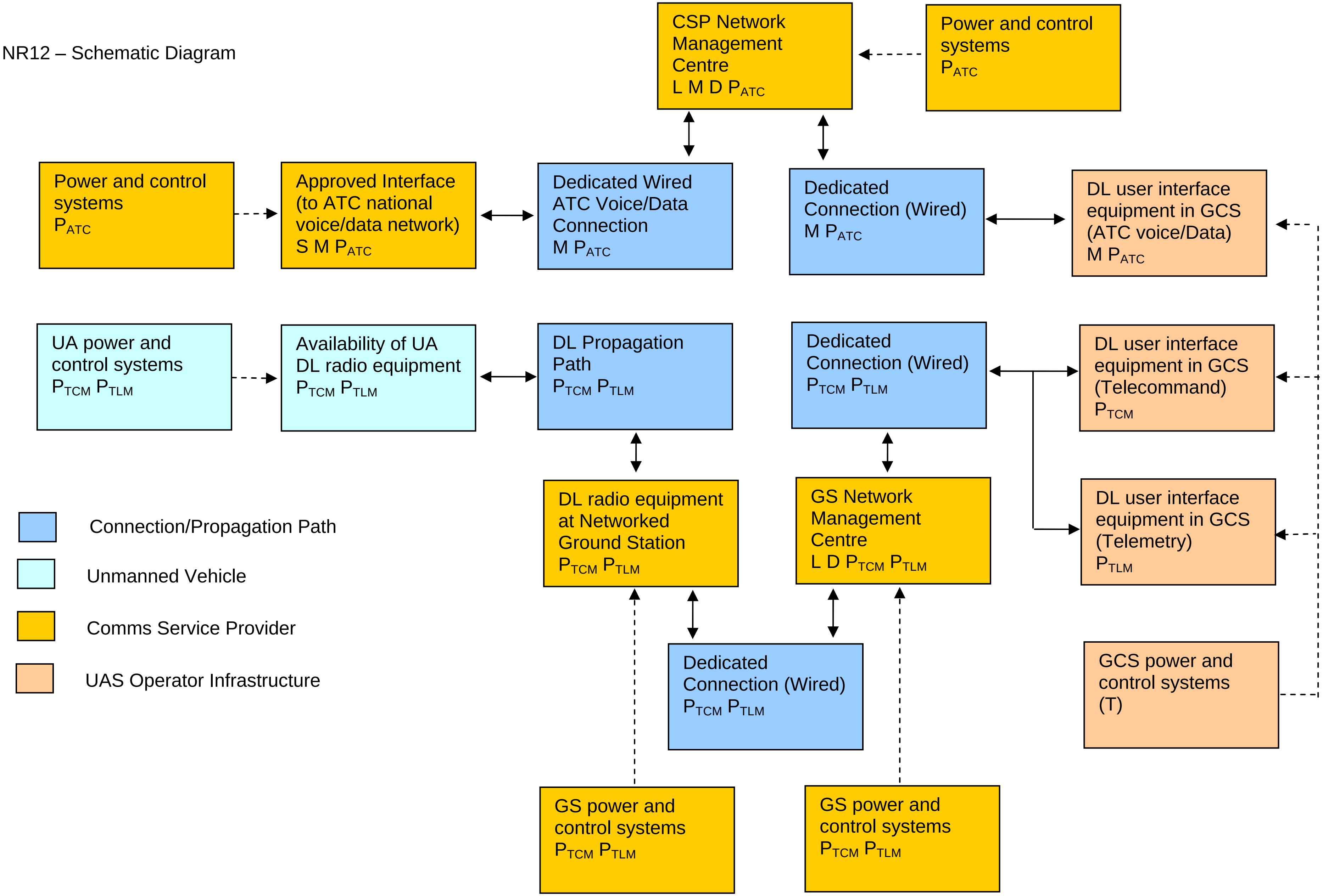


A.4.12 NR12 – ATC Voice/Data Communications via Networked Wired Interface, TLM & TLC via Networked Terrestrial Datalink (NNW-NTD)

NR12 – Functional Diagram



NR12 – Schematic Diagram



CSP Network Management Centre
L M D P_{ATC}

Power and control systems
P_{ATC}

Power and control systems
P_{ATC}

Approved Interface (to ATC national voice/data network)
S M P_{ATC}

Dedicated Wired ATC Voice/Data Connection
M P_{ATC}

Dedicated Connection (Wired)
M P_{ATC}

DL user interface equipment in GCS (ATC voice/Data)
M P_{ATC}

UA power and control systems
P_{TCM} P_{TLM}

Availability of UA DL radio equipment
P_{TCM} P_{TLM}

DL Propagation Path
P_{TCM} P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telecommand)
P_{TCM}

DL radio equipment at Networked Ground Station
P_{TCM} P_{TLM}

GS Network Management Centre
L D P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telemetry)
P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

GCS power and control systems
(T)

