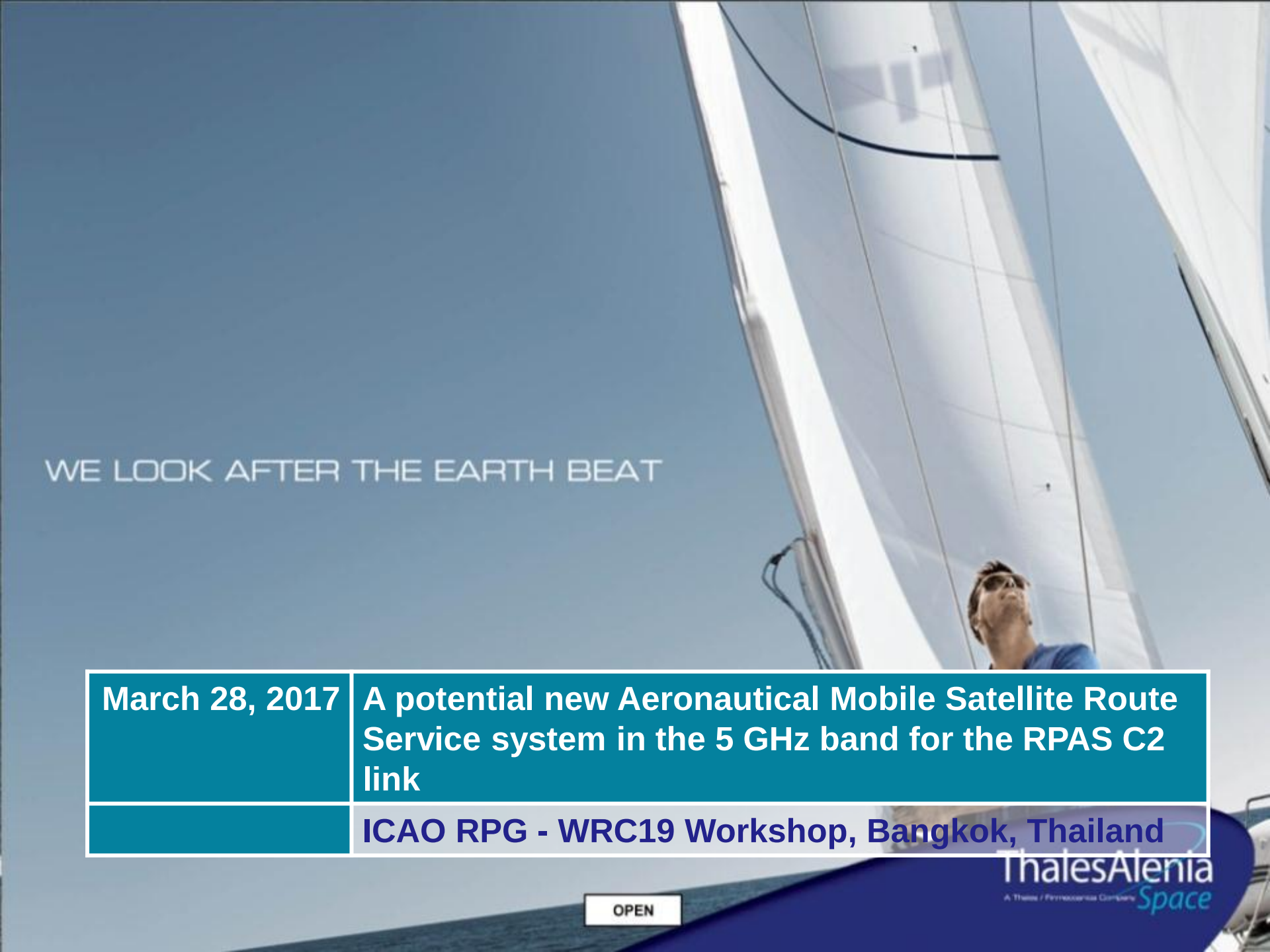

March 28, 2017	**A potential new Aeronautical Mobile Satellite Route Service system in the 5 GHz band for the RPAS C2 link**
	ICAO RPG - WRC19 Workshop, Bangkok, Thailand

