European Aviation Safety Agency

Research Project EASA.2008/8

Preliminary Impact Assessment on the Safety of Communications for Unmanned Aircraft Systems

Volume 2

Annexes

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Final Report of the Preliminary Impact Assessment On the Safety of Communications for Unmanned Aircraft Systems (UAS)

Volume 2 Annexes

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Prepared by:

Title	Adrian Clough, Mike Ainley, Sarah Hunt
Signature	Adrian Cloug, Mike Ainley, Sarah Hunt
Date	08 December 2009

Authorised by: Mike Ainley

Title	Project Manager
Signature	Mike Ainley
Date	08 December 2009

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Issue	Date	Detail of Changes
0.1	26 September 2009	First draft
0.2	06 November 2009	Final draft for PSC review
1.0	08 December 2009	First release

Contents

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	Data link (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	Data link 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

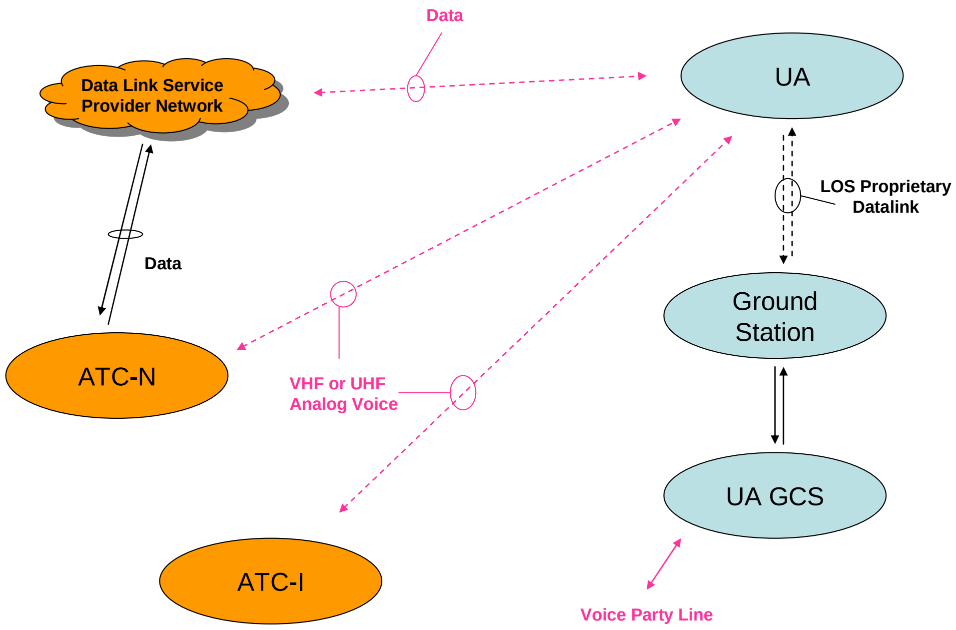
I – Potential for system element to be intermittent

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

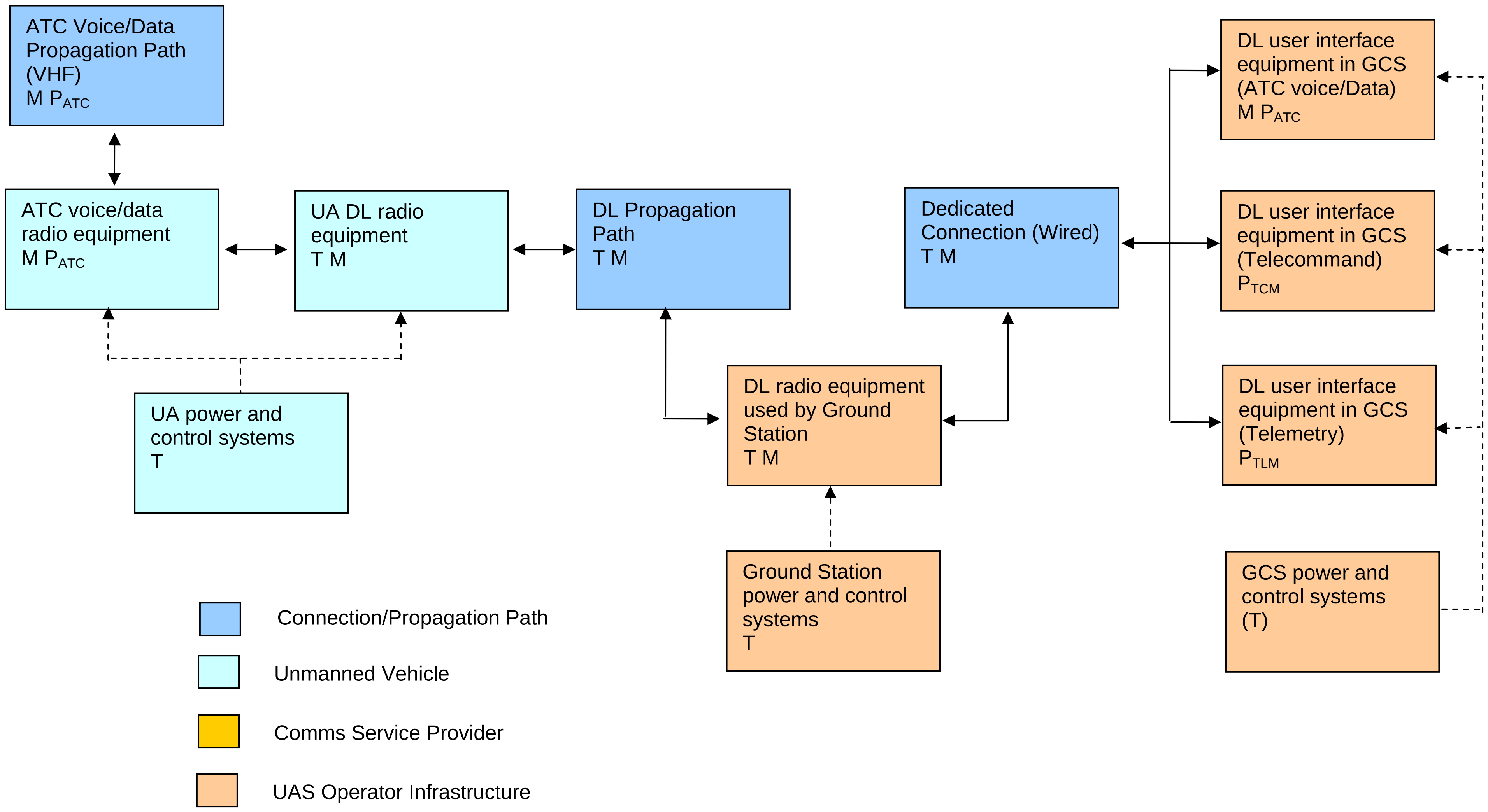
A.3 ATC Relay Architectures

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

AR1 – Functional Diagram



AR1 – Schematic Diagram



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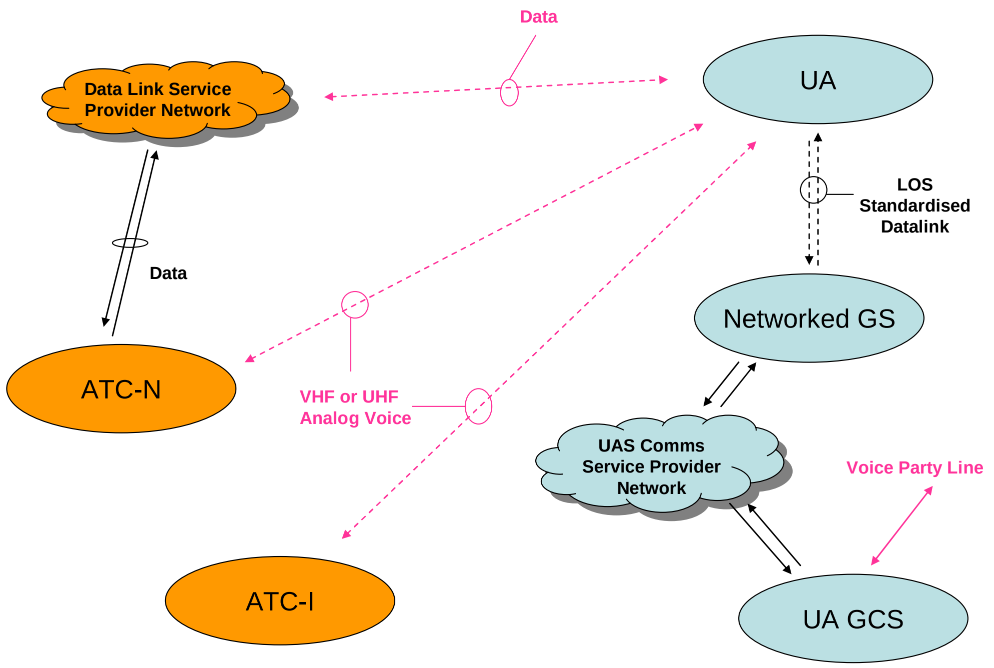
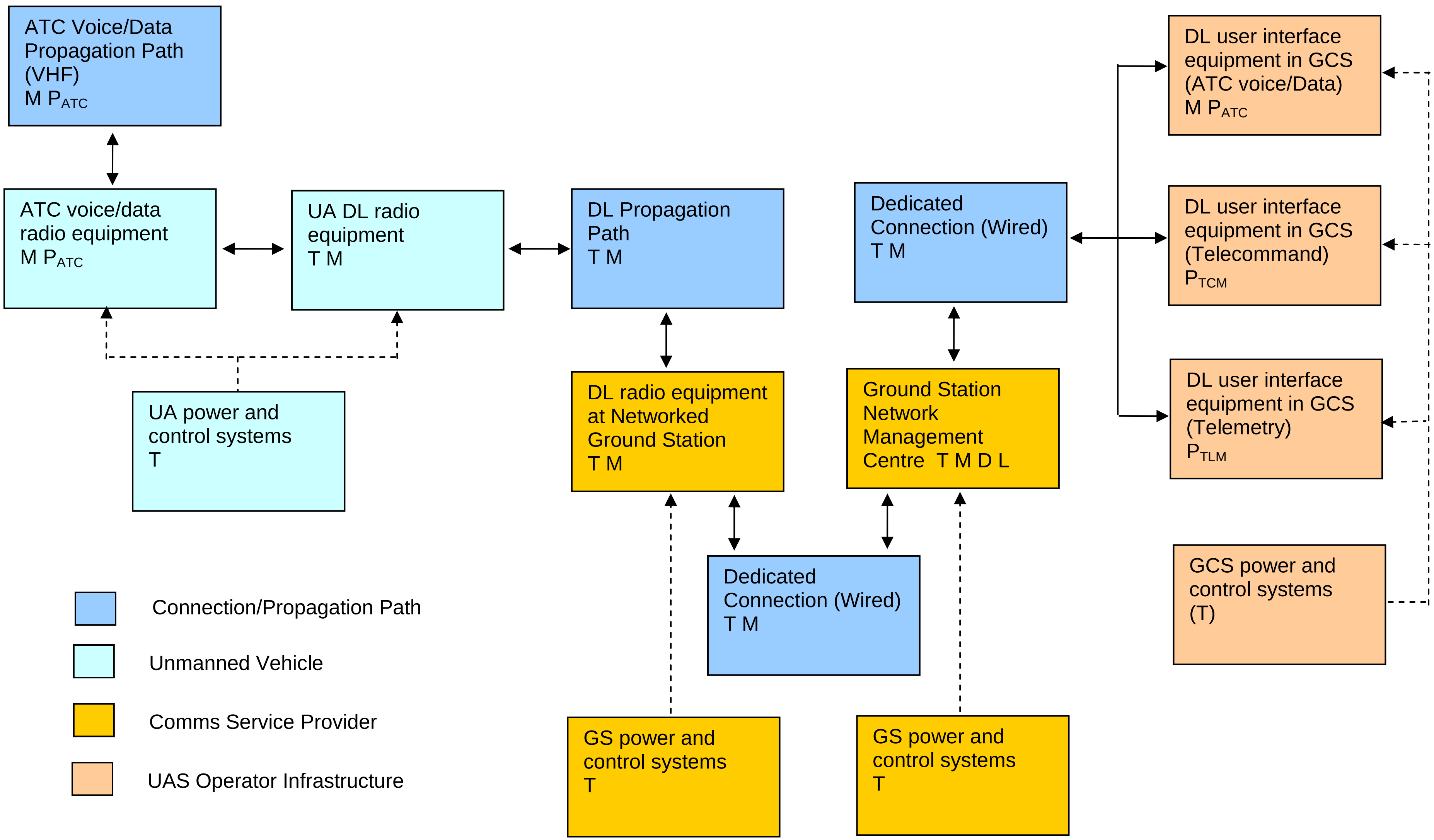
A.3.2 AR2 – ATC Voice/Data Communications, TLM & TCM via Networked Terrestrial Radio (ANTR)

AR2 – Functional Diagram

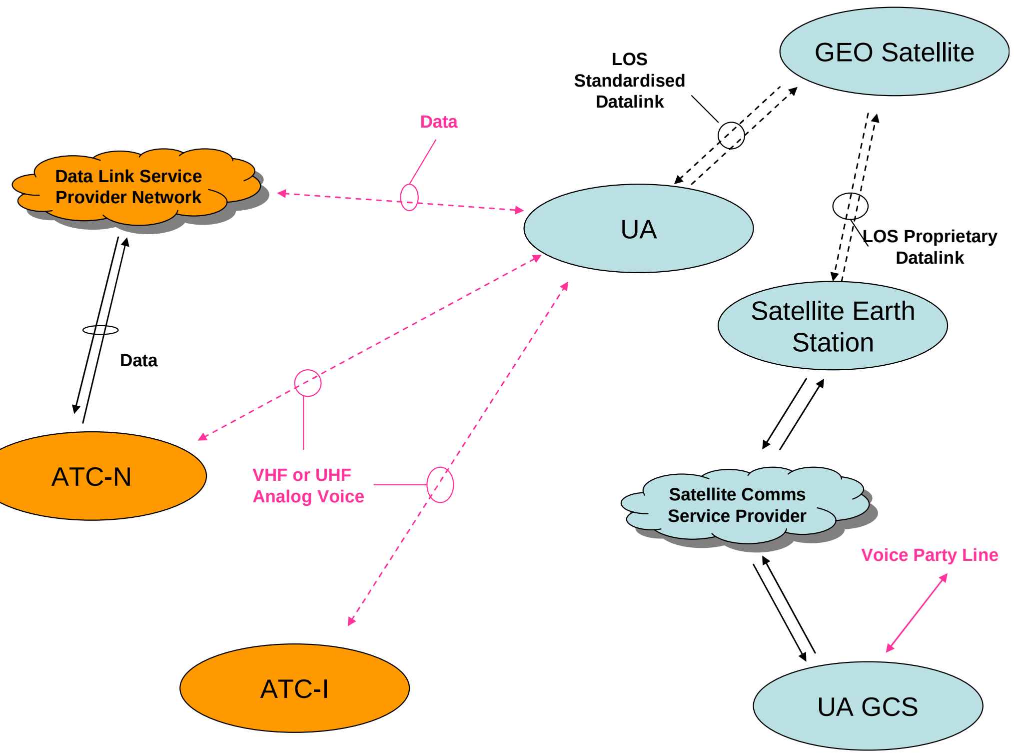


AR2 – Schematic Diagram



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

AR3 – Functional Diagram



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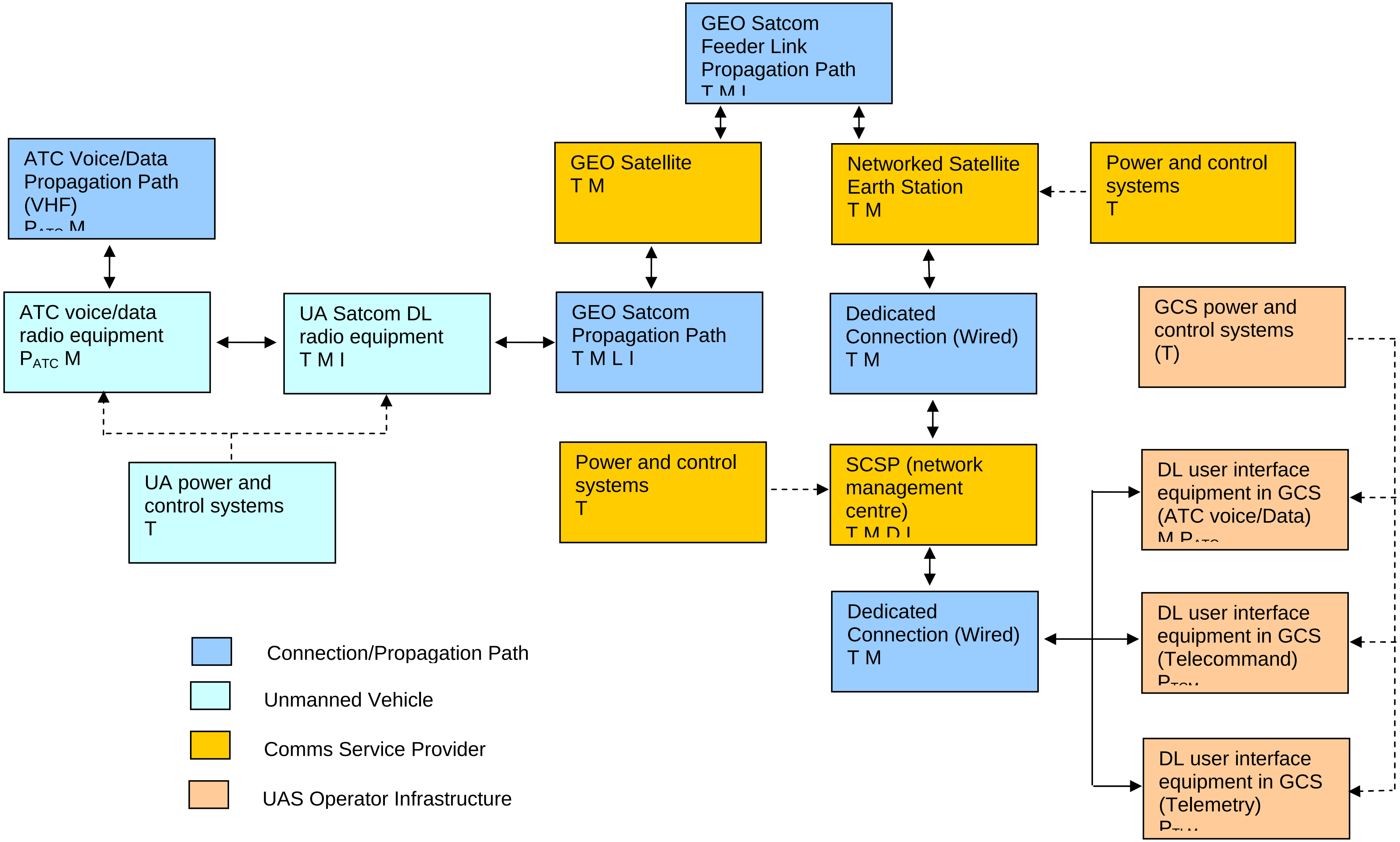
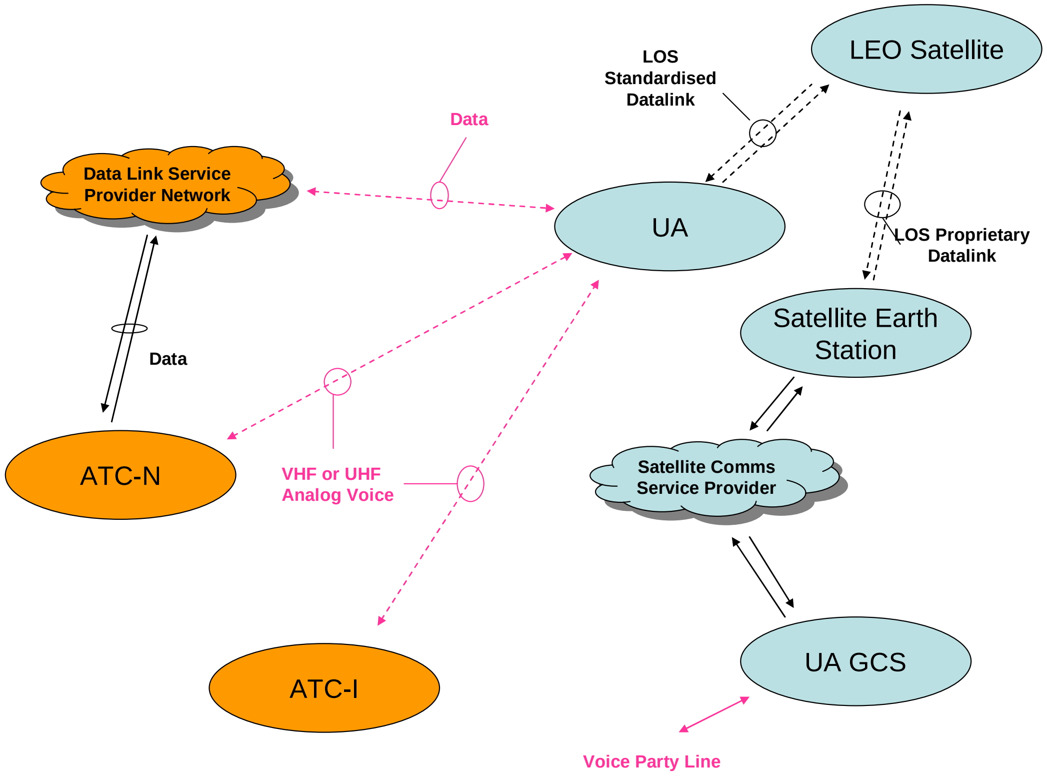
AR3 – Schematic Diagram