GS power and control systems
P_{TCM} P_{TLM}

GS power and control systems
P_{TCM} P_{TLM}

🟦 Connection/Propagation Path

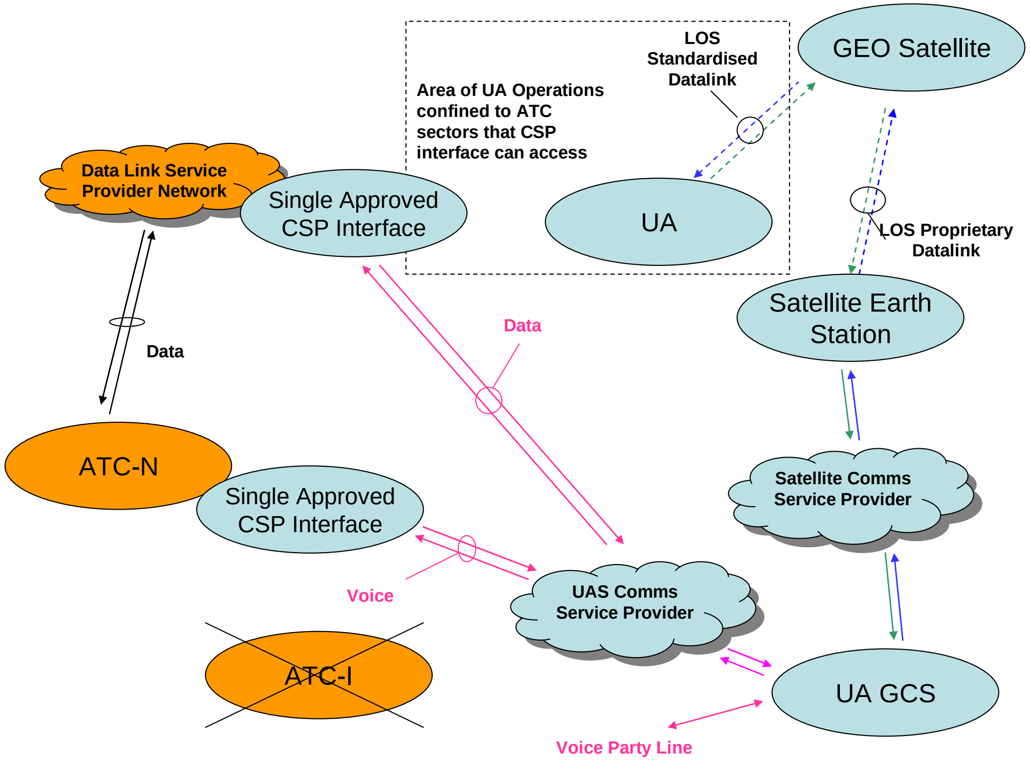
⬜ Unmanned Vehicle

🟨 Comms Service Provider

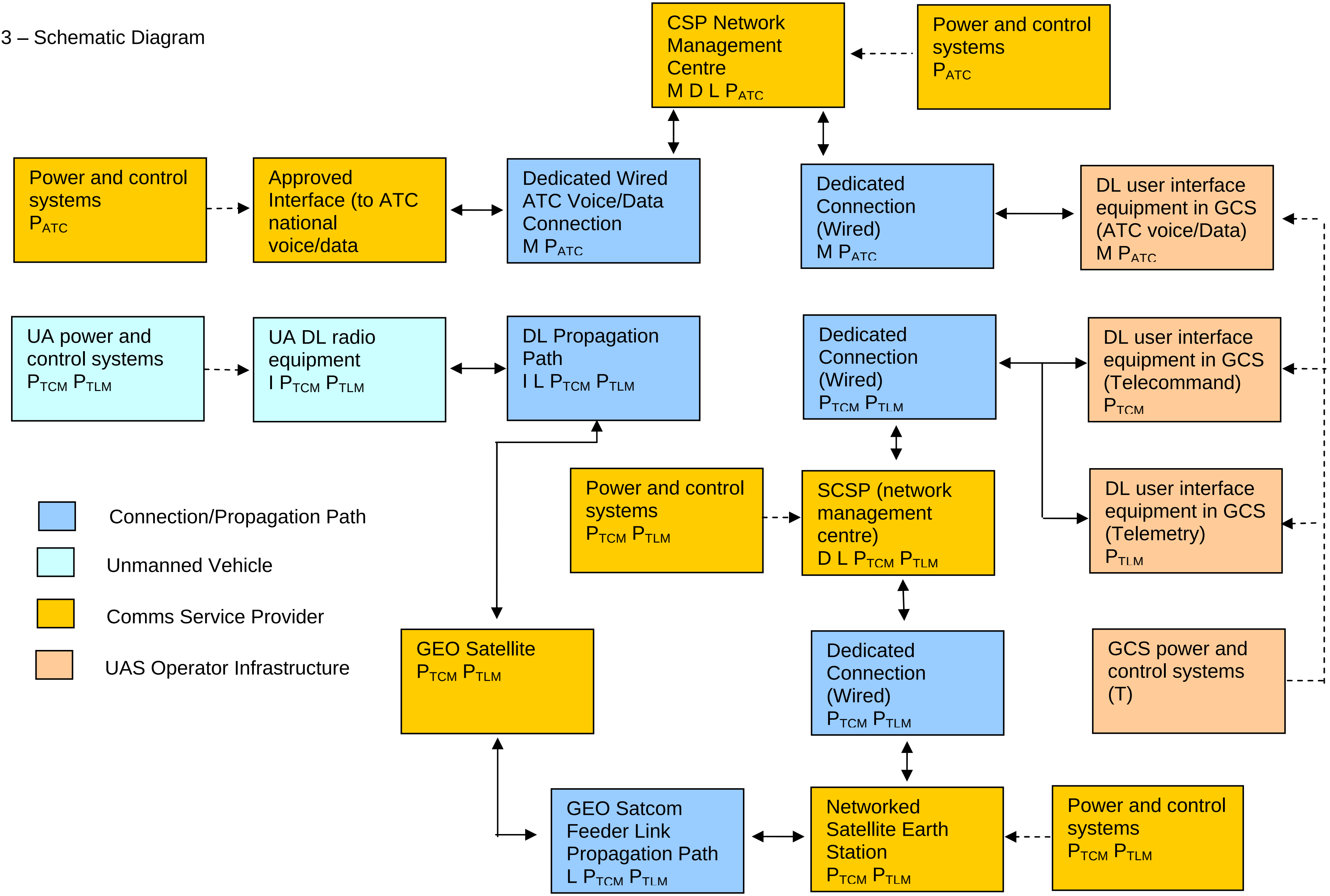
🟧 UAS Operator Infrastructure

A.4.13 NR13 – ATC Voice/Data Communications via Networked Wired Interface, TLM & TLC via Geostationary Satellite Datalink (NNW-GSD)

NR13 – Functional Diagram



NR13 – Schematic Diagram



CSP Network Management Centre
M D L P_{ATC}

Power and control systems
P_{ATC}

Power and control systems
P_{ATC}

Approved Interface (to ATC national voice/data

Dedicated Wired ATC Voice/Data Connection
M P_{ATC}

Dedicated Connection (Wired)
M P_{ATC}

DL user interface equipment in GCS (ATC voice/Data)
M P_{ATC}

UA power and control systems
P_{TCM} P_{TLM}

UA DL radio equipment
I P_{TCM} P_{TLM}

DL Propagation Path
I L P_{TCM} P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telecommand)
P_{TCM}

Power and control systems
P_{TCM} P_{TLM}

SCSP (network management centre)
D L P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telemetry)
P_{TLM}

GEO Satellite
P_{TCM} P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

GCS power and control systems (T)