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Command and Control (C2) link

RPA

Command and Control (C2) link

- Telecontrol & Telemetry, i.e. Command & Control data
- Air Traffic Control (ATC) voice & data
- Situational awareness data, including optional Video

Remote Pilot Station

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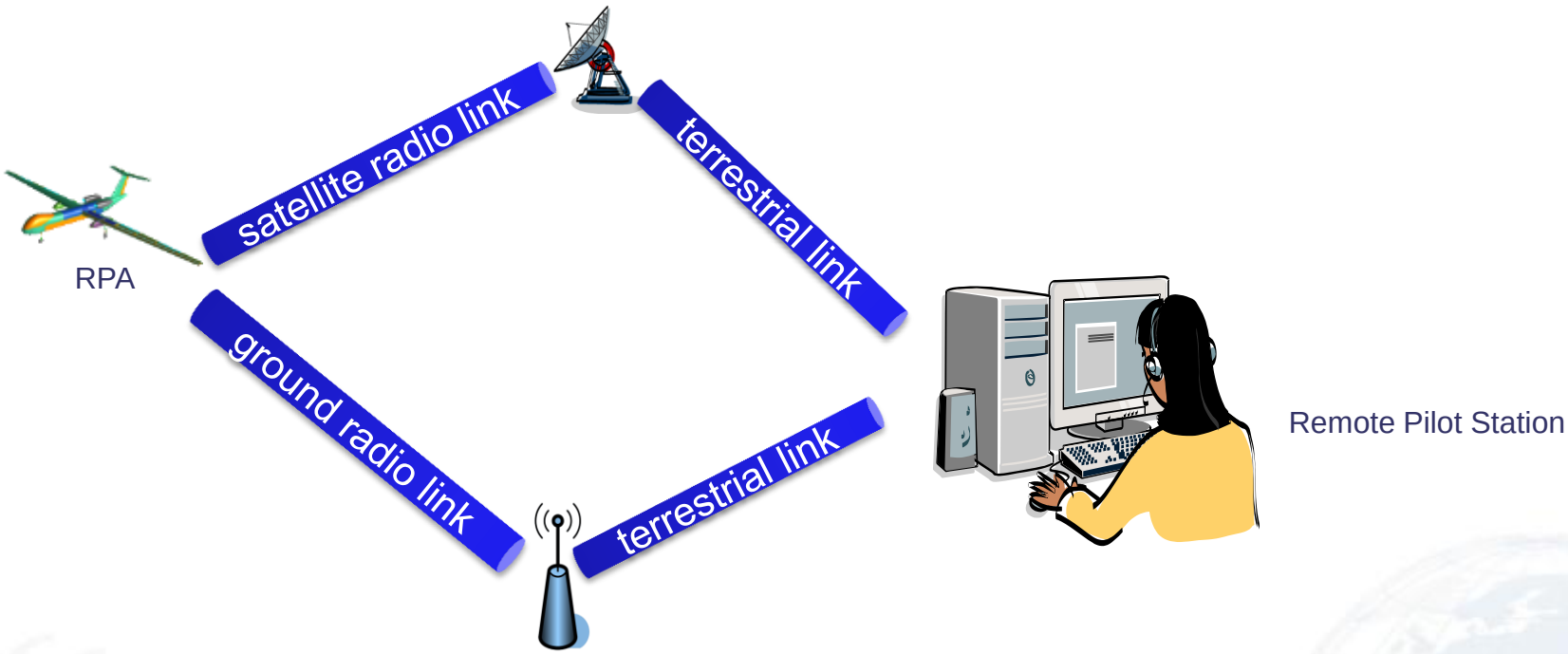
Command and Control (C2) link – Hybrid System view