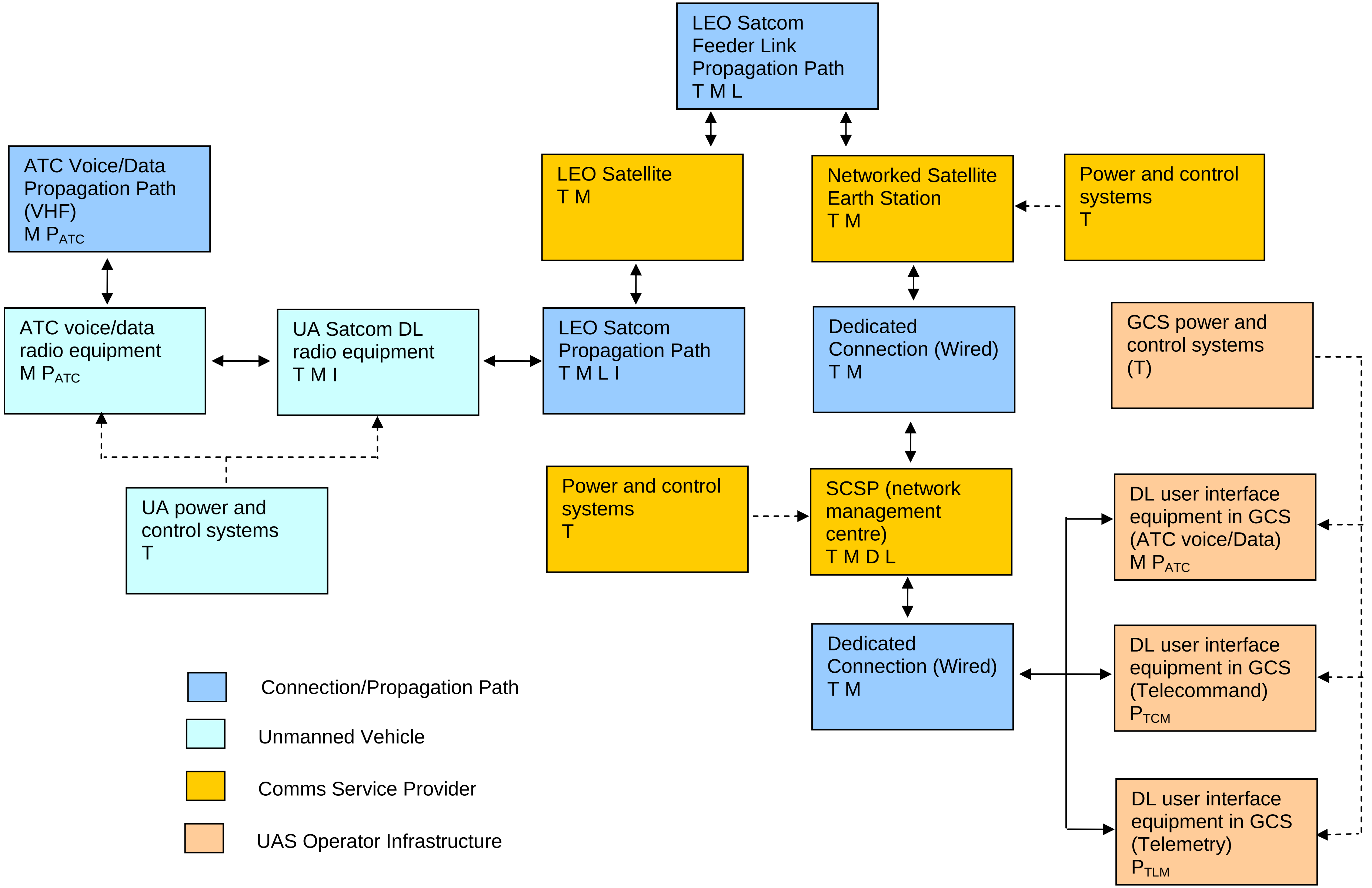


AR4 – ATC Voice/Data Communications, TLM & TCM via Networked Low Earth Orbit Satellite Radio (ANLSR)

AR4 – Functional Diagram

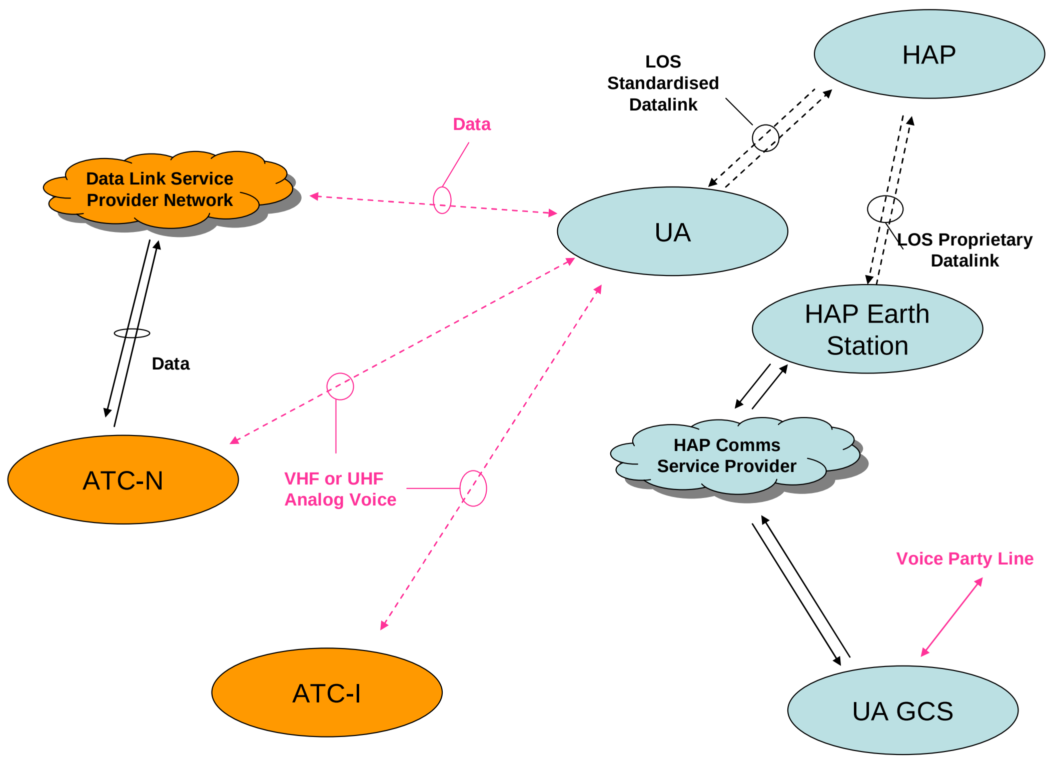


AR4 – Schematic Diagram

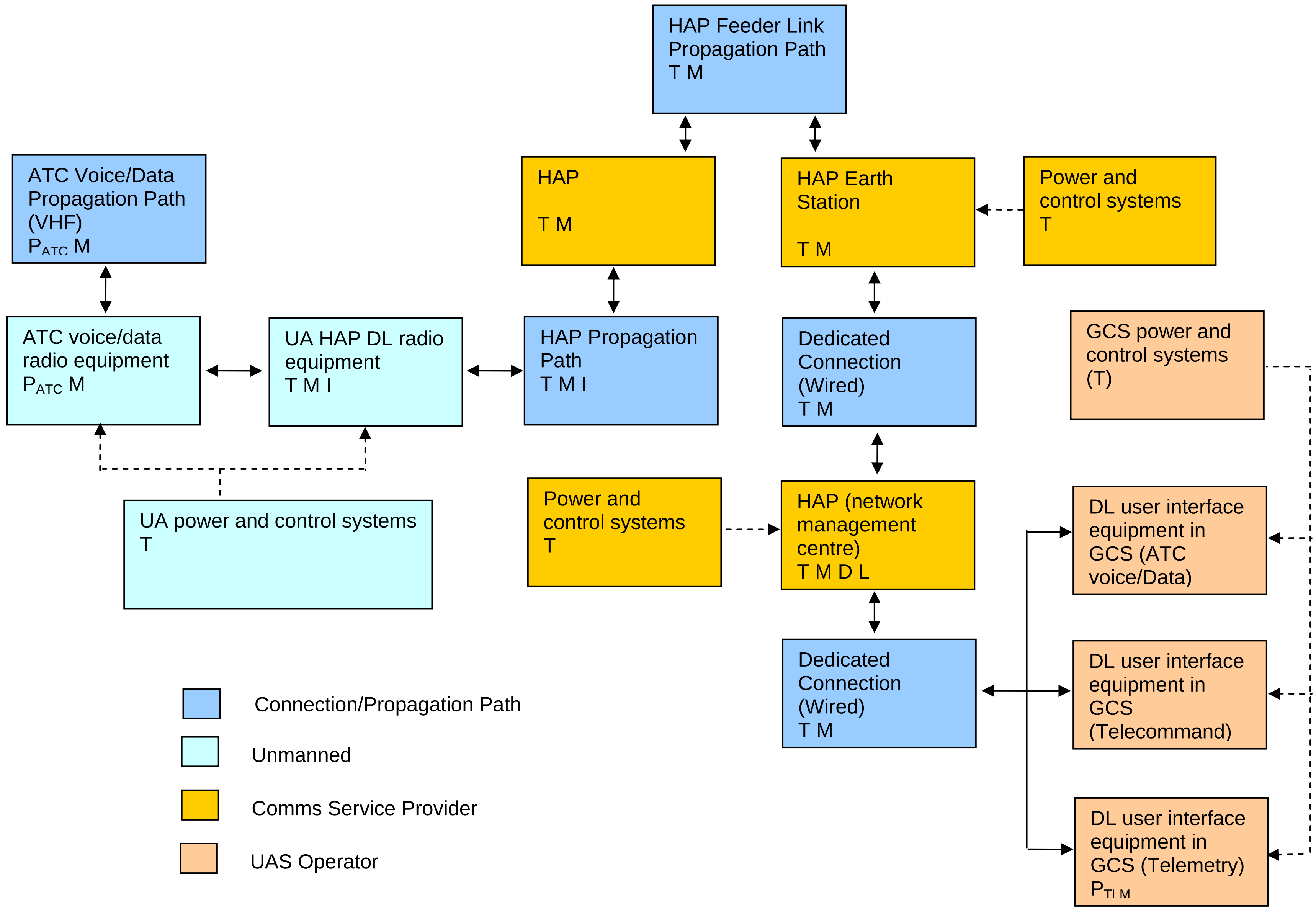


A.3.4 AR5 – ATC Voice/Data Communications, TLM & TCM via Networked High Altitude Platform Radio (ANHR)

AR5 – Functional Diagram



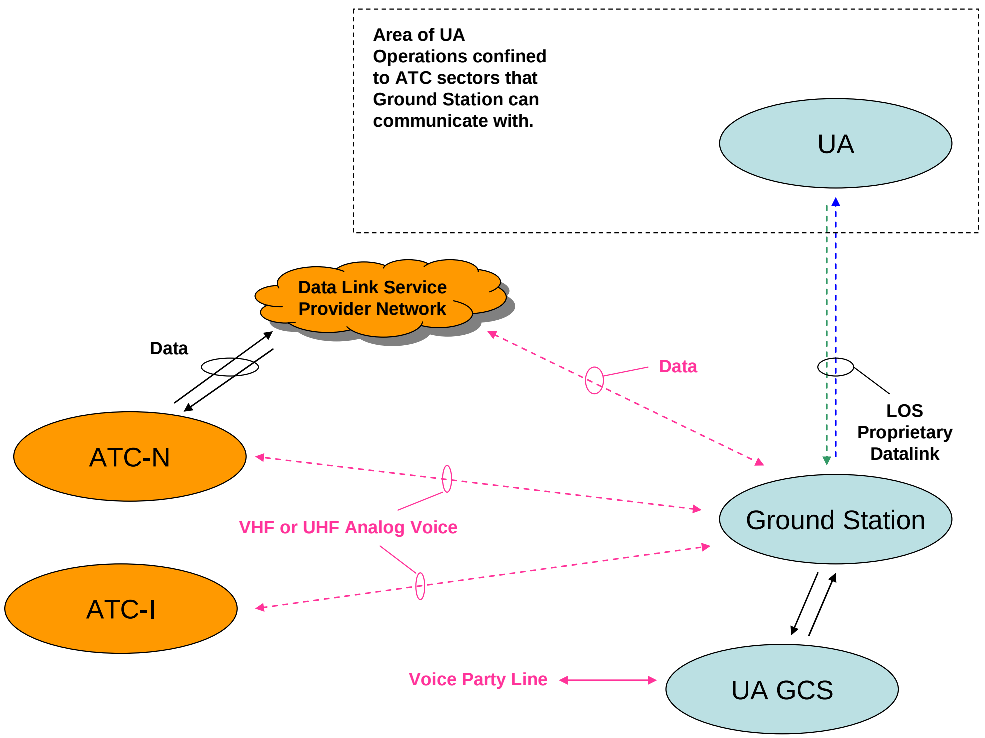
AR5 – Schematic Diagram



A.4 Non-ATC Relay Architectures

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

NR1 – Functional Diagram



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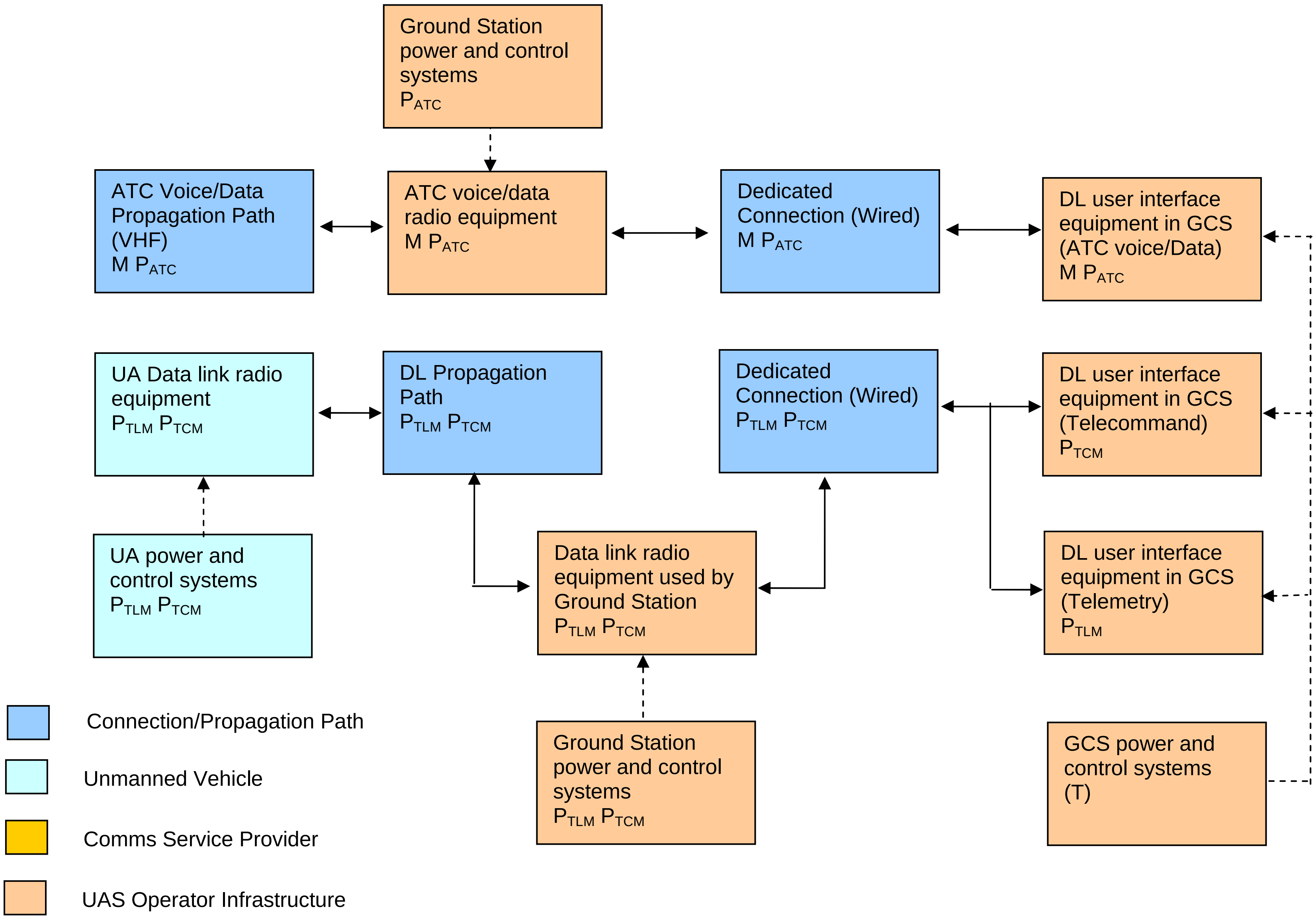
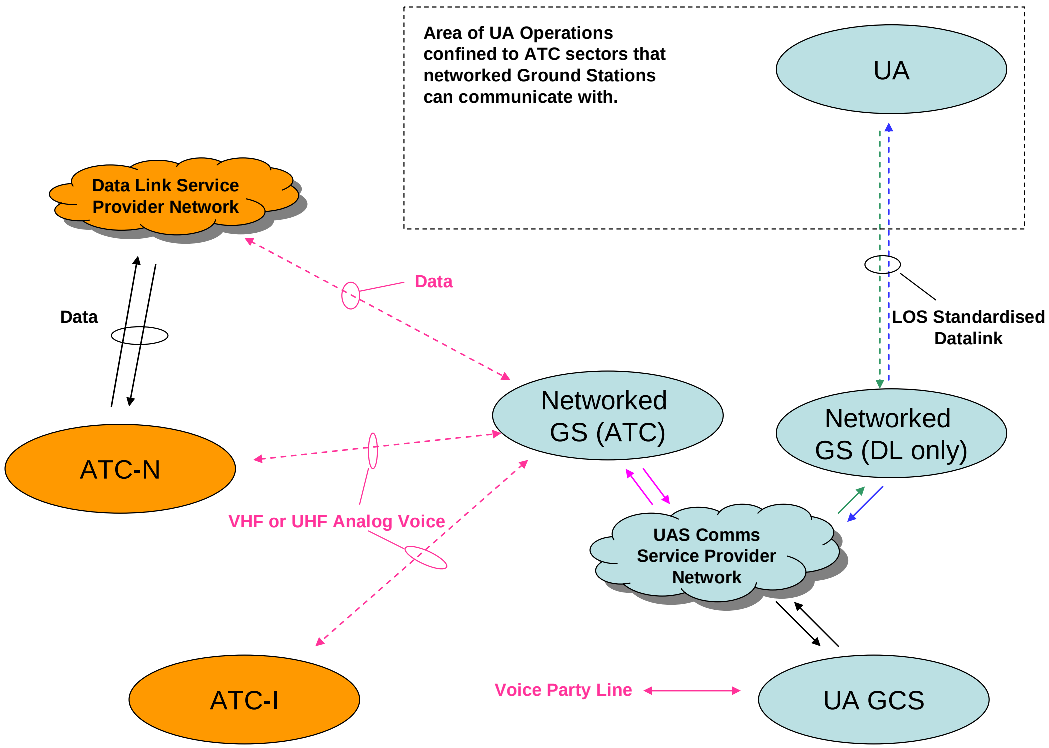
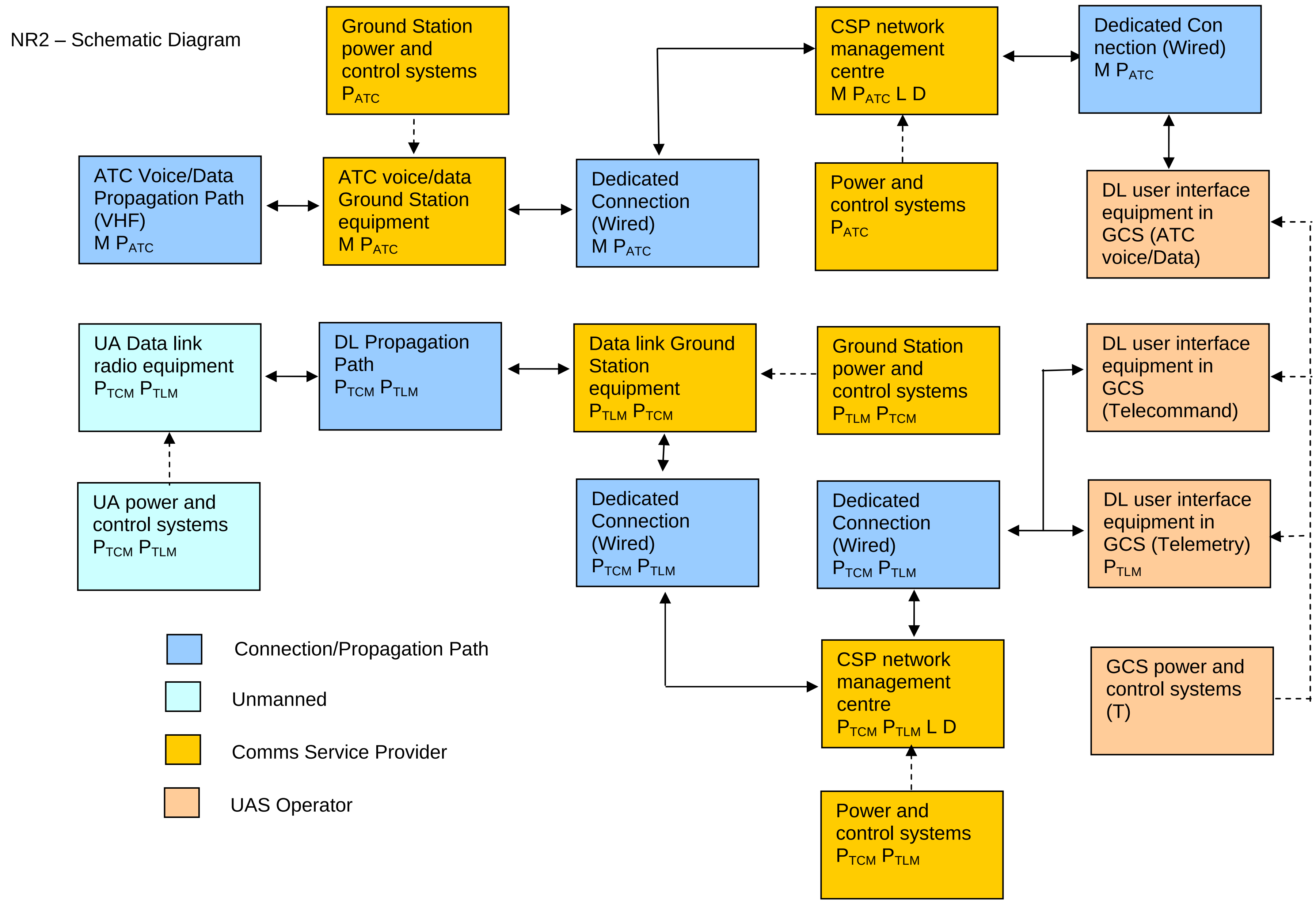
NR1 – Schematic Diagram