GEO Satcom Feeder Link Propagation Path
L P_{TCM} P_{TLM}

Networked Satellite Earth Station
P_{TCM} P_{TLM}

Power and control systems
P_{TCM} P_{TLM}

🟦 Connection/Propagation Path

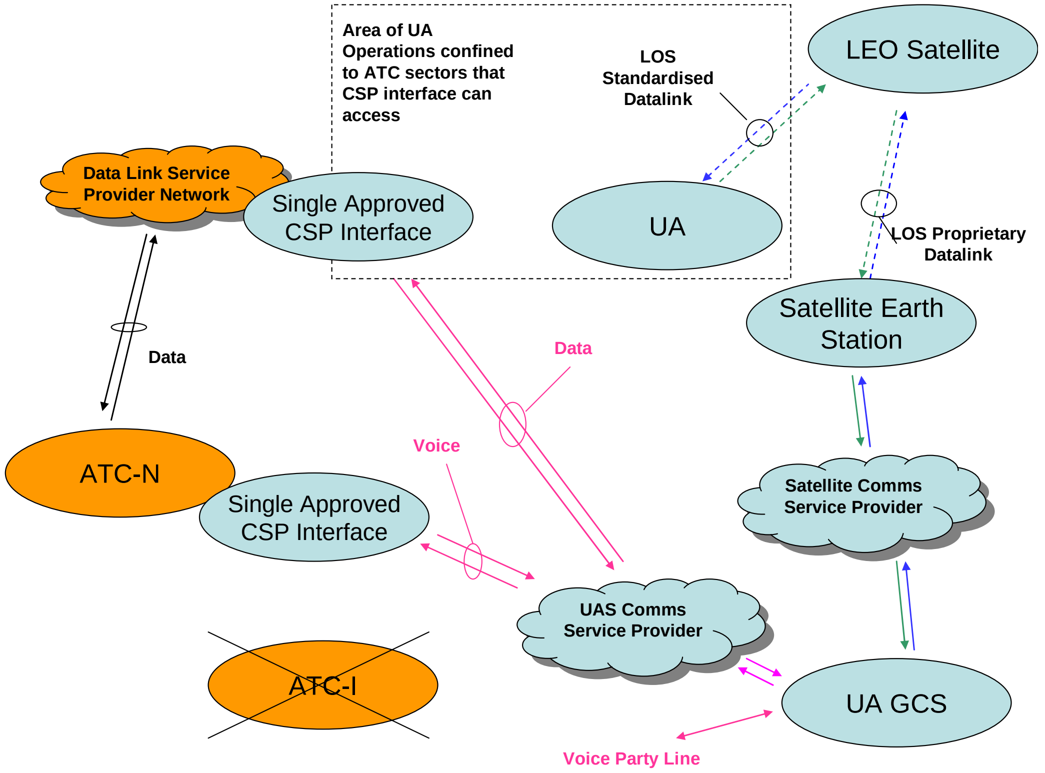
⬜ Unmanned Vehicle

🟨 Comms Service Provider

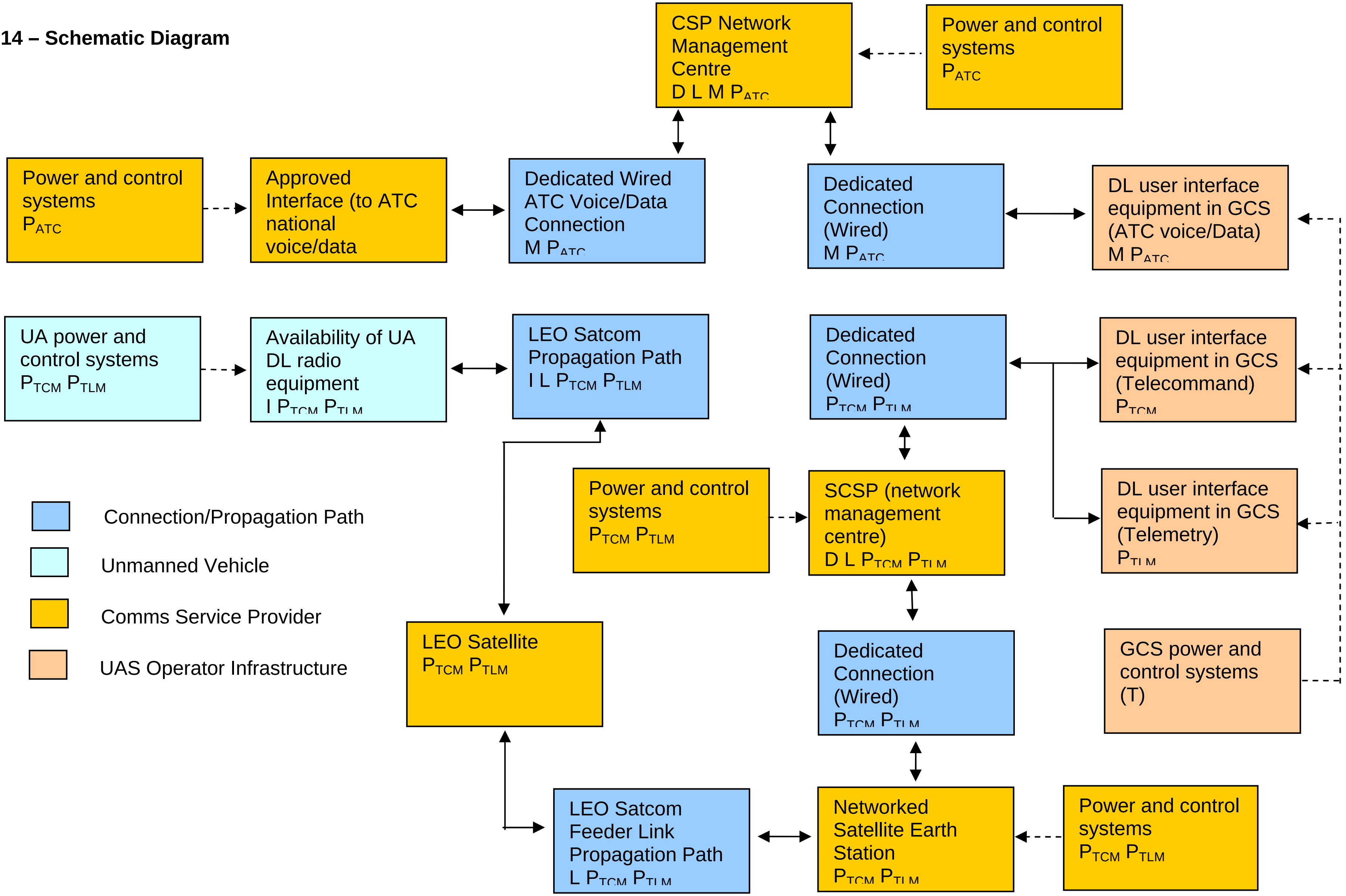
🟧 UAS Operator Infrastructure

A.4.14 NR14 – ATC Voice/Data Communications via Networked Wired Interface, TLM & TLC via Low Earth Orbit Satellite Datalink (NNW-LSD)

NR14 – Functional Diagram



NR14 – Schematic Diagram



CSP Network Management Centre
D L M P_{ATC}

Power and control systems
P_{ATC}

Power and control systems
P_{ATC}

Approved Interface (to ATC national voice/data

Dedicated Wired ATC Voice/Data Connection
M P_{ATC}

Dedicated Connection (Wired)
M P_{ATC}

DL user interface equipment in GCS (ATC voice/Data)
M P_{ATC}

UA power and control systems
P_{TCM} P_{TLM}

Availability of UA DL radio equipment
I P_{TCM} P_{TLM}

LEO Satcom Propagation Path
I L P_{TCM} P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telecommand)
P_{TCM}

Power and control systems
P_{TCM} P_{TLM}

SCSP (network management centre)
D L P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telemetry)
P_{TLM}

LEO Satellite
P_{TCM} P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

GCS power and control systems
(T)