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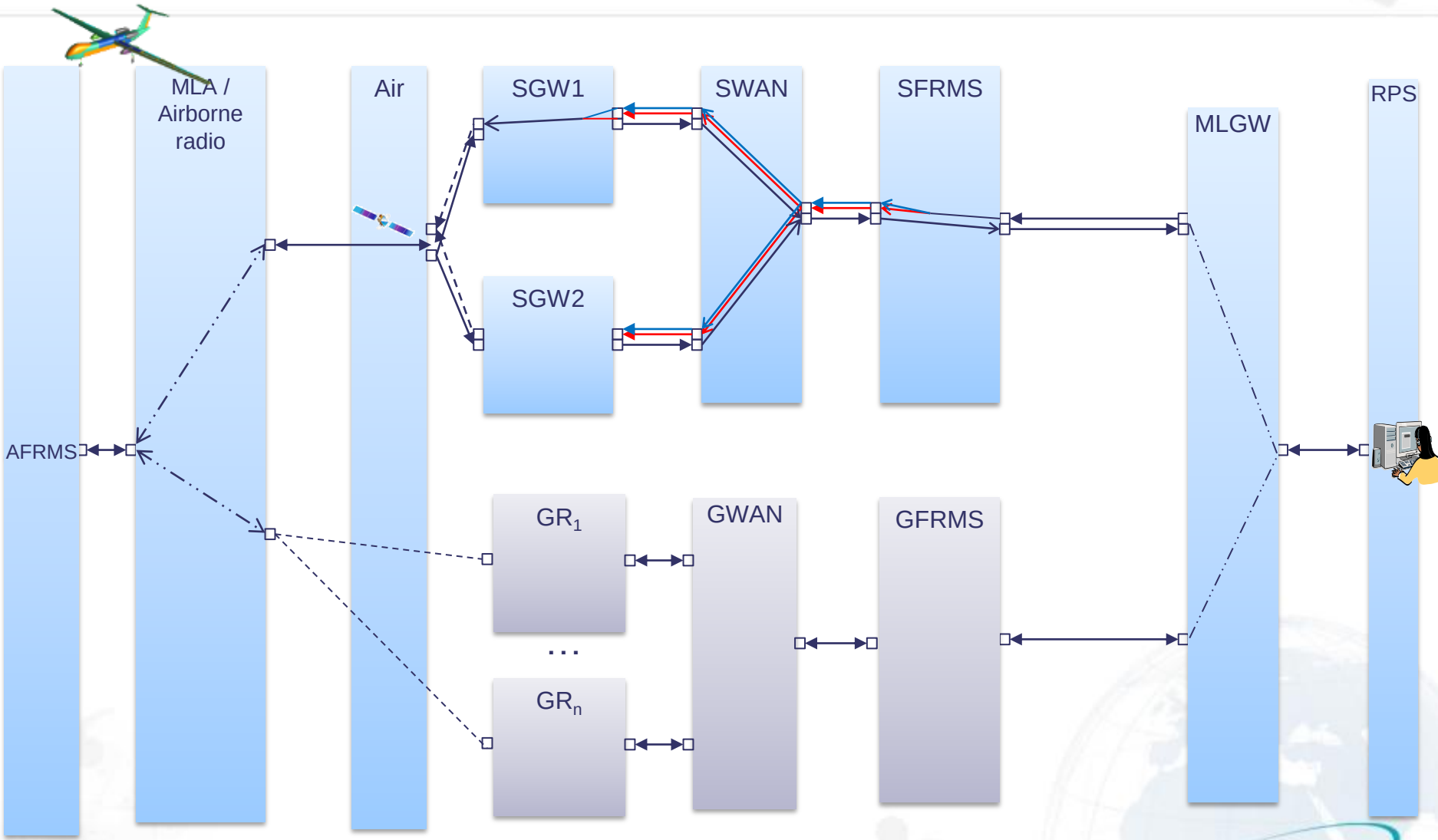
Communication chain (user traffic)



AFRMS Aircraft Flight & Radio Management system
GFRMS Ground Flight & Radio Management system
SFRMS Satellite Flight & Radio Management system
MLA Multi-Link Adaptor
SGW Satellite GateWay