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

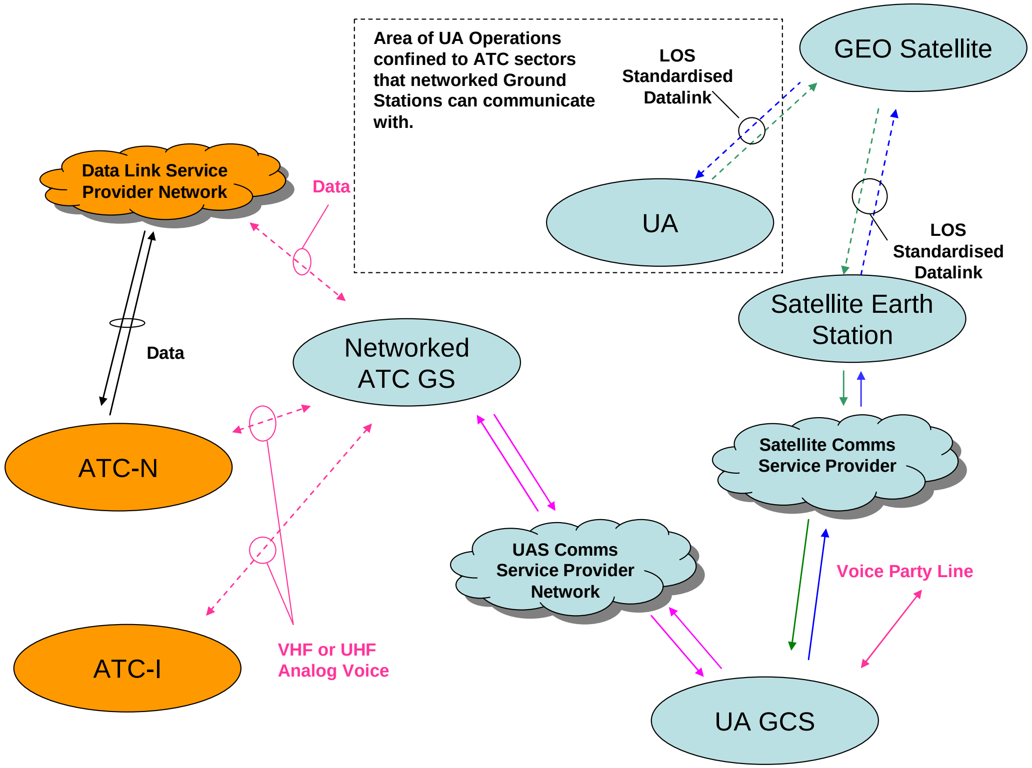
NR2 – Functional Diagram



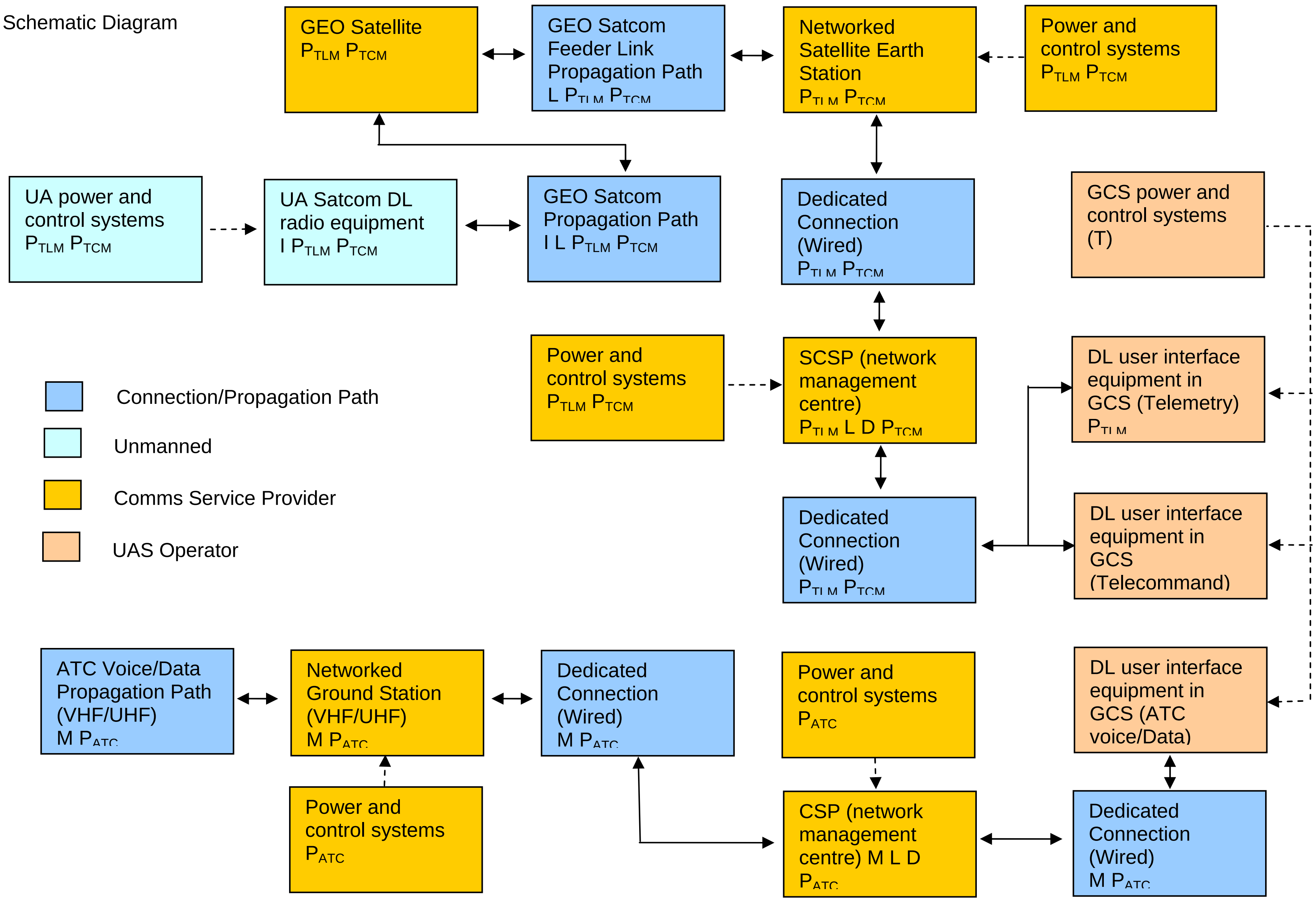

NR2 – Schematic Diagram
Ground Station power and control systems P_{ATC}
CSP network management centre M P_{ATC} L D
Dedicated Connection (Wired) M P_{ATC}
ATC Voice/Data Propagation Path (VHF) M P_{ATC}
ATC voice/data Ground Station equipment M P_{ATC}
Dedicated Connection (Wired) M P_{ATC}
Power and control systems P_{ATC}
DL user interface equipment in GCS (ATC voice/Data)
UA Data link radio equipment P_{TCM} P_{TLM}
DL Propagation Path P_{TCM} P_{TLM}
Data link 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}
Connection/Propagation Path
Unmanned
Comms Service Provider
UAS Operator
CSP network management centre P_{TCM} P_{TLM} L D
GCS power and control systems (T)
Power and control systems P_{TCM} P_{TLM}

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

NR3 – Functional Diagram



NR3 – Schematic Diagram



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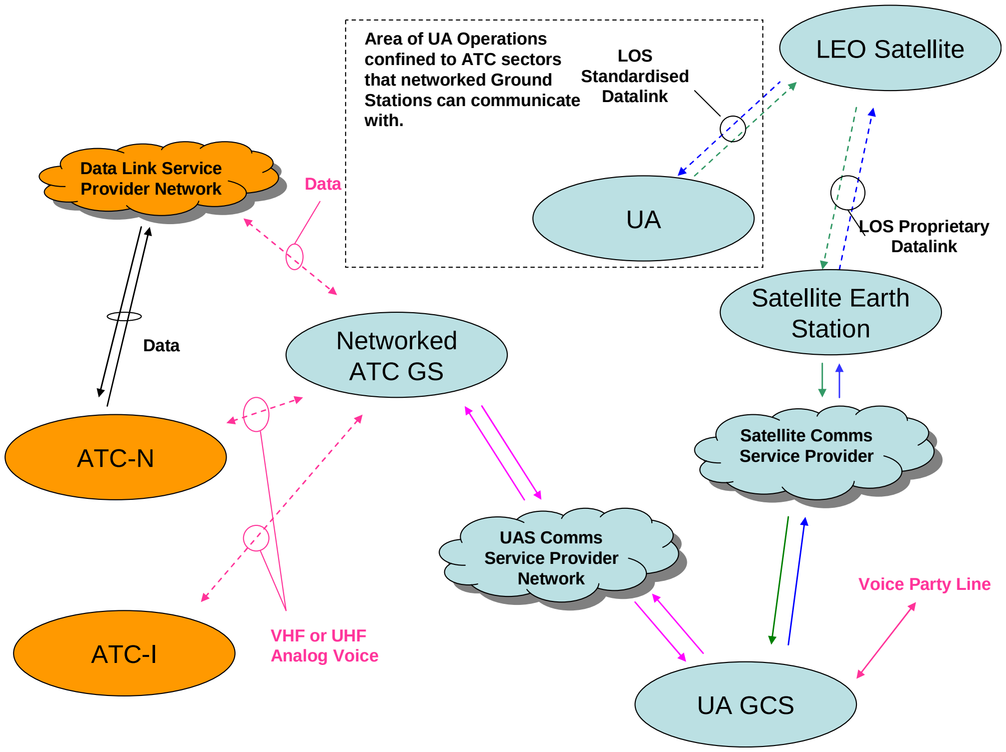
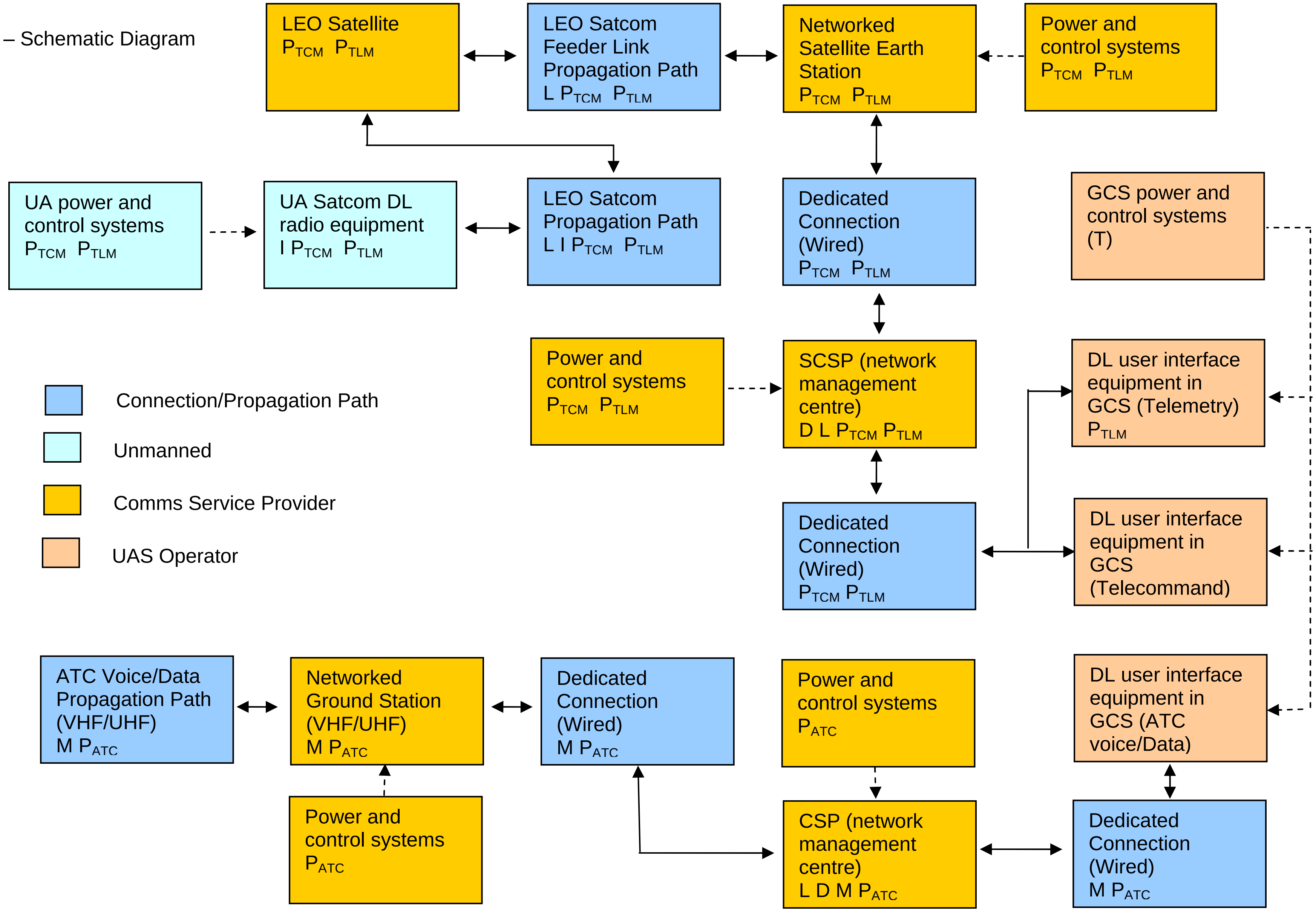
A.4.4 NR4 – ATC Voice/Data Communications via Networked Ground-based ATC Radio, TLM & TLC via Low Earth Orbit Satellite Data link (NNGR-LSD)

NR4 – Functional Diagram



NR4 – Schematic Diagram



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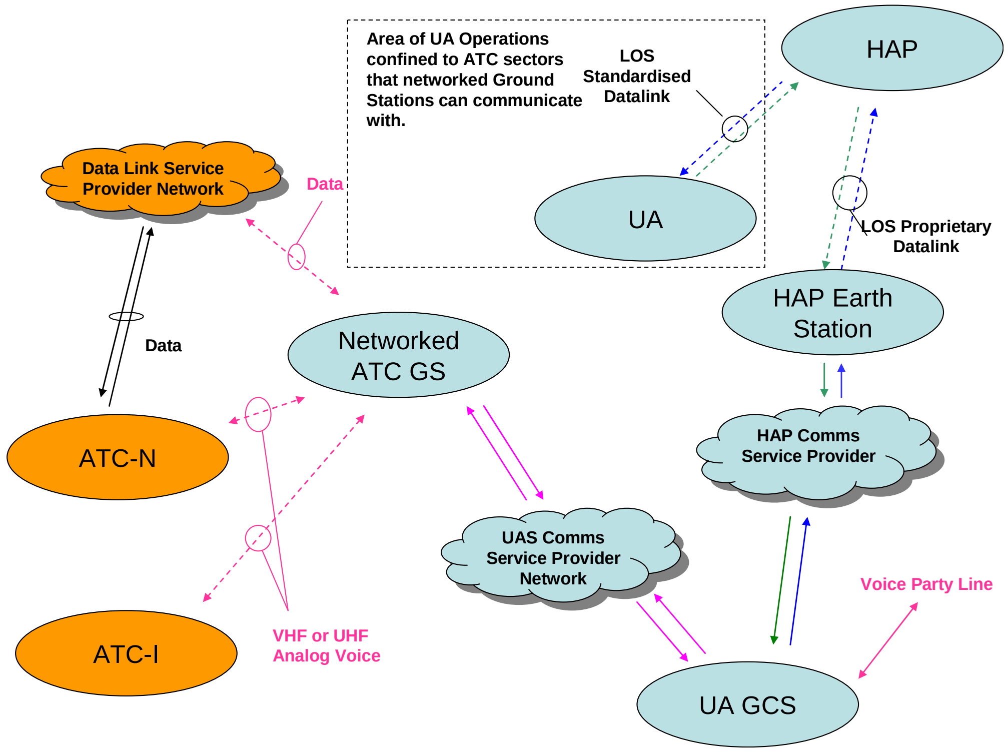
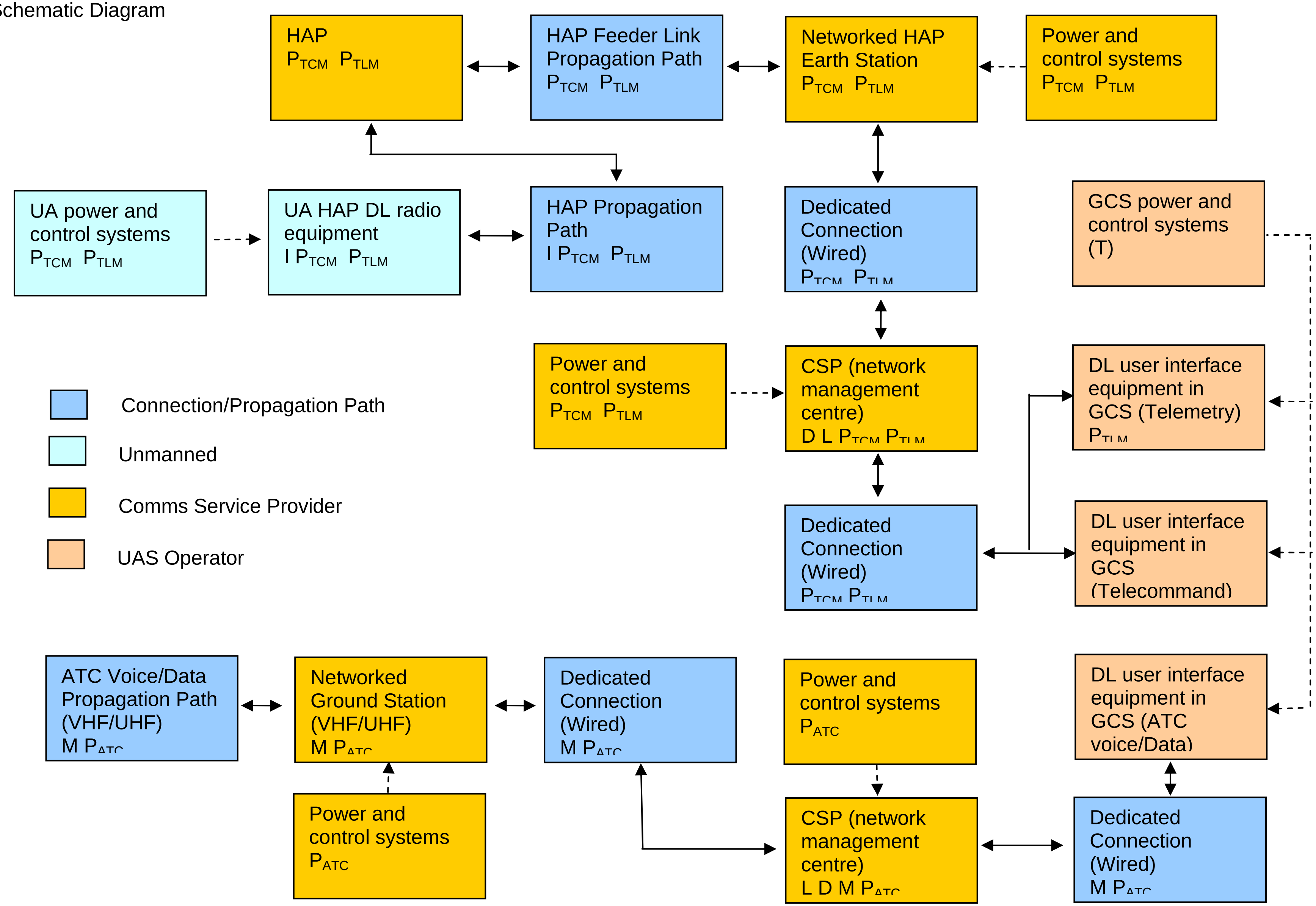
A.4.5 NR5 – ATC Voice/Data Communications via Networked Ground-based ATC Radio, TLM & TLC via Low Earth Orbit Satellite Data link (NNGR-LSD)