LEO Satcom Feeder Link Propagation Path
L P_{TCM} P_{TLM}

Networked Satellite Earth Station
P_{TCM} P_{TLM}

Power and control systems
P_{TCM} P_{TLM}

🟦 Connection/Propagation Path

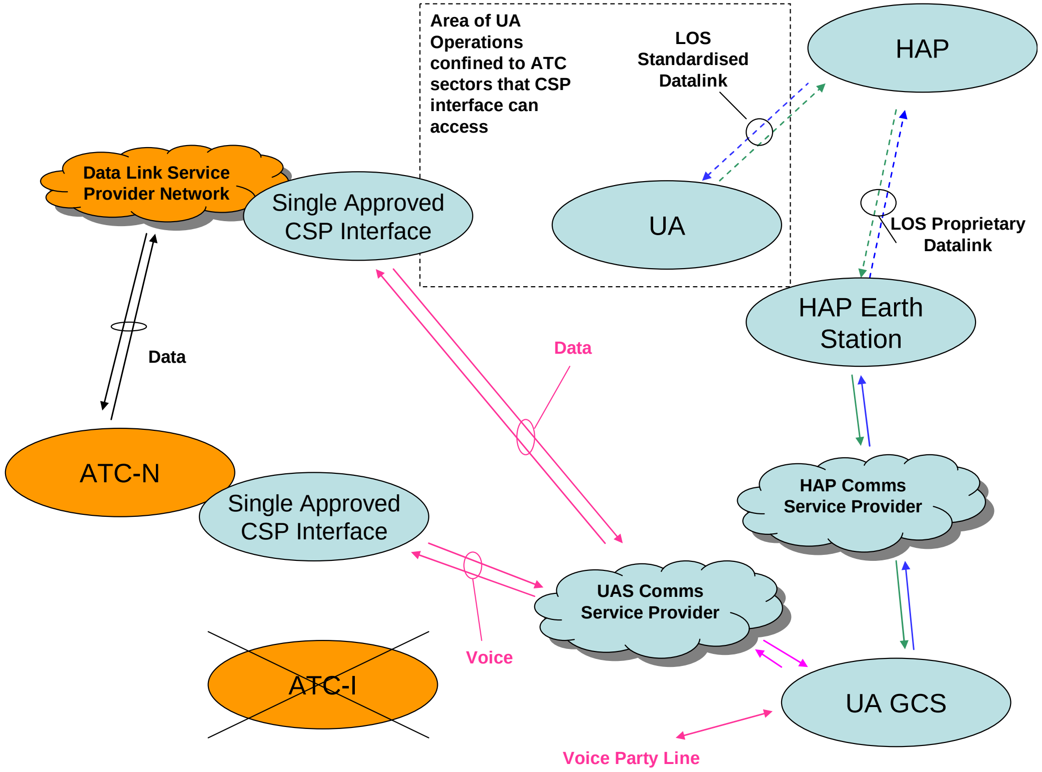
🟦 Unmanned Vehicle

🟨 Comms Service Provider

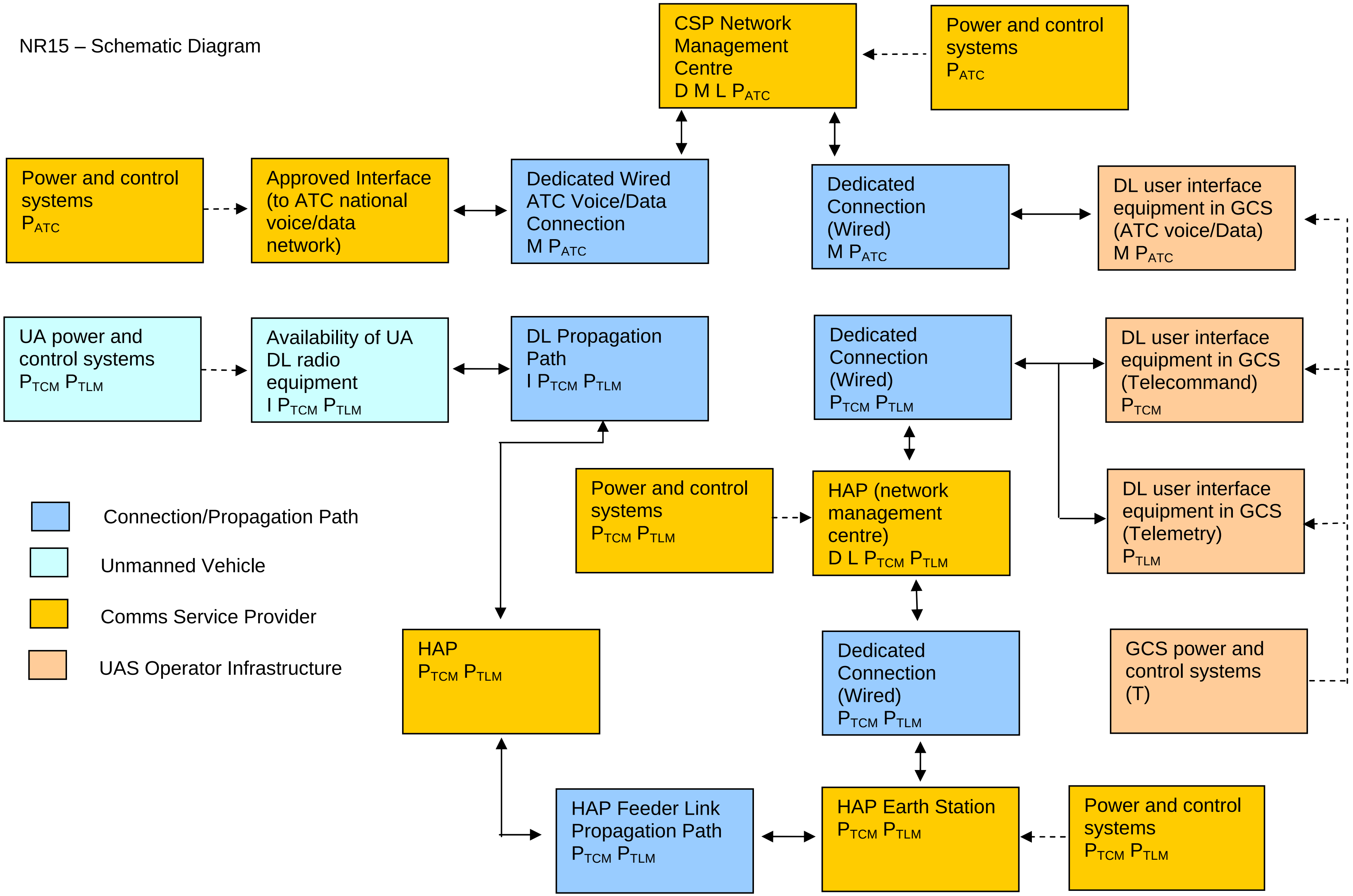
🟧 UAS Operator Infrastructure

A.4.15 NR15 – ATC Voice/Data Communications via Networked Wired Interface, TLM & TLC via High Altitude Platform Datalink (NNW-HD)

NR15 – Functional Diagram



NR15 – Schematic Diagram



CSP Network Management Centre
D M L P_{ATC}

Power and control systems
P_{ATC}

Power and control systems
P_{ATC}

Approved Interface (to ATC national voice/data network)

Dedicated Wired ATC Voice/Data Connection
M P_{ATC}

Dedicated Connection (Wired)
M P_{ATC}

DL user interface equipment in GCS (ATC voice/Data)
M P_{ATC}

UA power and control systems
P_{TCM} P_{TLM}

Availability of UA DL radio equipment
I P_{TCM} P_{TLM}

DL Propagation Path
I P_{TCM} P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telecommand)
P_{TCM}

Power and control systems
P_{TCM} P_{TLM}

HAP (network management centre)
D L P_{TCM} P_{TLM}

DL user interface equipment in GCS (Telemetry)
P_{TLM}

HAP
P_{TCM} P_{TLM}

Dedicated Connection (Wired)
P_{TCM} P_{TLM}

GCS power and control systems
(T)

HAP Feeder Link Propagation Path
P_{TCM} P_{TLM}

HAP Earth Station
P_{TCM} P_{TLM}

Power and control systems
P_{TCM} P_{TLM}

🟦 Connection/Propagation Path

⬜ Unmanned Vehicle

🟨 Comms Service Provider

🟧 UAS Operator Infrastructure

B Appendix B Risk analysis Scores

This appendix provides details of the risk analysis scores, for each of the 20 architectures that were determined during the workshop.