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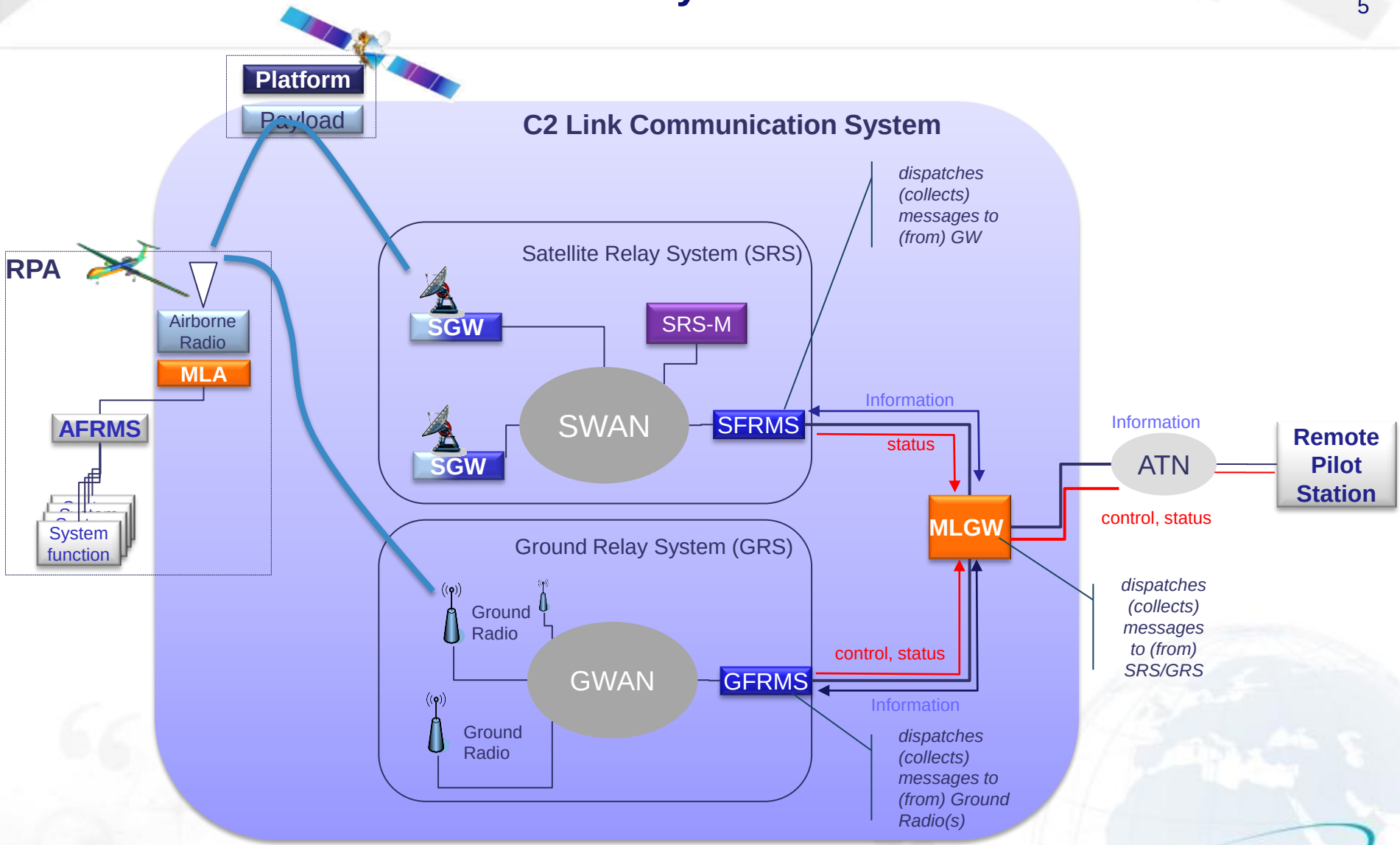
The 5GHz Solution – Detailed System View