NR5 – Functional Diagram

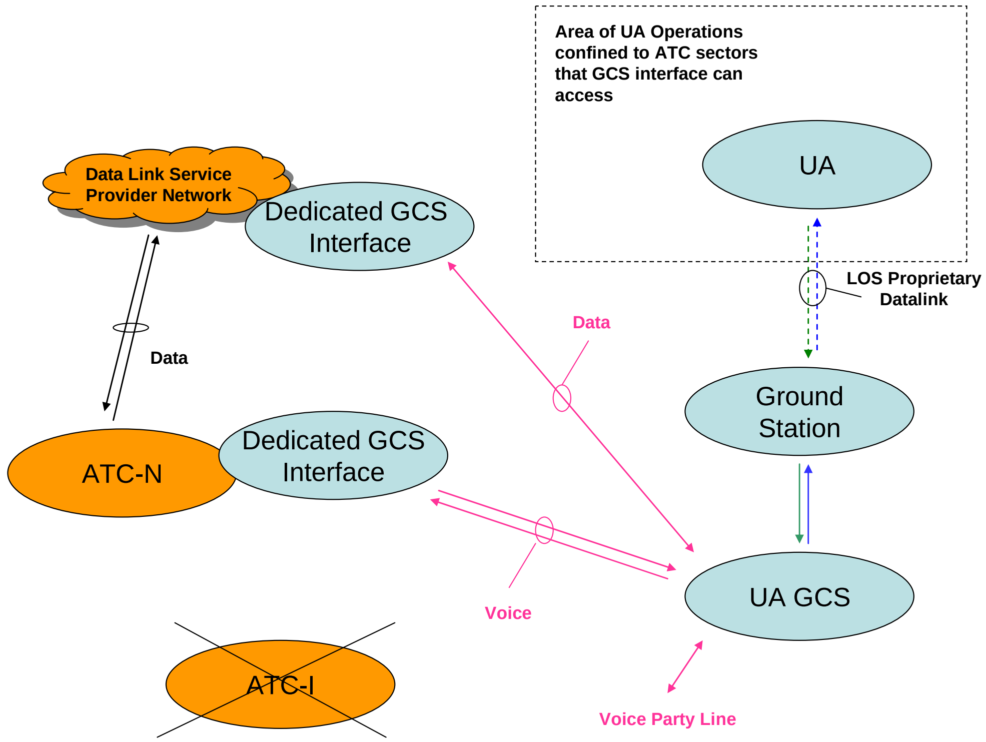


NR5 – Schematic Diagram

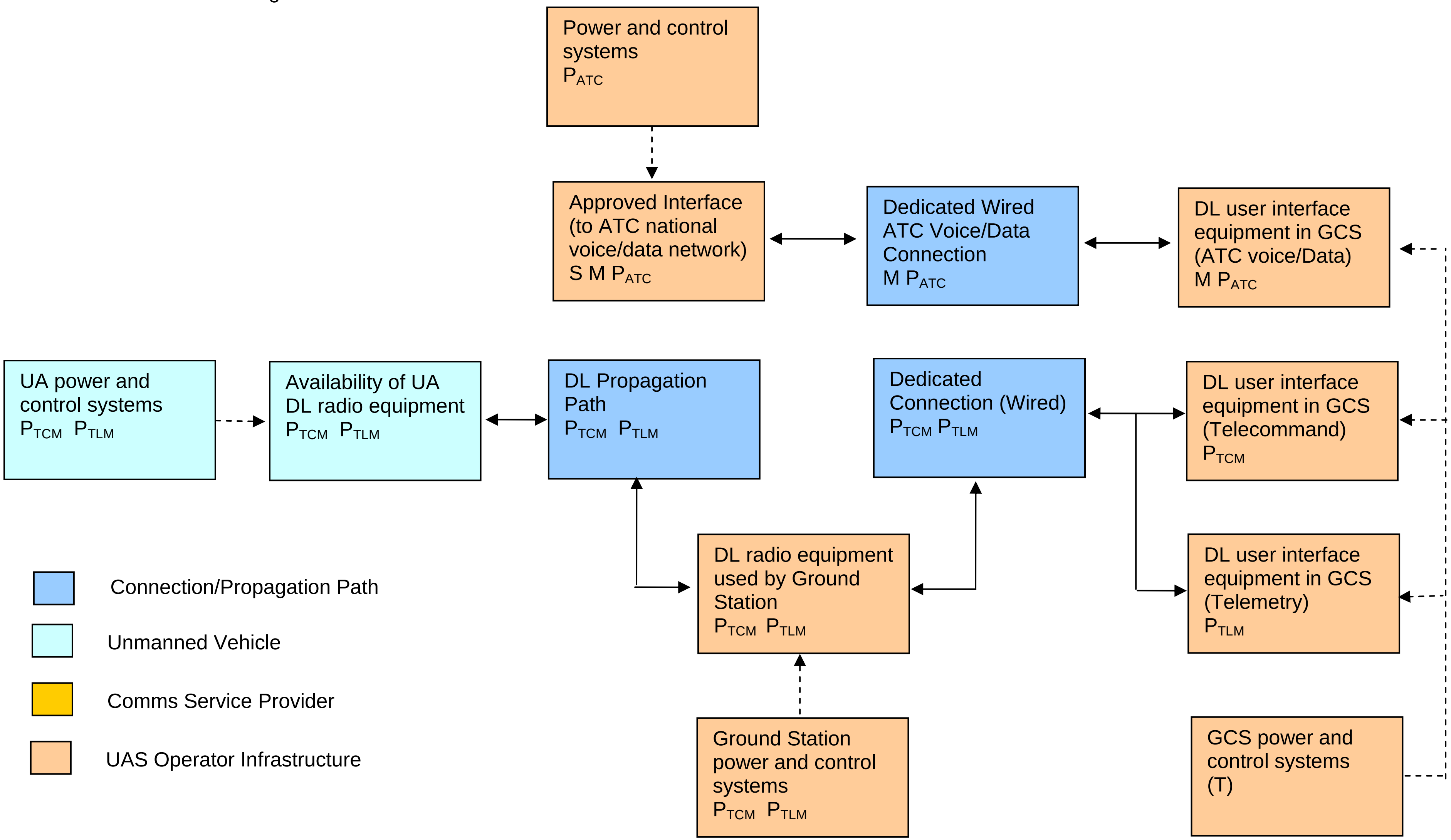


A.4.6 NR6 – ATC Voice/Data Communications via Dedicated Wired Interface, TLM & TLC via Dedicated Terrestrial Data link (NDW-DTD)

NR6 – Functional Diagram

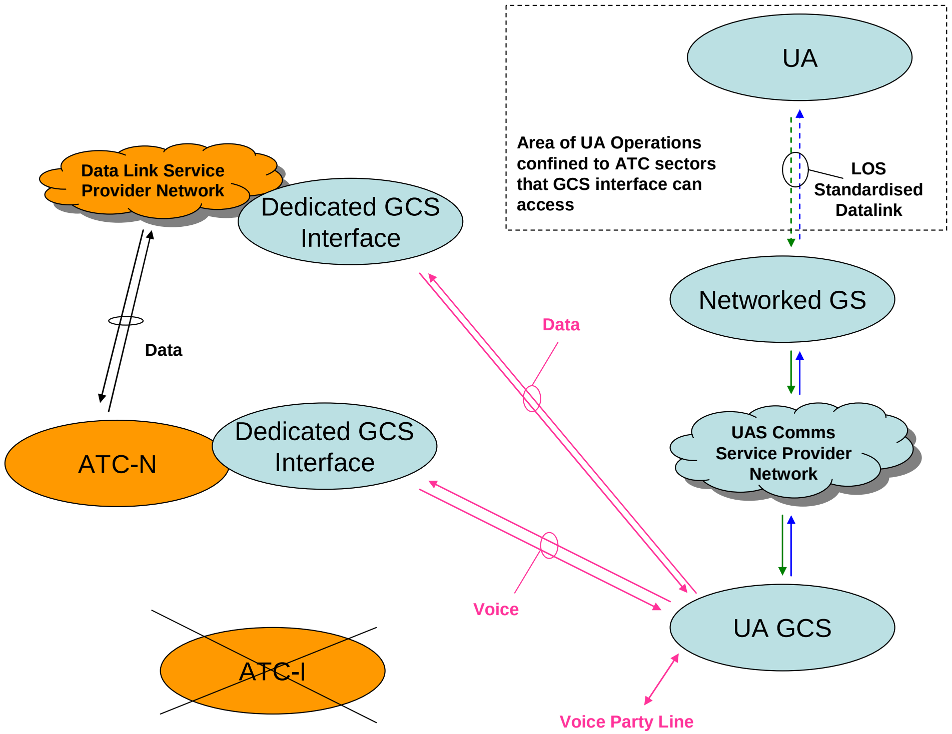


NR6 – Schematic Diagram

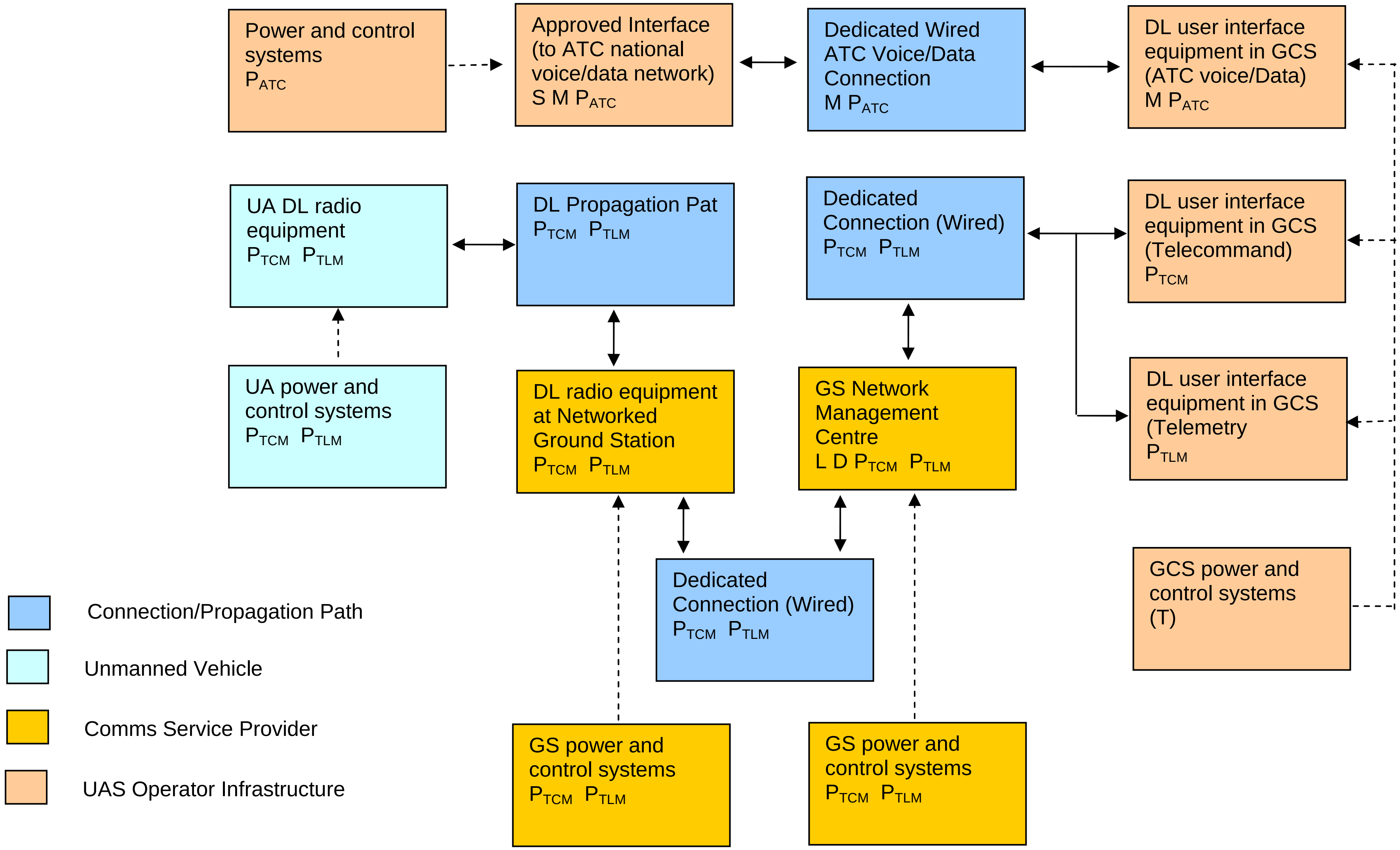


A.4.7 NR7 – ATC Voice/Data Communications via Dedicated Wired Interface, TLM & TLC via Networked Terrestrial Data link (NDW-NTD)

NR7 – Functional Diagram

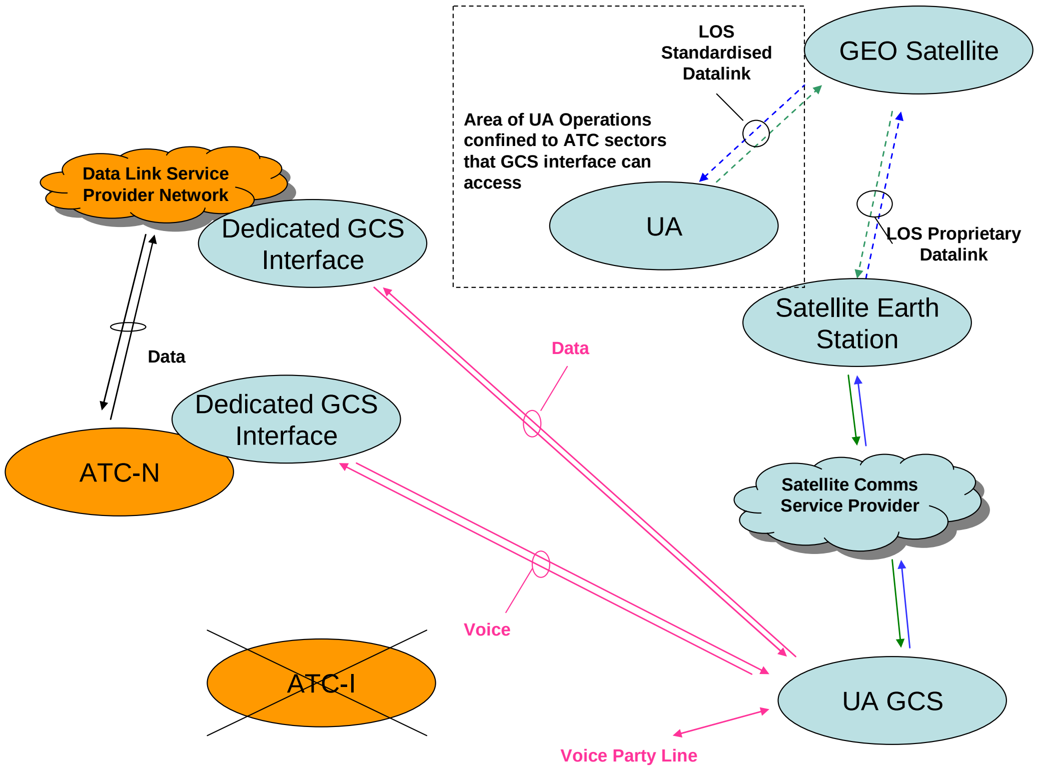


NR7 – Schematic Diagram

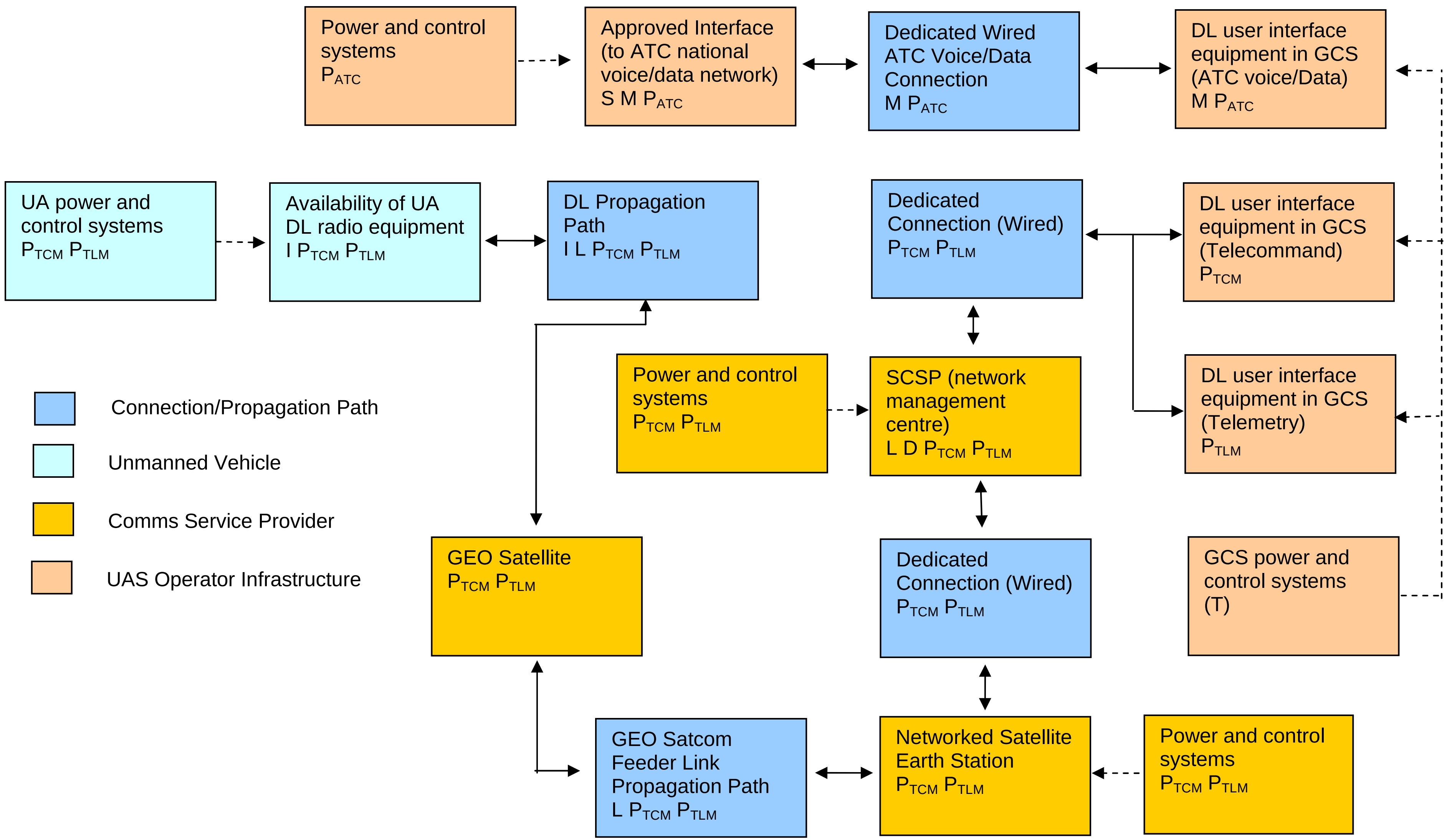


A.4.8 NR8 – ATC Voice/Data Communications via Dedicated Wired Interface, TLM & TLC via Geostationary Satellite Data link (NDW-GSD)