B.1 AR1

Keyword	Hazard	No of elements	Severity	Likelihood	Risk	Risk tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC	6	4	3	12	72	ATC comms still available to other a/c in the area	UAV would have to operate autonomously if available.
Partial Loss	Loss of ATC voice/data comms	3	2	1	2	6	ATC procedures, use of transponder	
	Loss of UAV telecommand data link	1	4	1	4	4	multiple redundancy	
	Loss of UAV telemetry data link	1	4	1	4	4		
Error of Input/Output	common to all architectures,so not considered.							
Misdirection of data	Control of wrong air vehicle - this architecture is robust						Command & control link certified and approved to high integrity	
Inconsistent information	no hazards identified							
Erroneous Updating	no hazards identified						Command & control link certified and approved to high integrity	assumed that errors are detected.
Failure to: start; stop; switch	no hazards identified							
Delayed/premature operation	This architecture is not vulnerable to latency							
Inadvertent operation	no hazards identified							
Intermittent or erratic operation	no hazards identified							
Misheard	Corruption of ATC voice comms	6	1	1	1	6	ATC read back	
Misunderstood	as misheard							
Used beyond intent	UAV goes out of C&C coverage	1	4	4	16	16		Lose all ATC comms & control.
	UAV goes out of ATC sector coverage	1	2	1	2	2	Still has voice comms with ATC	
Out of time synchronisation	no hazards identified							
				Risk score	41	110		
Positive								
Connect to any ATC infrastructure on any frequency			Risk Summary					
Not many interfaces - simplistic form			High	0				
no third party control issues			Medium	12				
			Low	10				
negative								
common mode of failure for ATC C&C								
Ground station has limited coverage								

B.2 AR2

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC	9	4	1	4	36	ATC comms still available to other a/c in the area	UAV would have to operate autonomously if available. Number of elements is pessimistic as it does not take account of overlapping coverage and movement of the UAV within range of other ground stations.
Partial Loss	Loss of ATC voice/data comms	3	2	1	2	6	ATC procedures, use of transponder	
	Loss of UAV telecommand data link	1	4	1	4	4	multiple redundancy	
	Loss of UAV telemetry data link	1	4	1	4	4		
Error of Input/Output	common to all architectures,so not considered.							
Misdirection of data	Control of wrong air vehicle	1	5	1	5	5	Command & control link certified and approved to high integrity	high integrity end to end authentication
Inconsistent information	no hazards identified							
Erroneous Updating	no hazards identified						Command & control link certified and approved to high integrity	assumed that errors are detected.
Failure to: start; stop; switch	no hazards identified							
Delayed/premature operation	Additional voice and data latency due to network management	1	2	1	2	2	ATC read back	time stamping of data may mitigate this.
Inadvertent operation	no hazards identified							
Intermittent or erratic operation	no hazard identified							
Misheard	Corruption of ATC voice comms	7	1	1	1	7	ATC read back	
Misunderstood	as misheard							
Used beyond intent	UAV goes out of C&C coverage - this architecture is robust	1	4	1	3	3		Lose all comms & control
	UAV goes out of ATC sector coverage	1	2	1	2	2	Still has voice comms with ATC	
Out of time synchronisation	no hazards identified							
				Risk Score	27	69		
Positive								
Connect to any ATC infrastructure on any frequency			Risk Summary					
Increased coverage			High	0				
Some redundancy			Medium	14				
			Low	5				
Negative								
common mode of failure for ATC C&C								
More complex								
dependent upon third parties								

B.3 AR3

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC	11	4	2	8	88	ATC comms still available to other a/c in the area	UAV would have to operate autonomously if available. Number of elements is pessimistic as it does not take account of overlapping coverage and movement of the UAV within range of other ground stations.
Partial Loss	Loss of ATC voice/data comms	3	3	1	3	9	ATC procedures, use of transponder	
	Loss of UAV telecommand data link	1	4	1	4	4	multiple redundancy	
	Loss of UAV telemetry data link	1	4	1	4	4		
Error of Input/Output	common to all architectures,so not considered.							
Misdirection of data	Control of wrong air vehicle	1	5	1	5	5	Command & control link certified and approved to high integrity	high integrity end to end authentication. Likelihood is low as end to end authentication is the same as AR2.
Inconsistent information	no hazards identified							
Erroneous Updating	no hazards identified						Command & control link certified and approved to high integrity	assumed that errors are detected.
Failure to: start; stop; switch	no hazards identified							
Delayed/premature operation	Additional voice and data latency due to network management and propogation path to/from satellite	3	2	5	10	30	ATC read back	
Inadvertent operation	no hazards identified							
Intermittent or erratic operation	Intermittent loss of satellite communications	2	4	2	8	16		
Misheard	Corruption of ATC voice comms	9	1	1	1	9	ATC read back	
Misunderstood	as misheard							
Used beyond intent	UAV goes out of C&C coverage - this architecture is robust	1	4	1	4	4		Lose all comms & control. Better coverage than AR2 (if emergency decent required)
	UAV goes out of ATC sector coverage	1	2	1	2	2	Still has voice comms with ATC	
Out of time synchronisation	no hazards identified							
				Risk Score	49	171		
Positive								
Connect to any ATC infrastructure on any frequency			Risk Summary					
Increased coverage particularly at low level			High	0				
Some redundancy			Medium	20				
			Low	12				
Negative								
Significant latency issues								
Common mode of failure for ATC C&C								
More complex particularly for UA satellite tracking								
Dependent upon third parties								

B.4 AR4

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC	10	4	2	8	80	ATC comms still available to other a/c in the area	UAV would have to operate autonomously if available. Number of elements is pessimistic as it does not take account of overlapping coverage and movement of the UAV within range of other ground stations.
					0	0		
Partial Loss	Loss of ATC voice/data comms	3	2	1	2	6	ATC procedures, use of transponder	
	Loss of UAV telecommand data link	1	4	1	4	4	multiple redundancy	
	Loss of UAV telemetry data link	1	4	1	4	4		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	1	5	1	5	5	Command & control link certified and approved to high integrity	high integrity end to end authentication. Likelihood is low as end to end authentication is the same as AR2.
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0	Command & control link certified and approved to high integrity	assumed that errors are detected.
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management and propogation path to/from satellite	3	2	3	6	18	ATC read back	Less propogation delay than AR3.
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	Intermittent loss of satellite communications	2	4	1	4	8		This architecture is slightly less prone to intermittancy than AR3
					0	0		
Misheard	Corruption of ATC voice comms	9	1	1	1	9	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage - this architecture is robust	1	4	1	4	4		Lose all comms & control. Better coverage than AR2 (if emergency decent required)
	UAV goes out of ATC sector coverage	1	2	1	2	2	Still has voice comms with ATC	
Out of time synchronisation	no hazards identified				0	0		
				Risk Score	40	140		
Positive								
Connect to any ATC infrastructure on any frequency		Risk Summary						
Increased coverage than AR3 particularly at low level		High	0					
Some redundancy		Medium	17					
		Low	15					
Negative								
Reduced latency issues wrt AR3								
Common mode of failure for ATC C&C								
More complex particularly for UA satellite tracking								
Dependent upon third parties								