NR8 – Functional Diagram



NR8 – Schematic Diagram



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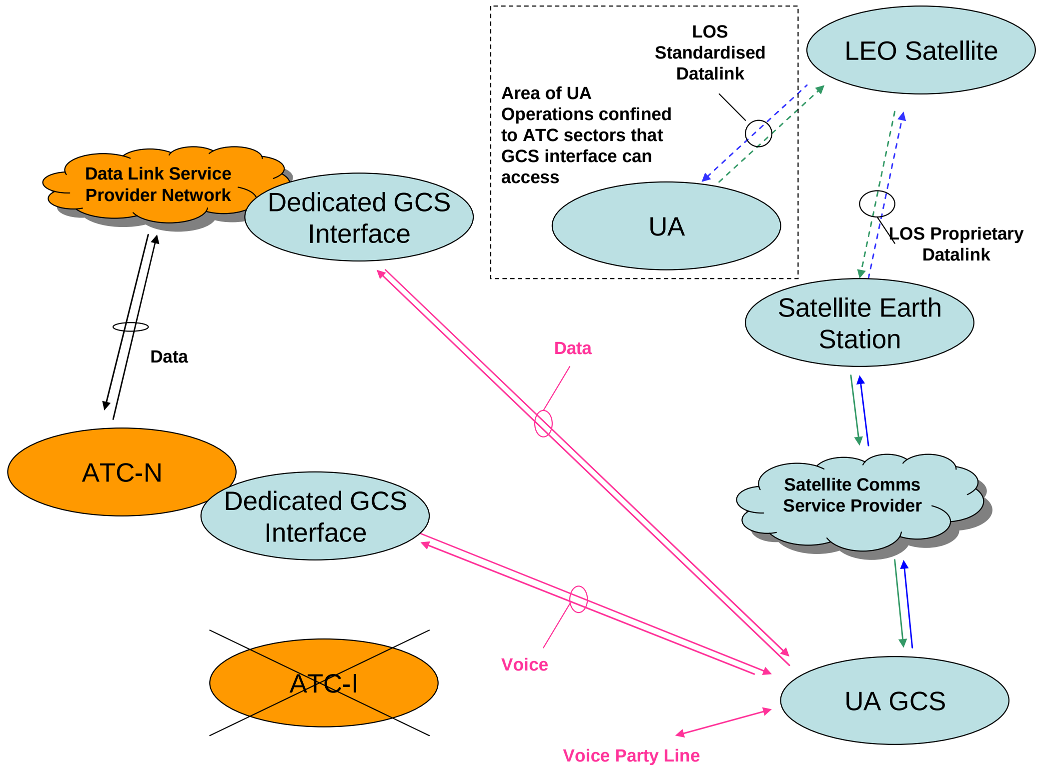
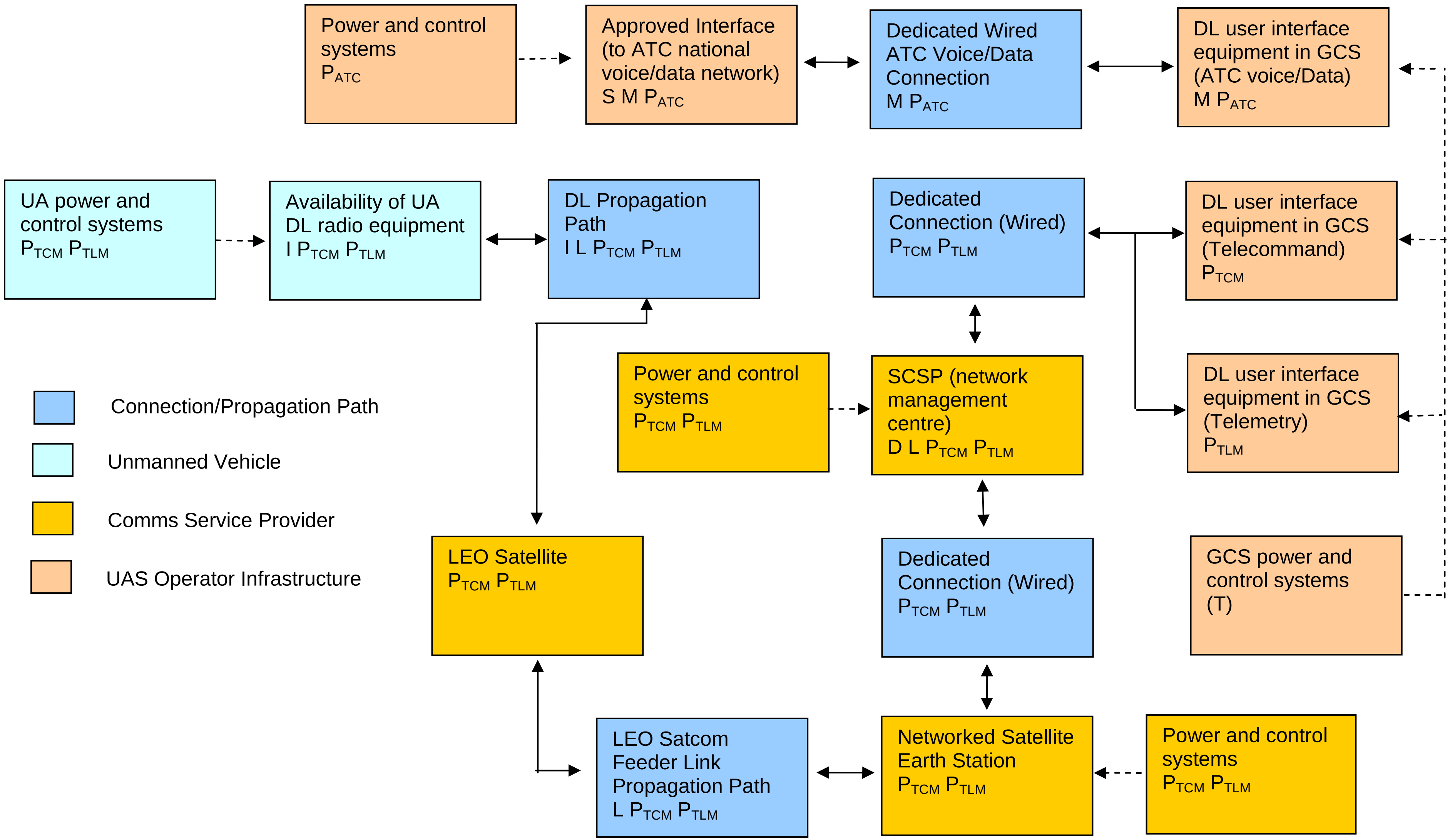
A.4.9 NR9 – ATC Voice/Data Communications via Dedicated Wired Interface, TLM & TLC via Low Earth Orbit Satellite Data link (NDW-LSD)

NR9 – Functional Diagram



NR9 – Schematic Diagram



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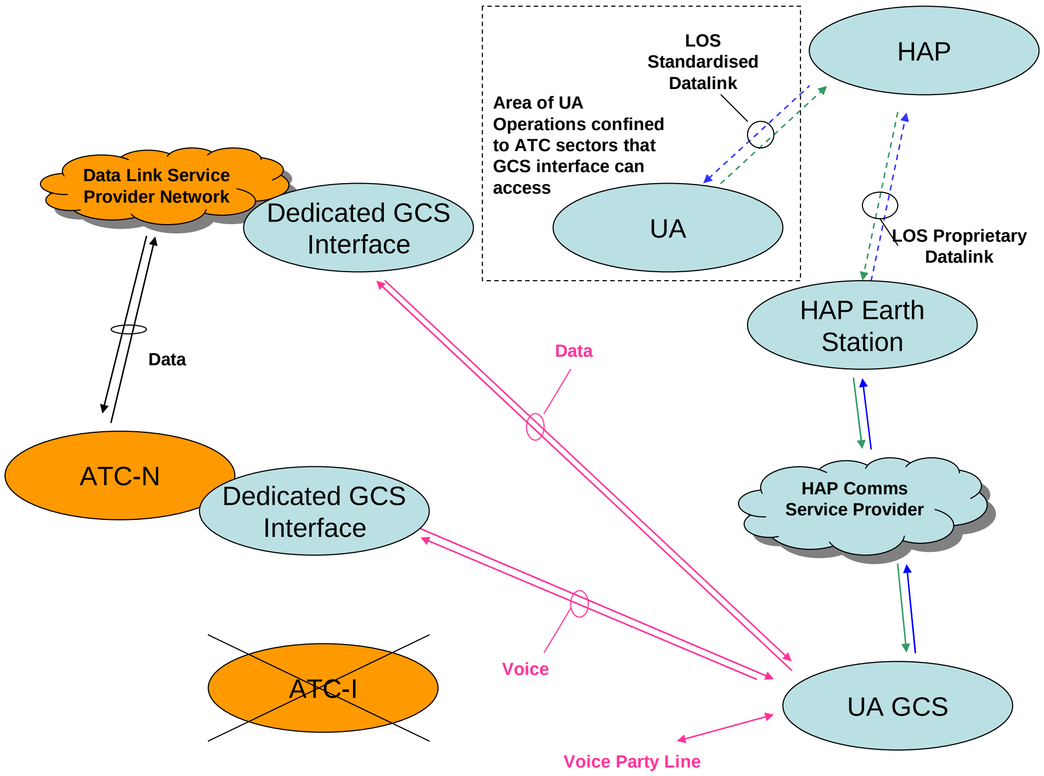
A.4.10 NR10 – ATC Voice/Data Communications via Dedicated Wired Interface, TLM & TLC via High Altitude Platform Data link (NDW-HD)

NR10 – Functional Diagram



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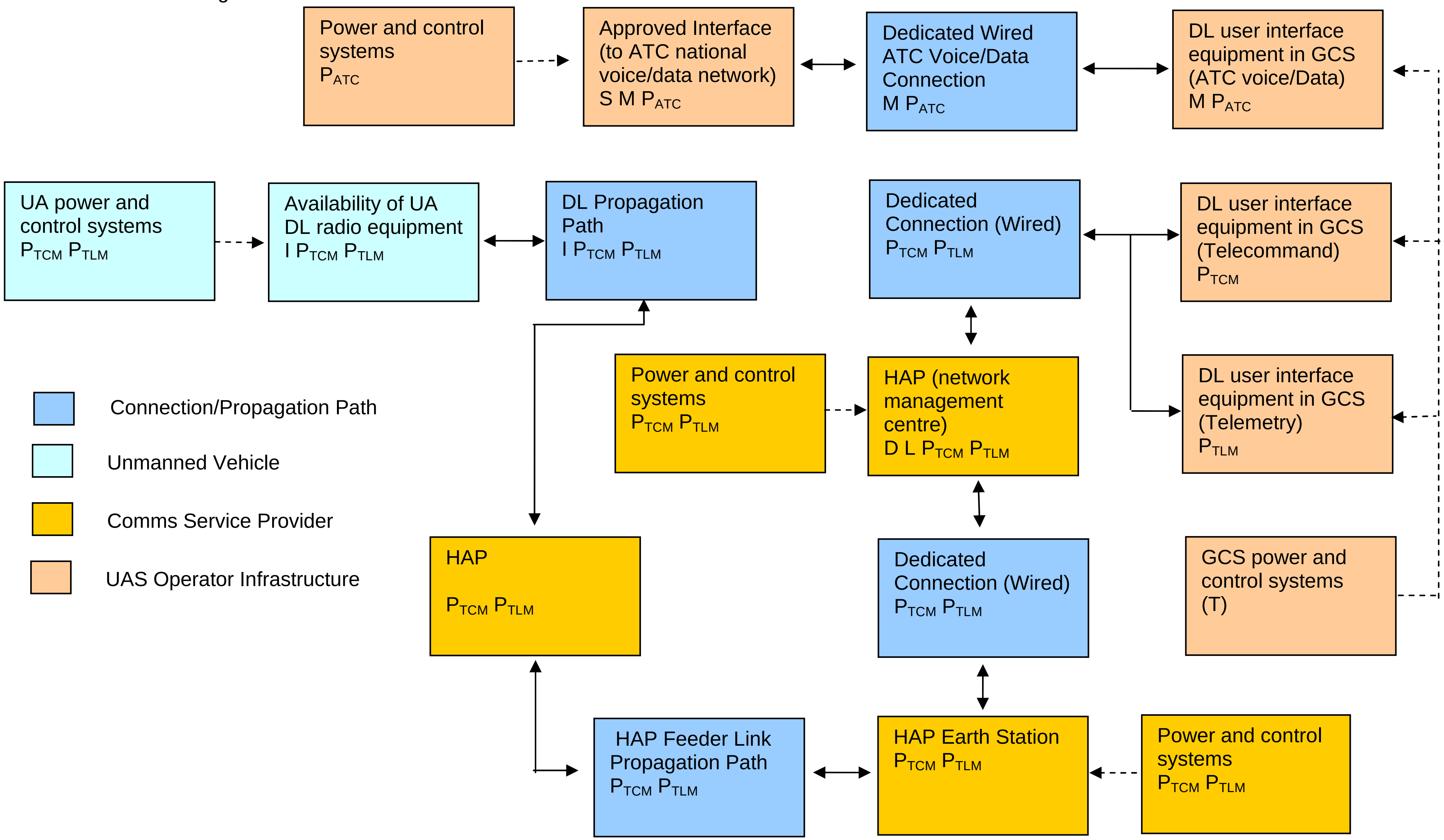
NR10 – Schematic Diagram



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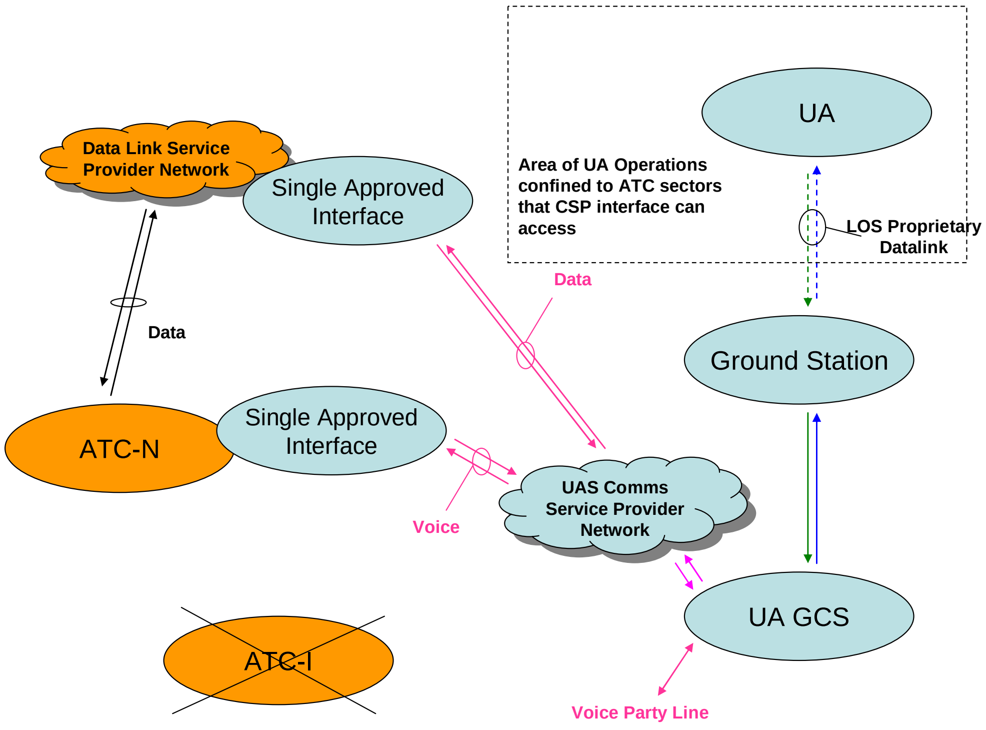
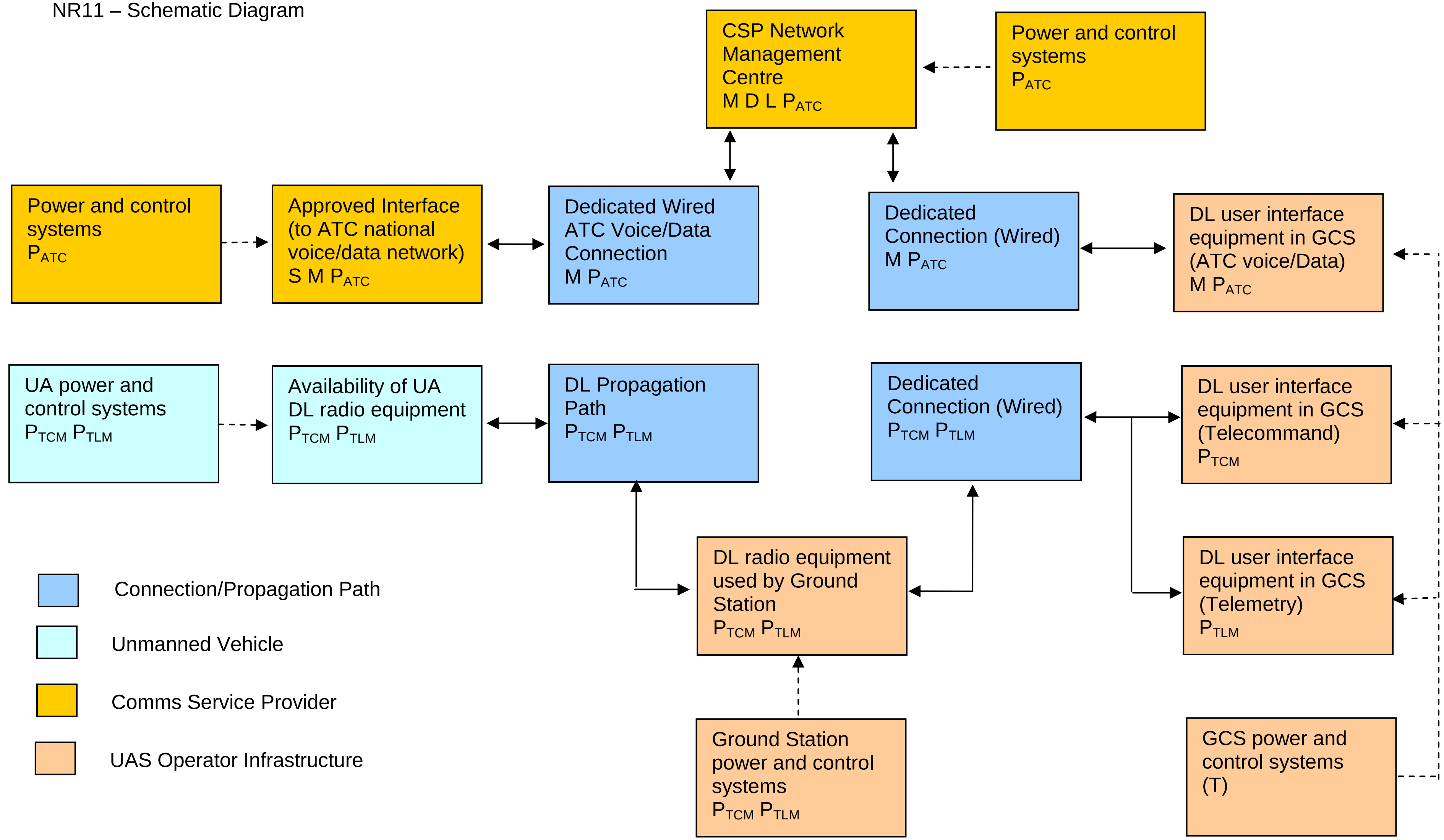
A.4.11 NR11 – ATC Voice/Data Communications via Networked Wired Interface, TLM & TLC via Dedicated Terrestrial Data link (NNW-DTD)

NR11 – Functional Diagram

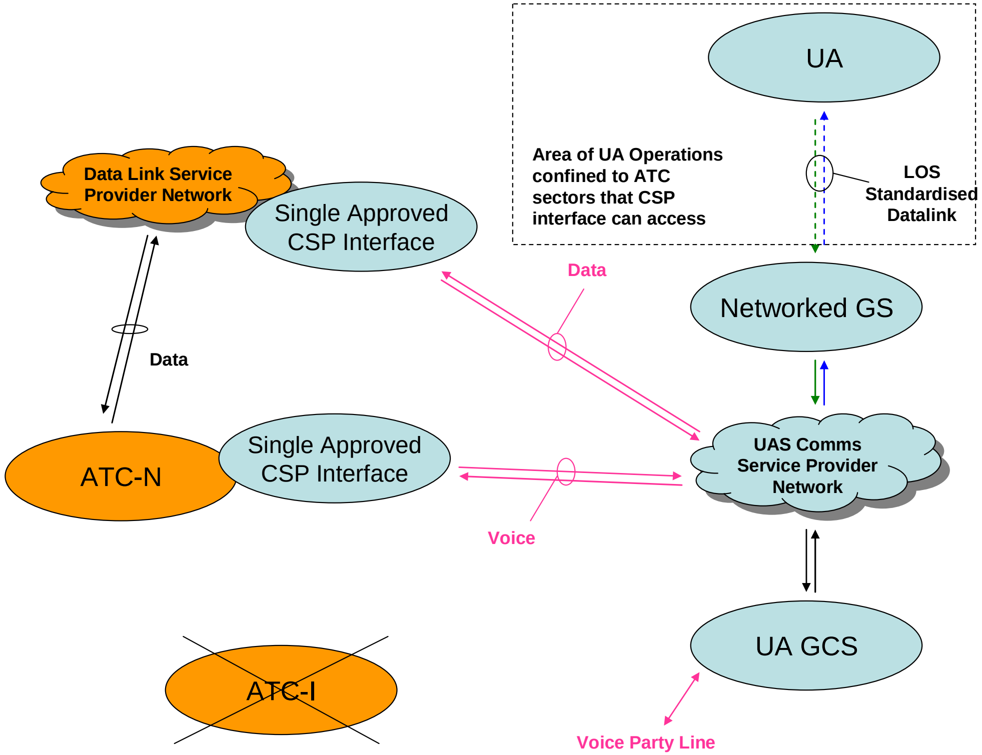


NR11 – Schematic Diagram

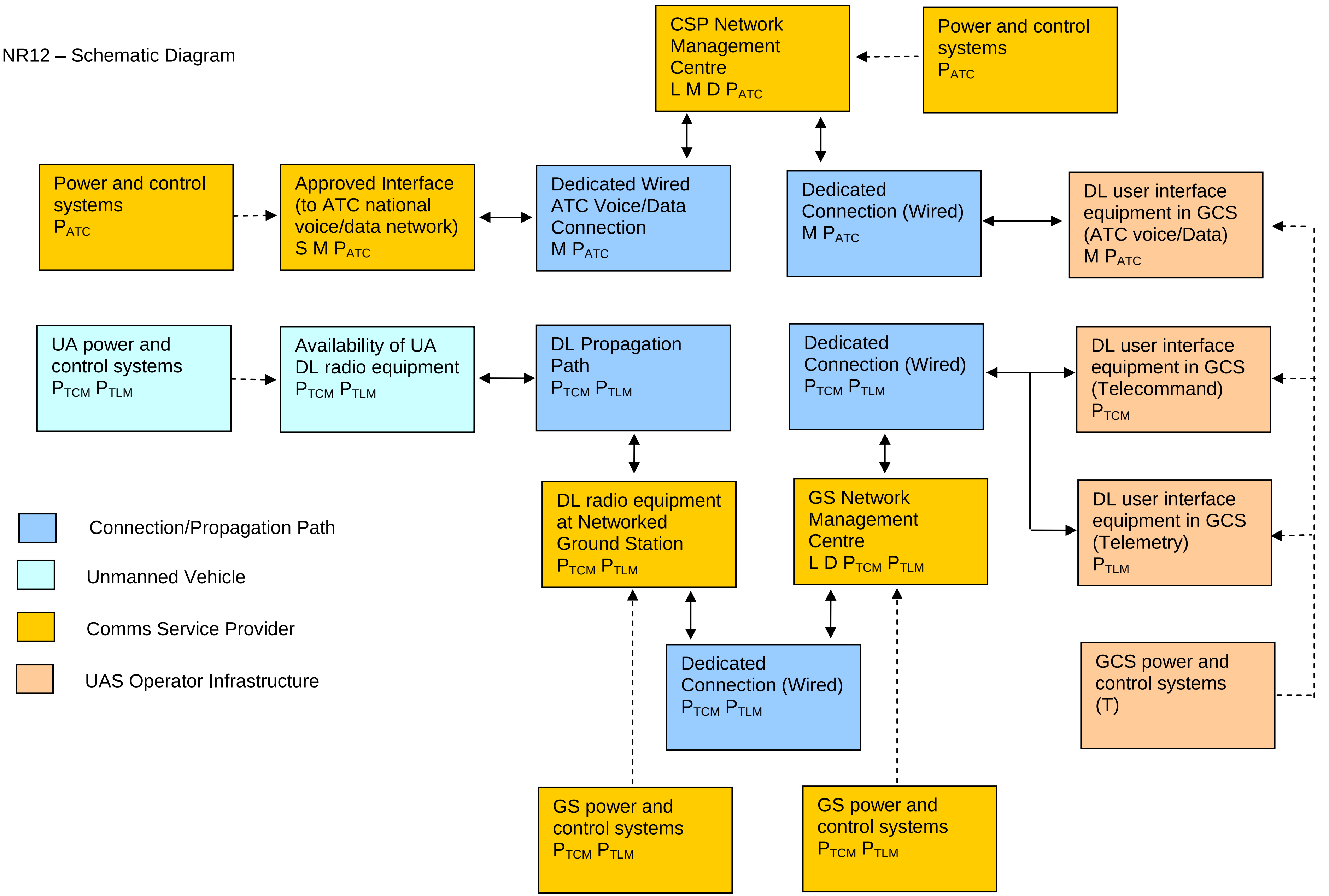


A.4.12 NR12 – ATC Voice/Data Communications via Networked Wired Interface, TLM & TLC via Networked Terrestrial Data link (NNW-NTD)

NR12 – Functional Diagram



NR12 – Schematic Diagram



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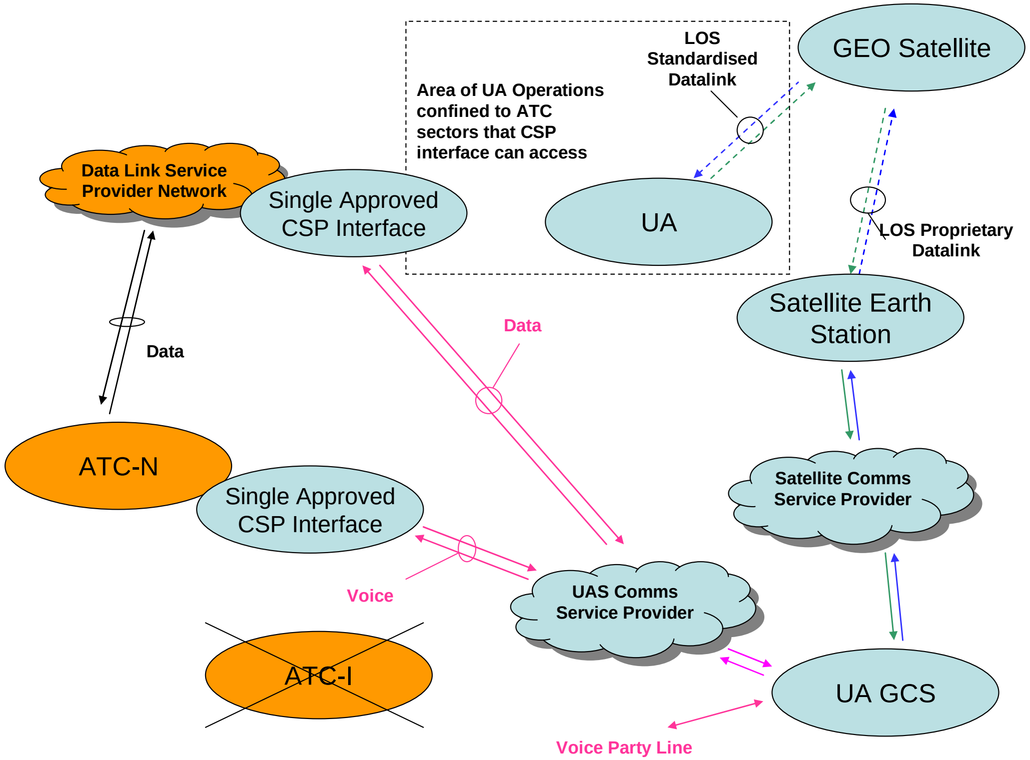
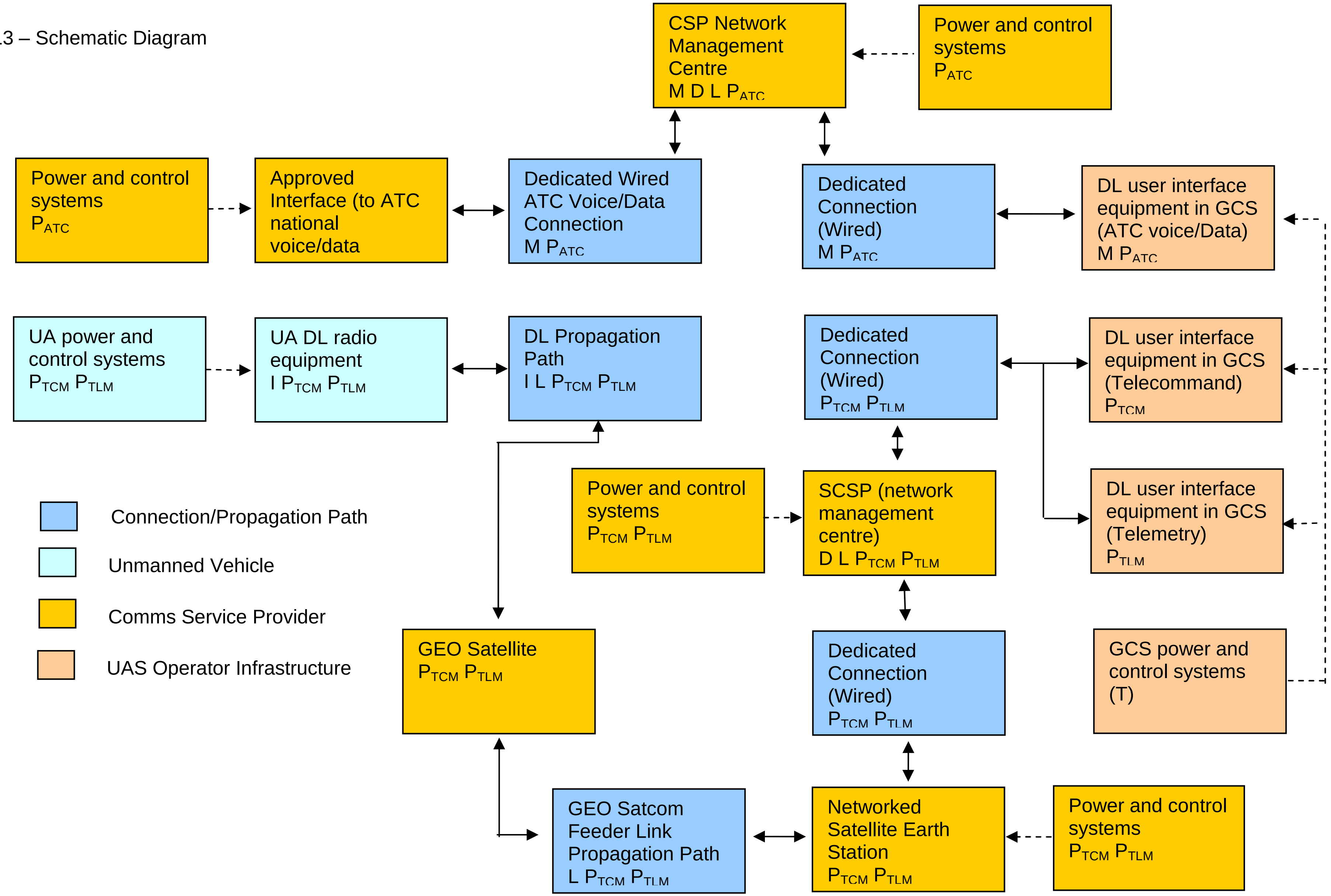
A.4.13 NR13 – ATC Voice/Data Communications via Networked Wired Interface, TLM & TLC via Geostationary Satellite Data link (NNW-GSD)

NR13 – Functional Diagram



NR13 – Schematic Diagram



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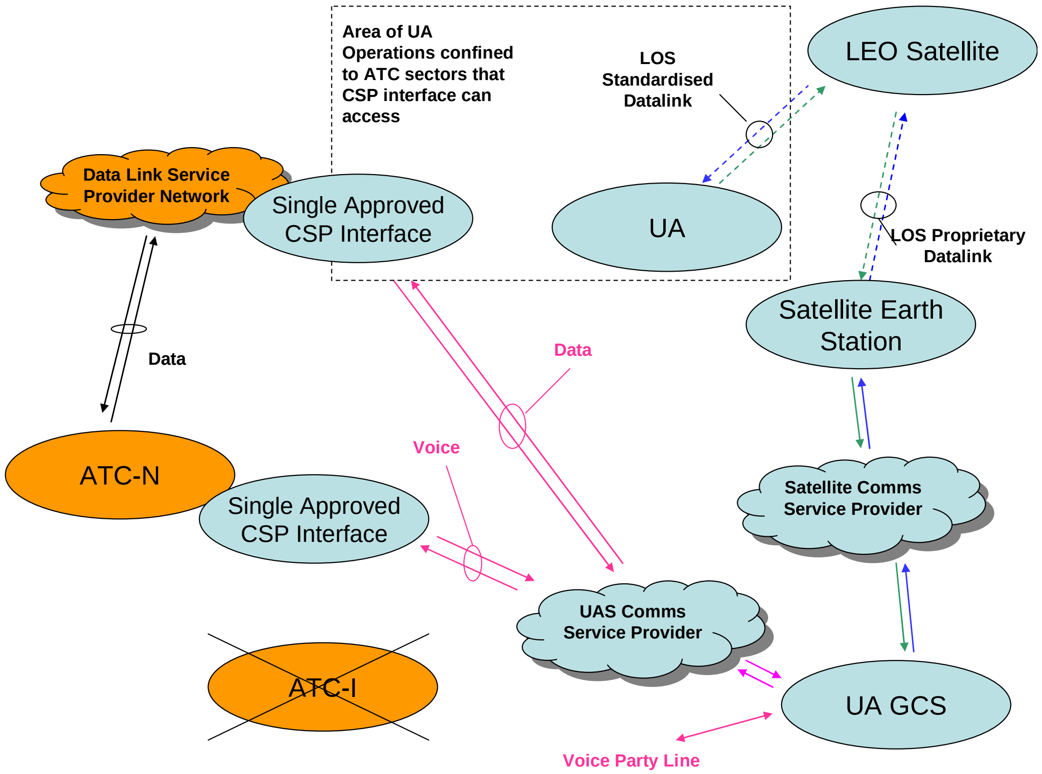
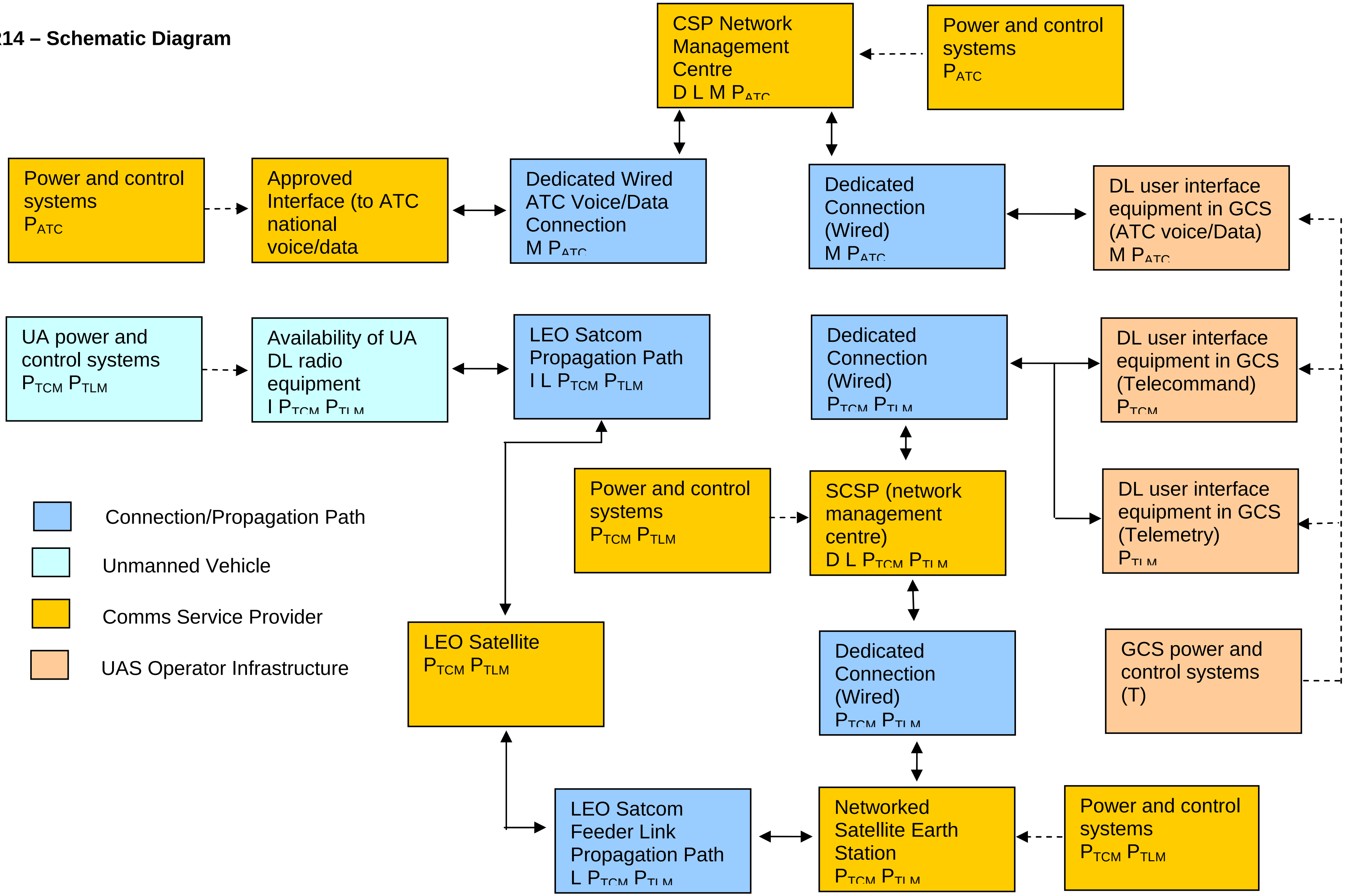
A.4.14 NR14 – ATC Voice/Data Communications via Networked Wired Interface, TLM & TLC via Low Earth Orbit Satellite Data link (NNW-LSD)