B.5 AR5

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC	11	4	2	8	88	ATC comms still available to other a/c in the area	UAV would have to operate autonomously if available. Number of elements is pessimistic as it does not take account of overlapping coverage and movement of the UAV within range of other ground stations. HAP is more vulnerable to failure
					0	0		
Partial Loss	Loss of ATC voice/data comms	3	2	1	2	6	ATC procedures, use of transponder	
	Loss of UAV telecommand data link	1	4	1	4	4	multiple redundancy	
	Loss of UAV telemetry data link	1	4	1	4	4	multiple redundancy	
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	1	5	1	5	5	Command & control link certified and approved to high integrity	high integrity end to end authentication. Likelihood is low as end to end authentication is the same as AR2.
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0	Command & control link certified and approved to high integrity	assumed that errors are detected.
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management.	1	2	3	6	6	ATC read back	Less propogation delay than AR3 & 4.
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	Intermittent loss of HAP communications	2	4	1	4	8		This architecture is slightly less prone to intermittancy than AR3
					0	0		
Misheard	Corruption of ATC voice comms	11	1	1	1	11	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage - this architecture is robust	1	4	2	8	8		Lose all comms & control. Better coverage than AR2 (if emergency decent required)
	UAV goes out of ATC sector coverage	1	2	1	2	2	Still has voice comms with ATC	
Out of time synchronisation	no hazards identified				0	0		
				Risk Score	44	142		
Positive								
Connect to any ATC infrastructure on any frequency		Risk Summary						
Increased coverage than AR2 particularly at low level or if emergency decent is required		High	0					
Some redundancy		Medium	17					
		Low	15					
Negative								
Reduced latency issues wrt AR3								
Common mode of failure for ATC C&C								
More complex particularly for UA satellite tracking								
Dependent upon third parties								

B.6 NR1

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	5	2	1	2	10	ATC read back	
	Loss of UAV telecommand data link	7	4	1	4	28	Multiple redundancy	
	Loss of UAV telemetry data link	7	4	1	4	28	Multiple redundancy	
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle - this architecture is robust				0	0		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	no hazards identified				0	0		
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	no hazards identified				0	0		
					0	0		
Misheard	Corruption of ATC voice comms	4	1	1	1	4	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	4	16	16	ATC comms still available to other a/c in the area	Lose all comms & control
	UAV goes out of ATC sector coverage	1	2	3	6	6	Still has voice comms with ATC	The voice comms may not be with the right controller.
					0	0		
Out of time synchronisation	no hazards identified				0	0		
				Risk Score	33	92		
Positive								
Direct connection of pilot and ATC								
Not many interfaces - simplistic form								
no third party control issues								
Negative								
Ground station has limited coverage constrained by location of ground station equipment.								
			Risk Summary					
			High	0				
			Medium	16				
			Low	10				

B.7 NR2

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	8	2	1	2	16	ATC read back	
	Loss of UAV telecommand data link	10	4	1	4	40	Multiple redundancy	
	Loss of UAV telemetry data link	10	4	1	4	40	Multiple redundancy	
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	2	5	1	5	10		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management	2	2	1	2	4	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	no hazards identified				0	0		
					0	0		
Misheard	Corruption of ATC voice comms	6	1	1	1	6	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	3	3	9	9	ATC comms still available to other a/c in the area	Lose all comms & control
	UAV goes out of ATC sector coverage	1	2	2	4	4	Still has voice comms with ATC	The voice comms may not be with the right controller.
					0	0		
Out of time synchronisation	no hazards identified				0	0		
				Risk Score	31	129		
Positive								
Networked ground station coverage								
Only 1 single point of failure								
Robust ATC comms architecture								
Negative								
3rd parties to control								
			Risk Summary					
			High	0				
			Medium	16				
			Low	10				

B.8 NR3

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	8	2	1	2	16	ATC read back	
	Loss of UAV telecommand data link	11	4	1	4	44	Multiple redundancy	
	Loss of UAV telemetry data link	11	4	1	4	44	Multiple redundancy	
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	2	5	1	5	10		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management and satellite propogation delay	4	2	1	2	8	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	Intermittent loss of satellite communications	2	4	2	8	16		
					0	0		
Misheard	Corruption of ATC voice comms	6	1	1	1	6	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	1	4	4	ATC comms still available to other a/c in the area	Lose all comms & control
	UAV goes out of ATC sector coverage	1	2	2	4	4	Still has voice comms with ATC	The voice comms may not be with the right controller.
					0	0		
Out of time synchronisation	no hazards identified				0	0		
				Risk Score	34	152		
Positive								
Networked ground station coverage								
Only 1 single point of failure								
Robust ATC comms architecture								
Increased C&C coverage particularly at low level								
Negative								
Two 3rd parties to control								
Delay introduced on C&C by satellite comms			Risk Summary					
			High	0				
			Medium	16				
			Low	10				

B.9 NR4

Keyword	Hazard	Number of elements	Consequence	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	8	2	1	2	16	ATC read back	
	Loss of UAV telecommand data link	12	4	1	4	48	Multiple redundancy	
	Loss of UAV telemetry data link	12	4	1	4	48	Multiple redundancy	
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	2	5	1	5	10		
	UAV communications with wrong ATC controller	1	2	1	2	2		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management and satellite propogation delay	4	2	1	2	8	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	Intermittent loss of satellite communications	2	4	1	4	8		This architecture is slightly less prone to intermittancy than AR3
					0	0		
Misheard	Corruption of ATC voice comms	6	1	1	1	6	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	1	4	4	ATC comms still available to other a/c in the area	Lose all comms & control
	UAV goes out of ATC sector coverage	1	2	2	4	4	Still has voice comms with ATC	The voice comms may not be with the right controller.
					0	0		
Out of time synchronisation	no hazards identified				0	0		
				Risk Score	32	154		
Positive								
Networked ground station coverage								
Only 1 single point of failure								
Robust ATC comms architecture								
Increased C&C coverage particularly at low level								
Negative								
Two 3rd parties to control								
Delay introduced on C&C by satellite comms			Risk Summary					
			High	0				
			Medium	16				
			Low	10				

B.10 NR5

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	8	2	1	2	16	ATC read back	
	Loss of UAV telecommand data link	12	4	1	4	48	Multiple redundancy	
	Loss of UAV telemetry data link	12	4	1	4	48	Multiple redundancy	
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	2	5	1	5	10		
	UAV communications with wrong ATC controller	1	2	1	2	2		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management and satellite propogation delay	2	2	1	2	4	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	Intermittent loss of satellite communications	2	4	1	4	8		This architecture is slightly less prone to intermittancy than AR3
					0	0		
Misheard	Corruption of ATC voice comms	5	1	1	1	5	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	2	8	8	ATC comms still available to other a/c in the area	Lose all comms & control
	UAV goes out of ATC sector coverage	1	2	2	4	4	Still has voice comms with ATC	The voice comms may not be with the right controller.
					0	0		
Out of time synchronisation	no hazards identified				0	0		
				Risk Score	36	153		
Positive								
Networked ground station coverage								
Only 1 single point of failure								
Robust ATC comms architecture								
Increased C&C coverage particularly at low level								
Negative								
Two 3rd parties to control								
			Risk Summary					
			High	0				
			Medium	16				
			Low	10				