NR14 – Functional Diagram

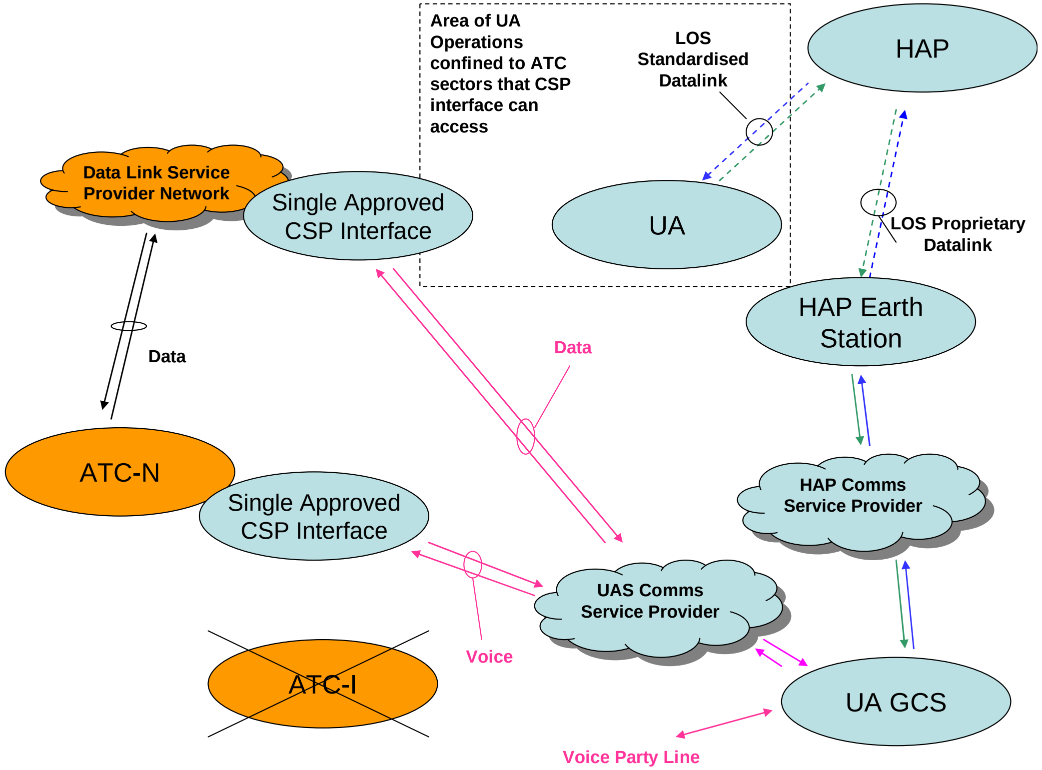


NR14 – Schematic Diagram

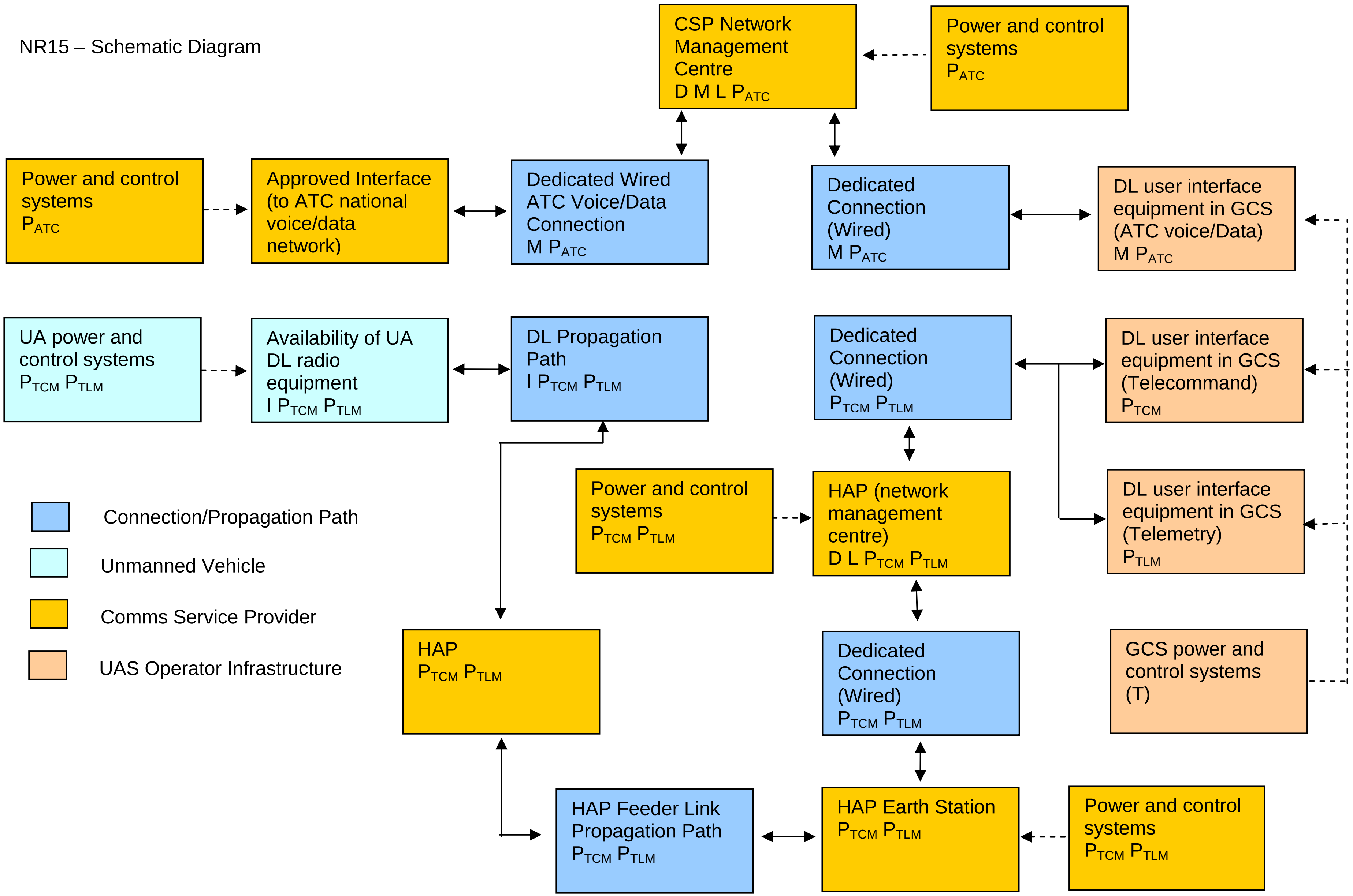


A.4.15 NR15 – ATC Voice/Data Communications via Networked Wired Interface, TLM & TLC via High Altitude Platform Data link (NNW-HD)

NR15 – Functional Diagram



NR15 – Schematic Diagram



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								

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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 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.

C.1 Candidate architectures Diagrams

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

C.2 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	Data link (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	Data link 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.

C.3 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.

C.4 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.

C.5 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)

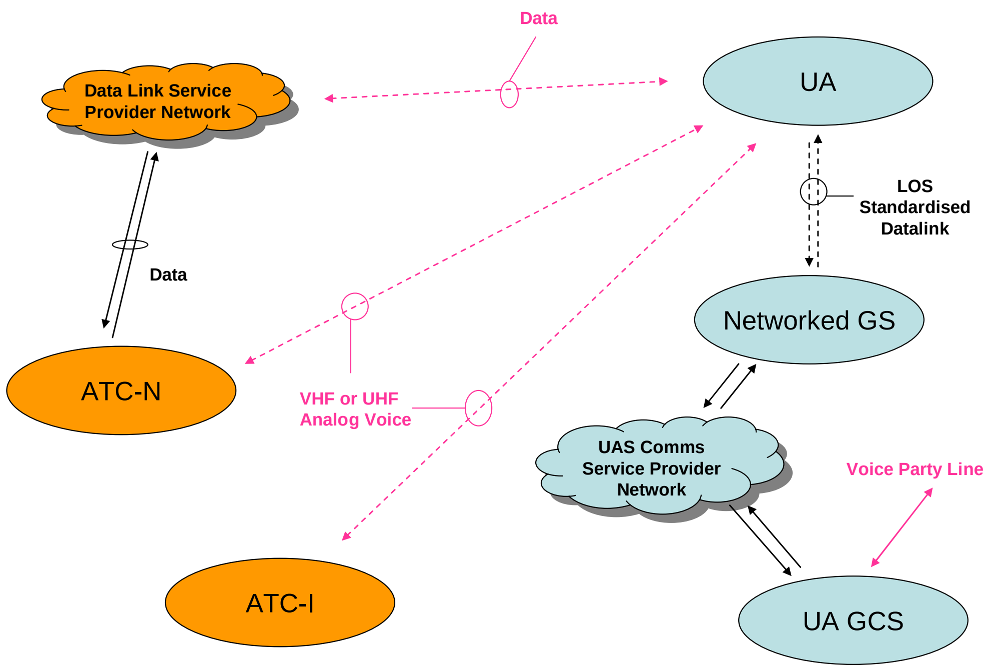
L – Potential for system element to introduce significant latency

I – Potential for system element to be intermittent

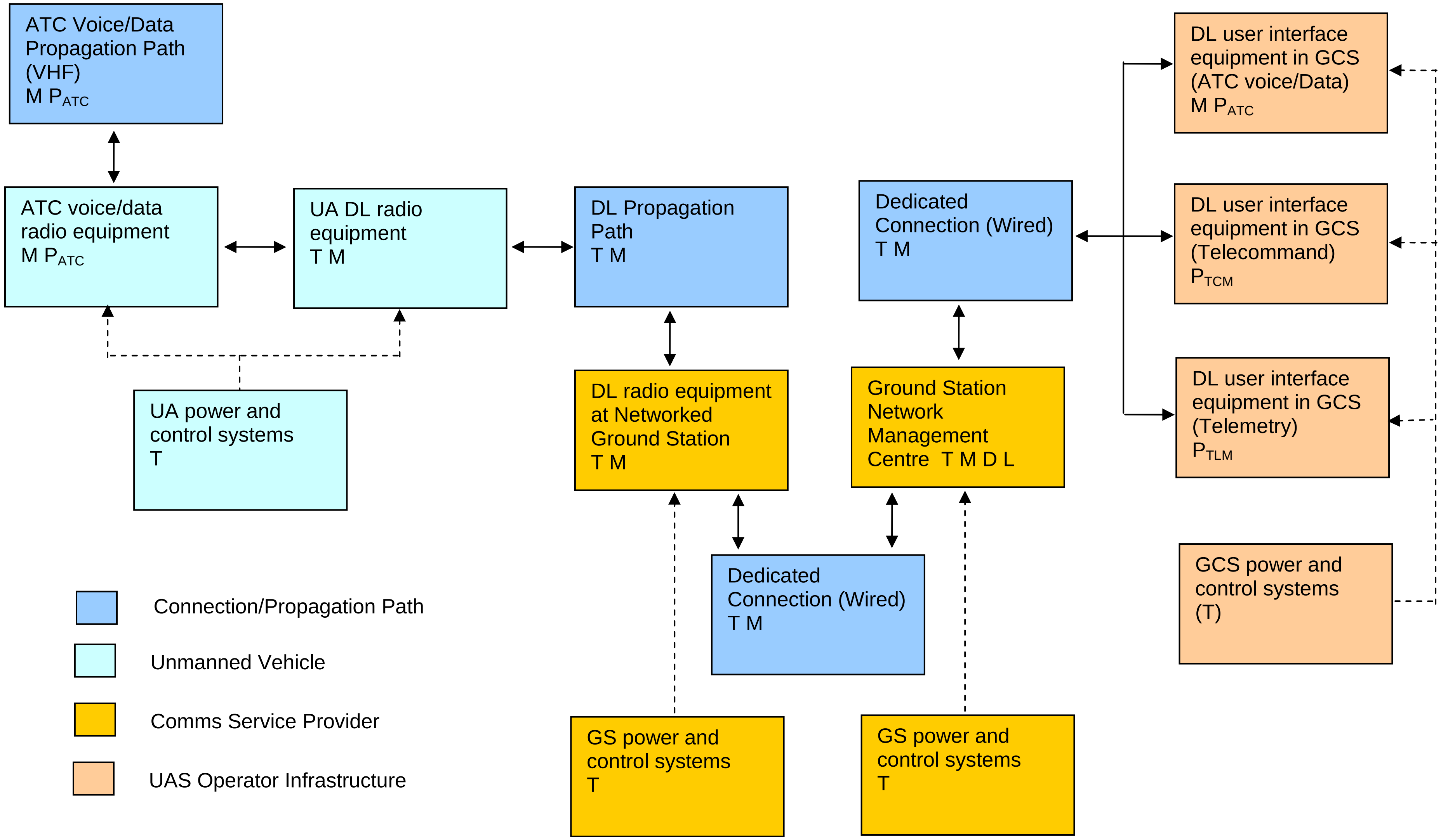
S – Potential for system element to fail through loss of synchronisation with other system elements

C.5.1 AR2 – ATC Voice/Data Communications, TLM & TCM via Networked Terrestrial Radio (ANTR)

AR2 – Functional Diagram

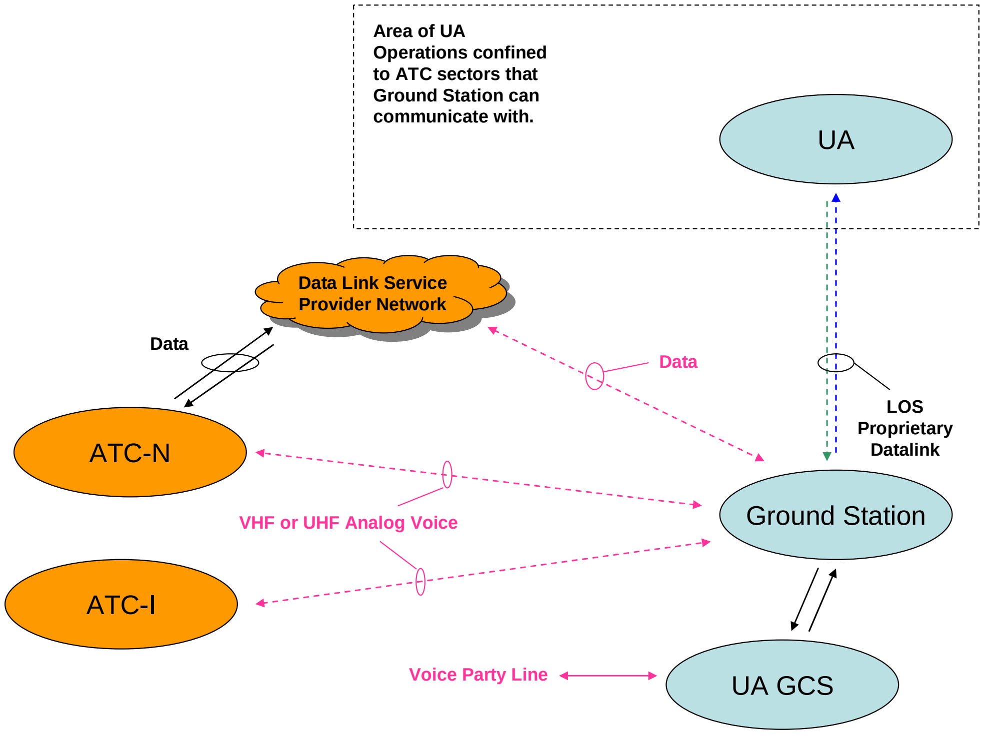


AR2 – Schematic Diagram

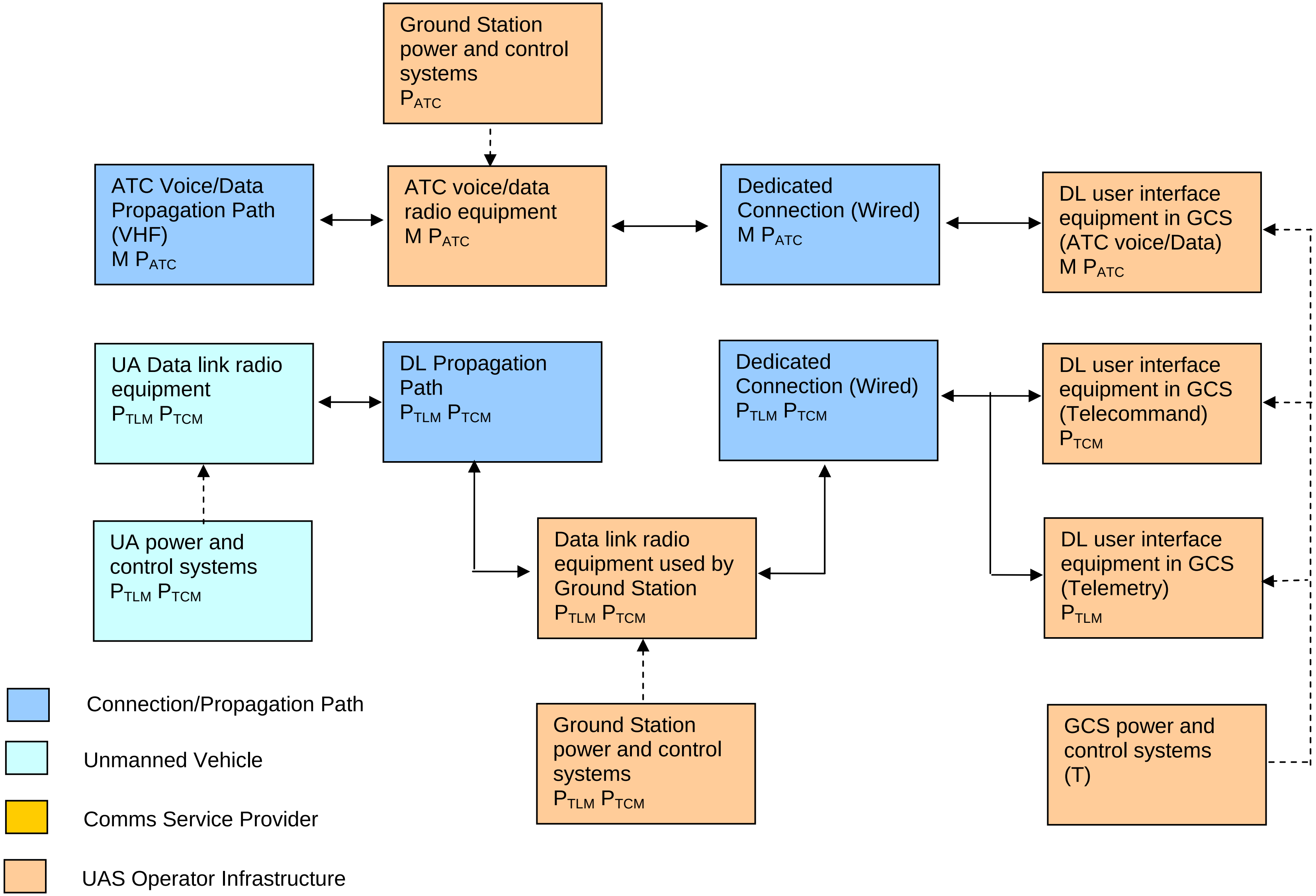


C.5.2 NR1 – ATC Voice/Data Communications via Dedicated Ground-based ATC Radio, TCM & TLM via Dedicated Terrestrial Data link (NDGR-DTD)

NR1 – Functional Diagram

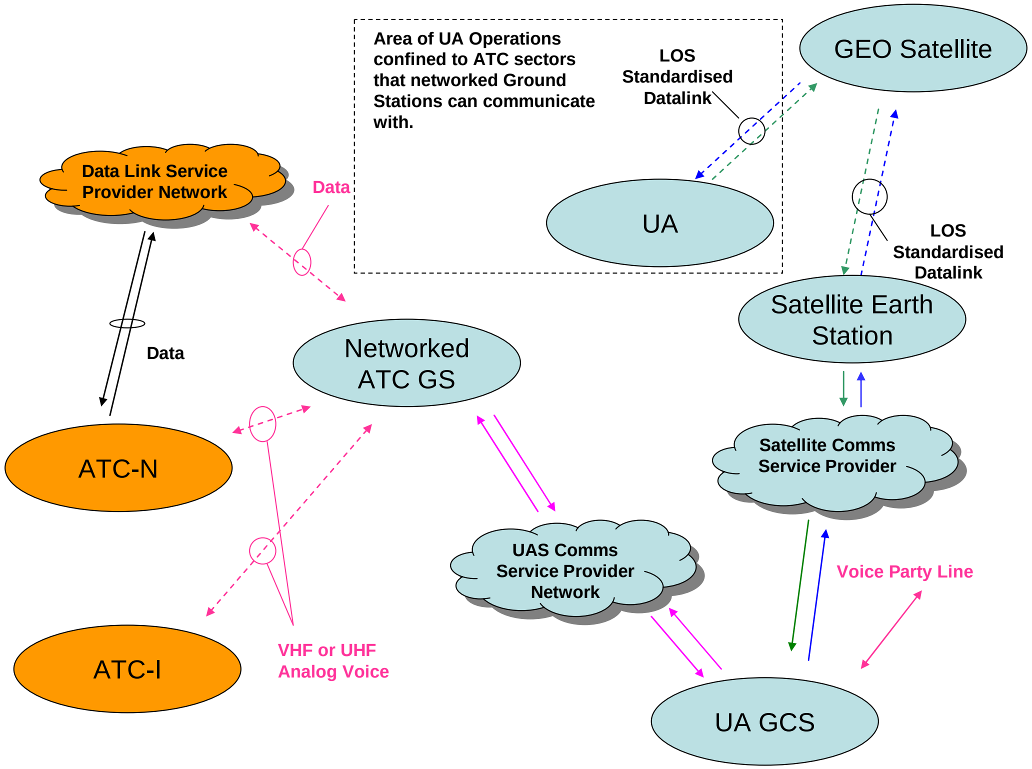


NR1 –
Schematic
Diagram

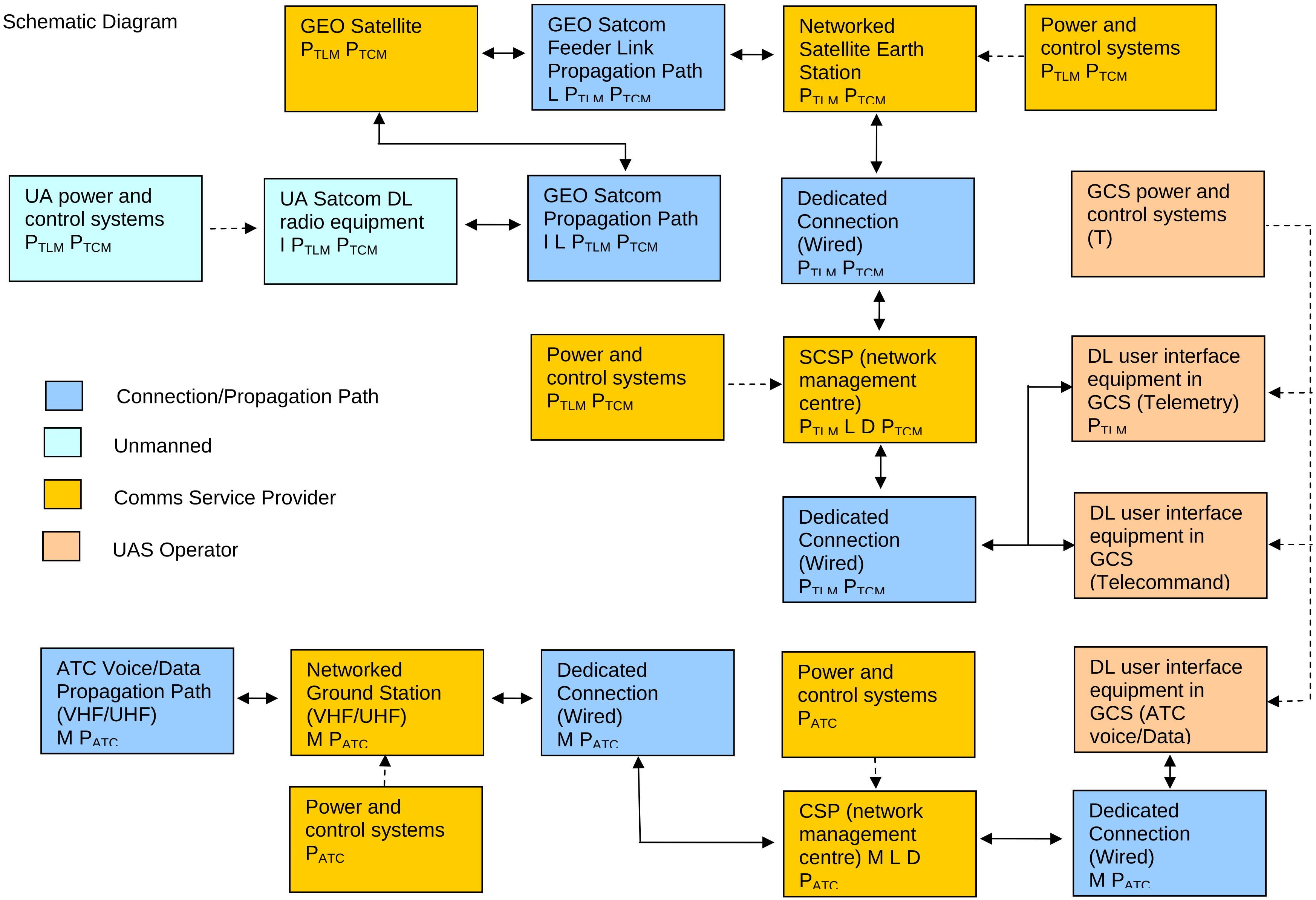


C.5.3 NR3 – ATC Voice/Data Communications via Networked Ground-based ATC Radio, TLM & TLC via Geostationary Satellite Data link (NNGR-GSD)