B.11 NR6

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	4	2	1	2	8	read back	
	Loss of UAV telecommand data link	7	4	1	4	28	Multiple redundancy	
	Loss of UAV telemetry data link	7	4	1	4	28		
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle - this architecture is robust				0	0		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	no hazards identified				0	0		
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	no hazards identified				0	0		
					0	0		
Misheard	Corruption of ATC voice comms	3	1	1	1	3	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	4	16	16		Lose all comms & control
	UAV goes out of ATC sector coverage	1	2	3	6	6	Still has voice comms with ATC	
					0	0		
Out of time synchronisation	Loss of synchronisation between the UAV network and the ATC network. Loss of ATC voice comms	1	2	1	2	2		
				Risk Score	35	91		
Positive								
Direct connection of pilot and ATC		Risk Summary						
Not many interfaces - simplistic form		High	0					
no third party control issues		Medium	16					
Better connectivity between pilot and ATC		Low	10					
Negative								
Ground station has limited coverage constrained by location of ground station equipment.								
Need one dedicated GCS interface for each UAV GCS. Could make ATC infrastructure complex								
Can't communicate with ATC-I								

B.12 NR7

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	4	2	1	2	8	ATC read back	
	Loss of UAV telecommand data link	10	4	1	4	40	Multiple redundancy	
	Loss of UAV telemetry data link	10	4	1	4	40	Multiple redundancy	
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	1	5	1	5	5		
	UAV communications with wrong ATC controller	1	2	1	2	2		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management	4	2	1	2	8	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	no hazards identified				0	0		
					0	0		
Misheard	Corruption of ATC voice comms	3	1	1	1	3	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	3	12	12		
	UAV goes out of ATC sector coverage	1	2	3	6	6	Still has voice comms with ATC	The voice comms may not be with the right controller. Not as bad as a fixed frequency architecture (NR2)
					0	0		
Out of time synchronisation	Loss of synchronisation between the UAV network and the ATC network. Loss of ATC voice comms	1	2	1	2	2		
				Risk Score	40	126		
Positive								
Direct connection of pilot and ATC		Risk Summary						
Not many interfaces for ATC comms path - simplistic form		High	0					
		Medium	16					
Better connectivity between pilot and ATC		Low	10					
Negative								
Need one dedicated GCS interface for each UAV GCS. Could make ATC infrastructure complex								
Can't communicate with ATC-I								

B.13 NR8

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	4	2	1	2	8	ATC read back	
	Loss of UAV telecommand data link	12	4	1	4	48	Multiple redundancy	
	Loss of UAV telemetry data link	12	4	1	4	48	Multiple redundancy	
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	1	5	1	5	5		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management	3	2	1	2	6	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	Intermittent loss of satellite communications	2	4	2	8	16		
					0	0		
Misheard	Corruption of ATC voice comms	3	1	1	1	3	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	1	4	4		
	UAV goes out of ATC sector coverage	1	2	3	6	6	Still has voice comms with ATC	The voice comms may not be with the right controller. Not as bad as a fixed frequency architecture (NR2)
					0	0		
Out of time synchronisation	Loss of synchronisation between the UAV network and the ATC network. Loss of ATC voice comms	1	2	1	2	2		
				Risk Score	38	146		
Positive								
Direct connection of pilot and ATC		Risk Summary						
Not many interfaces for ATC comms path - simplistic form		High	0					
Increased C&C coverage particularly at low level		Medium	16					
Better connectivity between pilot and ATC		Low	10					
Negative								
Need one dedicated GCS interface for each UAV GCS. Could make ATC infrastructure complex								
Can't communicate with ATC-I								

B.14 NR9

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	4	2	1	2	8	ATC read back	
	Loss of UAV telecommand data link	12	4	1	4	48	Multiple redundancy	
	Loss of UAV telemetry data link	12	4	1	4	48	Multiple redundancy	
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	1	5	1	5	5		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management	3	2	1	2	6	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	Intermittent loss of satellite communications	2	4	2	8	16		
					0	0		
Misheard	Corruption of ATC voice comms	3	1	1	1	3	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	1	4	4		
	UAV goes out of ATC sector coverage	1	2	3	6	6	Still has voice comms with ATC	The voice comms may not be with the right controller. Not as bad as a fixed frequency architecture (NR2)
					0	0		
Out of time synchronisation	Loss of synchronisation between the UAV network and the ATC network. Loss of ATC voice comms	1	2	1	2	2		
				Risk Score	38	146		
Positive								
Direct connection of pilot and ATC		Risk Summary						
Not many interfaces for ATC comms path - simplistic form		High	0					
Increased C&C coverage particularly at low level		Medium	16					
Better connectivity between pilot and ATC		Low	10					
Negative								
Need one dedicated GCS interface for each UAV GCS. Could make ATC infrastructure complex								
Can't communicate with ATC-I								

B.15 NR10

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	4	2	1	2	8	ATC read back	
	Loss of UAV telecommand data link	12	4	1	4	48	Multiple redundancy	
	Loss of UAV telemetry data link	12	4	1	4	48	Multiple redundancy	
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	1	5	1	5	5		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management	1	2	1	2	2	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	Intermittent loss of satellite communications	2	4	2	8	16		
					0	0		
Misheard	Corruption of ATC voice comms	3	1	1	1	3	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	2	8	8		
	UAV goes out of ATC sector coverage	1	2	3	6	6	Still has voice comms with ATC	The voice comms may not be with the right controller. Not as bad as a fixed frequency architecture (NR2)
					0	0		
Out of time synchronisation	Loss of synchronisation between the UAV network and the ATC network. Loss of ATC voice comms	1	2	1	2	2		
				Risk Score	42	146		
Positive								
Direct connection of pilot and ATC		Risk Summary						
Not many interfaces for ATC comms path - simplistic form		High	0					
Increased C&C coverage particularly at low level		Medium	16					
Better connectivity between pilot and ATC		Low	10					
Negative								
Need one dedicated GCS interface for each UAV GCS. Could make ATC infrastructure complex								
Can't communicate with ATC-I								
Dependent upon third parties								

B.16 NR11

Keyword	Hazard	Number of elements	Consequence	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	7	2	1	2	14	read back and data expiry times	
	Loss of UAV telecommand data link	7	4	1	4	28	Multiple redundancy	
	Loss of UAV telemetry data link	7	4	1	4	28		
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle - this architecture is robust				0	0		
	UAV communications with wrong ATC controller	1	2	1	2	2		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional ATC voice and data latency due to network management	1	2	1	2	2	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	no hazards identified				0	0		
					0	0		
Misheard	Corruption of ATC voice comms	5	1	1	1	5	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	4	16	16		Lose all comms & control
	UAV goes out of ATC sector coverage	1	2	2	4	4	Still has voice comms with ATC	
					0	0		
Out of time synchronisation	Loss of synchronisation between the UAV network and the ATC network. Loss of ATC voice comms	1	2	1	2	2		
				Risk Score	37	101		
Positive								
Direct connection of pilot and ATC								
Not many interfaces - simplistic form								
Better connectivity between pilot and ATC								
Single interface and safety case for ATC and data comms.								
Negative								
C&C Ground station has limited coverage constrained by location of ground station equipment.								
UAV reliance on third party for ATC comms.								
No ability to communicate with ATC-I.								