NR3 – Functional Diagram

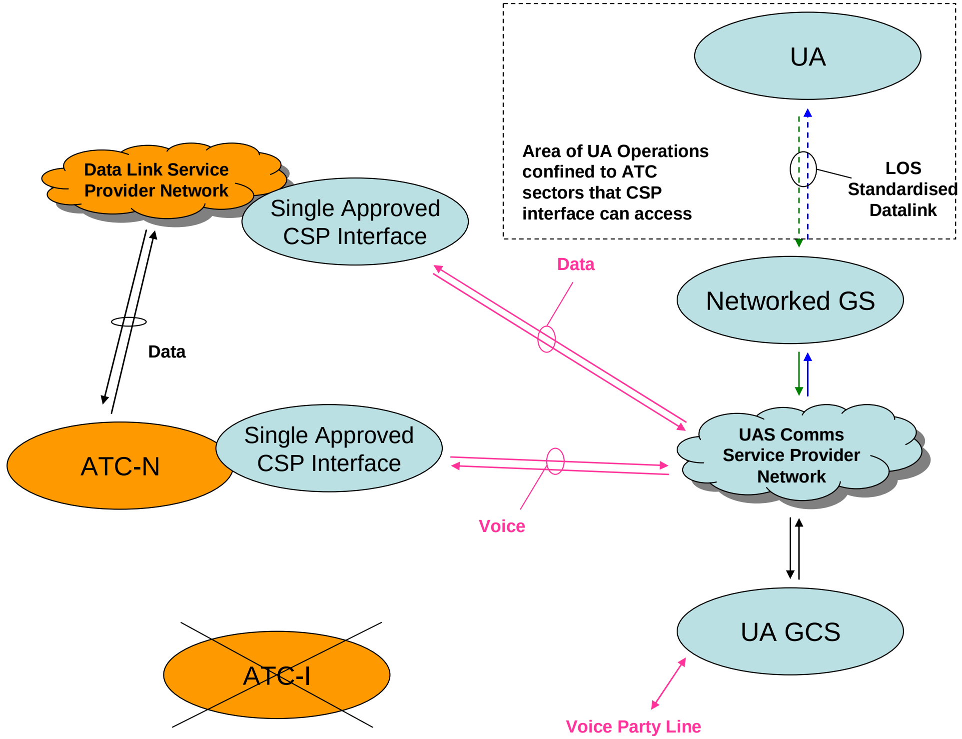


NR3 – Schematic Diagram



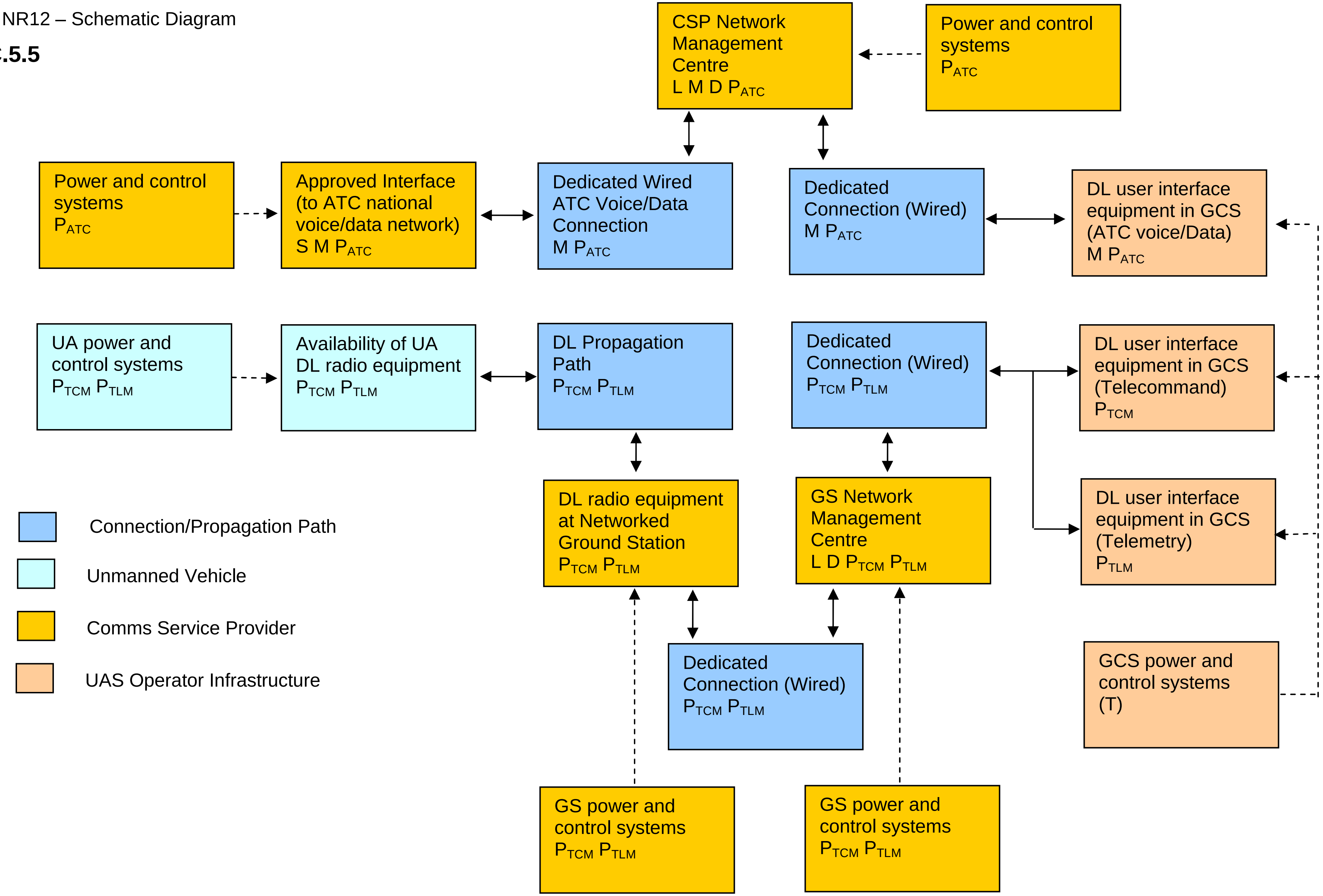
C.5.4 NR12 – ATC Voice/Data Communications via Networked Wired Interface, TLM & TLC via Networked Terrestrial Data link (NNW-NTD)

NR12 – Functional Diagram



NR12 – Schematic Diagram

C.5.5



D Group 2 Stakeholder Questionnaire

Page 1: Information for Respondents

The purpose of this questionnaire is to gain a wide cross section of stakeholder opinion on communication infrastructures for Unmanned Aircraft Systems (UAS). The aim is to gain general opinion in the areas of UAS development, regulation and operation. Collection of the results is being performed by QinetiQ Ltd* in the UK on behalf of EASA.

The results of this questionnaire will not be publicly attributable to any individual and/or organisation and any such information is treated with strictest confidence. Information obtained will not be used for any other purpose or passed to any other organisation. An analysis of results will be included within the final EASA report for the project 'Preliminary Impact Assessment for UAS communication systems.' Your opinions are vital to the development of civil UAS and inclusion within the preliminary impact assessment; this is an important initial input to the Regulatory Impact Assessment (RIA) process.

Note: You may answer the questionnaire multiple times to reflect the needs of different UAS roles or applications.

In order to progress through this survey, please use the following navigation links:

- Click the Next >> button to continue to the next page.
- Click the Previous >> button to return to the previous page.
- Click the Submit >> button to submit your survey.

NOTE: If you do not have an opinion/answer on a particular question please leave the question blank.

*QinetiQ strictly adheres to a Third Party Information Policy which mandates the storage and management of data in accordance with the UK Data Protection Act 1998.

Page 2: Contact Information

What is your role within the Unmanned Aerial System (UAS) industry?

UA/S Manufacturer
UA/S Operator
Systems/Avionics manufacturer/supplier
Communication Service Provider
ANSP
Regulator
Support services – e.g. airport/ maintenance/ training – please specify
Other – please specify

Please fill in general information below:

Name
Company
Size of organisation (approximate no. of people employed)
Country
Email Address
Phone Number

Are you willing to be contacted by QinetiQ for clarification of answers if required?

Yes
No

Enter security code (from the invitation email)

PAGE 3: General Applications

In general it is recognised that UAS may require different communication links, such as:

- A command and control data link (C2) between the remote control station and the Unmanned Aircraft (UA);
- Voice/data communications (and the exchange of surveillance data) with Air Traffic Control (ATC) service providers;
- “Sense and avoid” in relation to neighbouring air traffic, severe weather, terrain;
- “Payload” data link (e.g. to downlink video images);
- C3 link which is defined as C2 and ATC communications relayed through the UA.

The primary aim of the following questions is to acquire stakeholders’ opinions on the first two communication links listed above. The way in which the data links are implemented may have a considerable impact on aspects of the UAS marketplace including: economy, social, spectrum, global interoperability and EU regulation. Hence it is necessary as a first step to explore the various topics associated with UAS communications to see their importance to industry.

The aim of this section is to identify applications of relevance for civil UAS operations and identification of potential areas that you forsee future requirements of operation.

Q1. When do you foresee the following UAS applications commencing outside segregated airspace (answer all that you think are applicable)?

	Before 2020	After 2020
Aerial Imaging and Mapping		
Agricultural Applications		
Airborne Pollution Observation & Tracking		
Atmospheric Research		
Border Patrol		
Cargo		
Chemical & Petroleum Spill Monitoring		
Communications Relay		
Drug Surveillance and Interdiction		
Humanitarian Aid		
Law Enforcement		
Maritime Surveillance		
Natural Hazard Monitoring		
Other		
Port Security		
Search and Rescue		
Traffic Monitoring		
Utility Inspections		

Other please specify:

Page 4: UAV Operational Context

It is important that this questionnaire is answered with only one application in mind, various applications may have different communication requirements from a UAS. This section considers where the UAS may operate

Q2. Please specify the chosen application against which these questions will be answered.

Q3. For the application selected please specify the area of operation (from the ground station) Operating altitude (drop down box within the following range- below 400 ft to up to 40000ft)

Maximum operating range (drop down box within the range less than 24NM to beyond 500 NM)

Q4. For the altitude and range selected above what is your preferred C2/C3 data link communications method (tick all that apply)

Satellite

Single ground station

Networked ground stations

N/A

Q5. Do you foresee any requirement to operate UAS over remote, maritime or polar regions devoid of infrastructure required for terrestrial based data link ground stations?

a) Yes

b) No

Q6. How important is it to have the capability to operate UAS in different countries, and to cross international boundaries?

a) Not important

b) Desirable

c) Essential

Page 5: Infrastructure

Infrastructure on both the UAS and ground systems has an implication on the practicalities of operating a UAS in non-segregated airspace. The questions below aim to find out what sort of infrastructure you think is necessary to support the UAS application you foresee.

Q7. If globally standardised and approved C2/C3 data link equipment were available, would you make use of it?

a) Yes

b) No

c) n/a or don't know

If No please explain:

Q8. What percentage of UAS operations do you expect to use the following C2/C3 communication infrastructures?

Single ground station

Networked ground stations

Satellite

Combination ground/ satellite

a) 0% to 20%
b) 21% to 40%
c) 41% to 60%
d) 61% to 80%
e) 81% to 100%

Q9. When do you require the following types of C2/C3 communications infrastructure to be available to support your business need?

Single ground station
Networked ground stations
Satellite
Combination ground/ satellite

a) 2010
b) 2012
c) 2014
d) 2016
e) 2018
f) 2020
g) n/a

Q10. How would you see the above infrastructure being provided?

In-house development of proprietary networks
Privately funded development of standardised networks
Publicly funded development of standardised networks

Q11. How do you intend to communicate with ATC?

	Before 2020	After 2020
Relay through UA using onboard COM equipment		
Ground based COM equipment		
Wired connection with ATC		
Via a Communications Service Provider		

Q12. What percentage of UAS platforms produced or operated by your organisation and intended for operation inside a controlled/known airspace environment will be capable of transponder <u>and</u> VHF (voice) transceiver carriage?

a) 0-20%

b) 21-40%
c) 41-60%
d) 61-80%
e) 81-100%

Q13. What percentage of UAS platforms produced or operated by your organisation and intended for operation inside a controlled/known airspace environment will be capable of transponder and VHF (voice) and VHF (data) transceiver carriage?

a) 0-20%
b) 21-40%
c) 41-60%
d) 61-80%
e) 81-100%

Page 6: Cost

Cost is a factor that is important to the development of the UAS industry. The questions below aim to capture the approximate range of cost and data requirements you would expect when operating an UAS.

Q14. What do you expect the cost per UA will be for the following communications standardised equipment (not including installation costs);

Terrestrial C2/C3 data link

Satellite C2/3 data link

a) Less than €10k

b) €10k to €49k

c) €50k to €99k

d) €100k to €250k

e) More than €250k

Q15. What are your expected data throughput requirements per UA?

Command and Control (C2)

Downlink of sense and avoid data

ATC voice communications

ATC data communications

a) 0 to 20kbps

b) 21 to 40

c) 41 to 60

d) 61 to 80

e) More than 80

Q16. Where communications are provided by a service provider, what costs would you expect per UA (€ per kbps)?

Command and Control (C2)

Downlink of sense and avoid data

ATC voice communications

ATC data communications

a) 0.1 to 0.5

b) 0.6 to 1.0

c) 1.1 to 2.0

d) 2.1 to 4.0

e) 4.1 to 6.0

f) More than 6.1

Page 7: Equipment

This section aims to gather information on the general equipage requirements for a UAS operating in non-segregated airspace.

Q17. What is an acceptable weight, power consumption, size and antenna gain of satellite communications equipment that a UA can support?

Supply Power Requirements (Watts)

1-49 Watts

50 to 99

100 to 199

200 to 299

300 to 499

Above 500

Weight (kg)

1- 4

5 to 9

10 to 14

15 to 19

20 to 24

Above 25

Size (Number of MCUs)

1 to 2

3 to 4

5 to 6

7 to 8

Above 8

Antenna Diameter (m)

Less than 0.5m

Less than 1m

Less than 2m

2m or more

Q18. What is an acceptable weight of terrestrial communications equipment that a UA can support?

Weight

1- 4 kgs

5 to 9

10 to 14

15 to 19

20 to 24

Above 25

Q19. The European Space Agency (ESA) is developing a new satellite system (i.e. Iris) to support air-ground communications for Air Traffic Management in the framework of SESAR. Iris should allow lighter avionics, smaller antennas on-board and cheaper service, when compared with today's technology. Do you think it would be worthwhile to explore the possibility of applying the Iris approach also to C2 datalink for UAS?

d) Yes

e) No

Page 8: Realization

This section aims to gain understanding of areas of importance for the realization of a UAS operating in non-segregated airspace. Understanding what areas you view as having a significant impact for advancement of the UAS industry.

Q20. On a scale of 1 to 5, (where 1=Not important and 5=Critical) how do you perceive the following areas to be constraining the development of the UAS industry in Europe?

- Regulation
- Global Standards
- Sense and Avoid
- Spectrum Availability
- Communications Infrastructure
- Environmental
- Social Acceptability
- Safety
- Availability of Trained Personnel (including internationally agreed competence requirements for them)
- Any other area to consider (if yes, please specify)

Other please specify:

Q21. Which of the following views do you most agree with on a scale of 1 (strongly disagree) to 5 (strongly agree)?

a) Sufficient spectrum should be sought to avoid UAS operations being constrained in any area, whatever the cost implications.

b) Operational limitations due to insufficient spectrum are inevitable, but will be overcome in time as the UAS industry grows.

c) It is acceptable to continue with the practice of seeking spectrum on a case-by-case basis, accepting that this could constrain the growth of UAS in many areas.

Q22. What are the constraining factors in using satellite communications for C2 and ATC (tick all that apply)

Available Spectrum

Communication cost

Equipment cost

Equipment Weight

Latency (signal delay)

Use of third party provider(s) for communication services

Reliability

Availability (service level/system coverage)

Security

Q23. The emerging Single European Sky (SES) Implementing Rule (IR) on Surveillance Performance and Interoperability (SPI), will require transponder carriage by UAVs operating in a controlled/known airspace environment. What percentage of UAS platforms produced or operated by your organisation and intended for operation inside a controlled/known airspace environment will be capable of transponder carriage?

a) 0-20%
b) 21-40%
c) 41-60%
d) 61-80%
e) 81-100%

Page 9: Standardisation

This section aims to find out your view on the importance of standardisation for the UAS industry.

Q24. How important is it for the UAS industry to have a standardised and interoperable set of standards for networked C2 datalink communications?

a. Not important

b. Desirable

c. Essential

Q25. How important is the need to achieve globally harmonised frequency allocation for UAS C2 datalink?

a. Not important

b. Desirable

c. Essential

Page 10 General

In general what will the impact be on your organisation over the coming years and is there any other important topics that have not been discussed within previous sections.

Q26. With the expansion UAS market what increase in manpower dedicated to UAS activity do you foresee over the following years

2010

2012

2014

2016

2018

2020

Beyond 2020

a) 0%
b) 1% to 20%
c) 21% to 40%
d) 41% to 60%
e) 61% to 80%
f) 81% to 100%
g) More than 100%

Q27. Do you see any other important issues to be considered in order to allow UAS operations in non-segregated airspace?

E 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
BLOS	Beyond Line of Sight
C2	Command and Control
C3	Command, Control and Communications
CATS	Combined Aerial Targets Service
CNS	Communication, Navigation and Surveillance
CS	Certification Specifications
CSP	Communications Service Provider
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
GAT	General Air Traffic
GCS	Ground Control Station
GS	(radio) Ground Station
HALE	High Altitude Long Endurance
ITT	Invitation to Tender
MCA	Multi Criteria Analysis
NCO	Network Centric Operation
NEC	Network Enabled Capability
PMP	Project Management Plan
SESAR	Single European Sky ATM Research Programme
SMART	Specific, Measurable, Achievable, Relevant, Timely
SSR	Secondary Surveillance Radar
SWIM	System Wide Information Management
UAS	Unmanned Aircraft System
UA (or UAV)	Unmanned Aircraft (Vehicle)
VHF	Very High Frequency

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European Aviation Safety Agency
Ottoplatz, 1
D-50679 Cologne, Germany

easa.europa.eu