B.17 NR12

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	7	2	1	2	14	read back and data expiry times	
	Loss of UAV telecommand data link	10	4	1	4	40	Multiple redundancy	
	Loss of UAV telemetry data link	10	4	1	4	40		
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	1	5	1	5	5		
	UAV communications with wrong ATC controller	1	2	1	2	2		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management	2	2	1	2	4	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	no hazards identified				0	0		
					0	0		
Misheard	Corruption of ATC voice comms	5	1	1	1	5	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	3	12	12		Lose all comms & control
	UAV goes out of ATC sector coverage	1	2	2	4	4	Still has voice comms with ATC	
					0	0		
Out of time synchronisation	Loss of synchronisation between the UAV network and the ATC network. Loss of ATC voice comms	1	2	1	2	2		
				Risk Score	38	128		
Positive								
Direct connection of pilot and ATC								
Not many interfaces - simplistic form								
Better connectivity between pilot and ATC								
Single interface and safety case for ATC and data comms.								
Negative								
UAV reliance on third party for C&C.								
No ability to communicate with ATC-I.								

B.18 NR13

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	7	2	1	2	14	ATC read back	
	Loss of UAV telecommand data link	12	4	1	4	48	Multiple redundancy	
	Loss of UAV telemetry data link	12	4	1	4	48	Multiple redundancy	
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	2	5	1	5	10		
	UAV communications with wrong ATC controller	1	2	1	2	2		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management and propogation delay	4	2	1	2	8	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	Intermittent loss of satellite communications	2	4	2	8	16		
					0	0		
Misheard	Corruption of ATC voice comms	5	1	1	1	5	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	1	4	4		
	UAV goes out of ATC sector coverage	1	2	2	4	4	Still has voice comms with ATC	The voice comms may not be with the right controller. Not as bad as a fixed frequency architecture (NR2)
					0	0		
Out of time synchronisation	Loss of synchronisation between the UAV network and the ATC network. Loss of ATC voice comms	1	2	1	2	2		
				Risk Score	38	161		
Positive								
Direct connection of pilot and ATC		Risk Summary						
Not many interfaces for ATC comms path - simplistic form		High	0					
Increased C&C coverage particularly at low level		Medium	16					
Better connectivity between pilot and ATC		Low	10					
Negative								
Can't communicate with ATC-I								

B.19 NR14

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	7	2	1	2	14	ATC read back	
	Loss of UAV telecommand data link	12	4	1	4	48	Multiple redundancy	
	Loss of UAV telemetry data link	12	4	1	4	48	Multiple redundancy	
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	2	5	1	5	10		
	UAV communications with wrong ATC controller	1	2	1	2	2		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management and propogation delay	4	2	1	2	8	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	Intermittent loss of satellite communications	2	4	2	8	16		
					0	0		
Misheard	Corruption of ATC voice comms	5	1	1	1	5	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	1	4	4		
	UAV goes out of ATC sector coverage	1	2	2	4	4	Still has voice comms with ATC	The voice comms may not be with the right controller. Not as bad as a fixed frequency architecture (NR2)
					0	0		
Out of time synchronisation	Loss of synchronisation between the UAV network and the ATC network. Loss of ATC voice comms	1	2	1	2	2		
				Risk Score	38	161		
Positive								
Direct connection of pilot and ATC		Risk Summary						
Not many interfaces for ATC comms path - simplistic form		High	0					
Increased C&C coverage particularly at low level		Medium	16					
Better connectivity between pilot and ATC		Low	10					
Single interface and safety case for ATC and data comms.								
Negative								
Can't communicate with ATC-I								

B.20 NR15

Keyword	Hazard	Number of elements	Severity	Likelihood	Risk	Risk Tot	Mitigation	Comments
Total Loss	Loss of command and control and ATC				0	0		
					0	0		
Partial Loss	Loss of ATC voice/data comms	7	2	1	2	14	read back and data expiry times	
	Loss of UAV telecommand data link	12	4	3	12	144	Limited redundancy	
	Loss of UAV telemetry data link	12	4	3	12	144		
					0	0		
Error of Input/Output	common to all architectures,so not considered.				0	0		
					0	0		
Misdirection of data	Control of wrong air vehicle	2	5	1	5	10	Command & control link certified and approved to high integrity	high integrity end to end authentication
	UAV communications with wrong ATC controller	1	2	1	2	2		
					0	0		
Inconsistent information	no hazards identified				0	0		
					0	0		
Erroneous Updating	no hazards identified				0	0		
					0	0		
Failure to: start; stop; switch	no hazards identified				0	0		
					0	0		
Delayed/premature operation	Additional voice and data latency due to network management and propogation delay	2	2	1	2	4	ATC read back	
					0	0		
Inadvertent operation	no hazards identified				0	0		
					0	0		
Intermittent or erratic operation	Intermittent loss of satellite communications	2	4	2	8	16		
					0	0		
Misheard	Corruption of ATC voice comms	5	1	1	1	5	ATC read back	
					0	0		
Misunderstood	as misheard				0	0		
					0	0		
Used beyond intent	UAV goes out of C&C coverage	1	4	2	8	8		Lose all comms & control
	UAV goes out of ATC sector coverage	1	2	2	4	4	Still has voice comms with ATC	
					0	0		
Out of time synchronisation	Loss of synchronisation between the UAV network and the ATC network. Loss of ATC voice comms	1	2	1	2	2		
				Risk Score	58	353		
Positive								
Direct connection of pilot and ATC								
Better connectivity between pilot and ATC								
Single interface and safety case for ATC and data comms.								
Improved coverage over terrestial								
Negative								
Ground station has limited coverage constrained by location of ground station equipment.								
Number and complexity of comms interfaces between dedicated wired ATC communication interfaces.								
UAV reliance on third party for ATC comms.								
No ability to communicate with other ATC.								
HAP is mobile and vulnerable.								
Third party dependence								

C Appendix C Glossary

ACAS	Airborne Collision Avoidance System
AMC	Acceptable Means of Compliance
ANSP	Air Navigation Service Provider
ASAS	Airborne Separation Assistance System
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
C2	Command and Control
C3	Command, Control and Communications
CATS	Combined Aerial Targets Service
CNS	Communication, Navigation and Surveillance
CS	Certification Specifications
DL	Datalink
DME	Distance Measuring Equipment
EASA	European Aviation Safety Agency
EU	European Union
FANS	Future Air Navigation System
FOM	Figure of Merit
FIR	Flight Information Region
GCS	Ground Control Station
GS	(radio) Ground Station
HALE	High Altitude Long Endurance
ITT	Invitation to Tender
MCA	Multi Criteria Analysis
MOD	UK Ministry of Defence
NCO	Network Centric Operation
NEC	Network Enabled Capability
PMP	Project Management Plan
SESAR	Single European Sky ATM Research Programme
SSR	Secondary Surveillance Radar
SWIM	System Wide Information Management
UAS	Unmanned Aerial System
UA (or UAV)	Unmanned Aircraft (or Unmanned Aerial Vehicle)
VHF	Very High Frequency