AFRMS Aircraft Flight & Radio Management system
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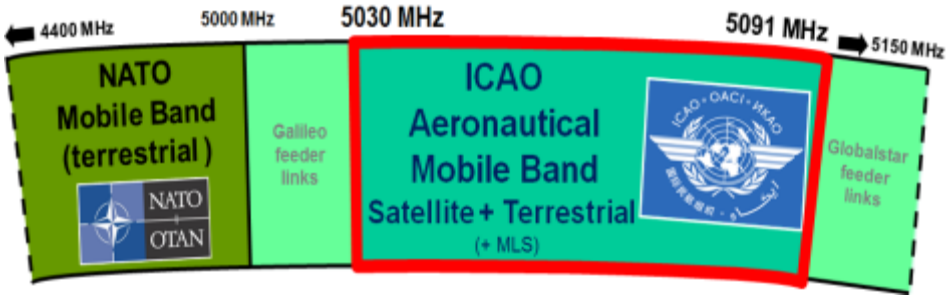
The 5GHz Solution – Spectrum: 5030-5091 MHz



- **61 MHz exclusively allocated worldwide to civil aviation services**
  - **Terrestrial & Satellite** Communication
  - Compatibility with existing system is ensured (see FSMP WG/3 WP10)
- Low rain attenuation ➔ all-weather operation with low cost and low SWaP (Size Weight and Power) airborne terminal
- **Terrestrial C2 link systems are likely to use this allocation** (where the 960-1164 MHz spectrum is already congested, e.g. in Europe) – MOPS exists (DO-362)
- **C-Band SATCOM MOPS** being prepared at EUROCAE WG-105

A global and unified C2 link capability offering through a single equipment an universal access to all civil airspace classes worldwide

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The 5GHz Solution – 5030-5091 MHz frequency band sharing

See FSMP-WG03-WP10

"Spectrum Sharing in C band for terrestrial and satcom C2 link for RPAS"

CONCLUSION

Sharing of the band can be achieved with limited operational impact

See FSMP-WG04-WP09

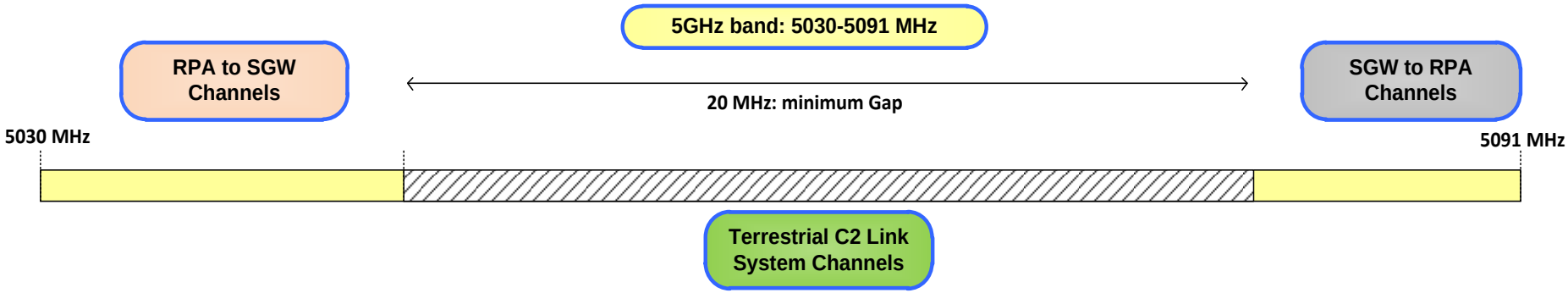
"Considerations for establishment of channel plans for the AMS(R)S and AM(R)S allocations in the 5030-5091 MHz frequency band for use by satellite and terrestrial systems supporting UAS C2 Links"

CONCLUSION

It is possible to define a carrier assignment strategy in the band that will limit coordination requirements to a minimum

The 5GHz Solution – 5030-5091 MHz frequency band sharing

- **Satellite System Channels**
  - 300 kHz to 1 MHz channels with flexibility between SGW and RPA
  - 40 kHz to 100 kHz channels with flexibility between RPA and SGW



- A sharing that **can be flexible** depending on the geographical region

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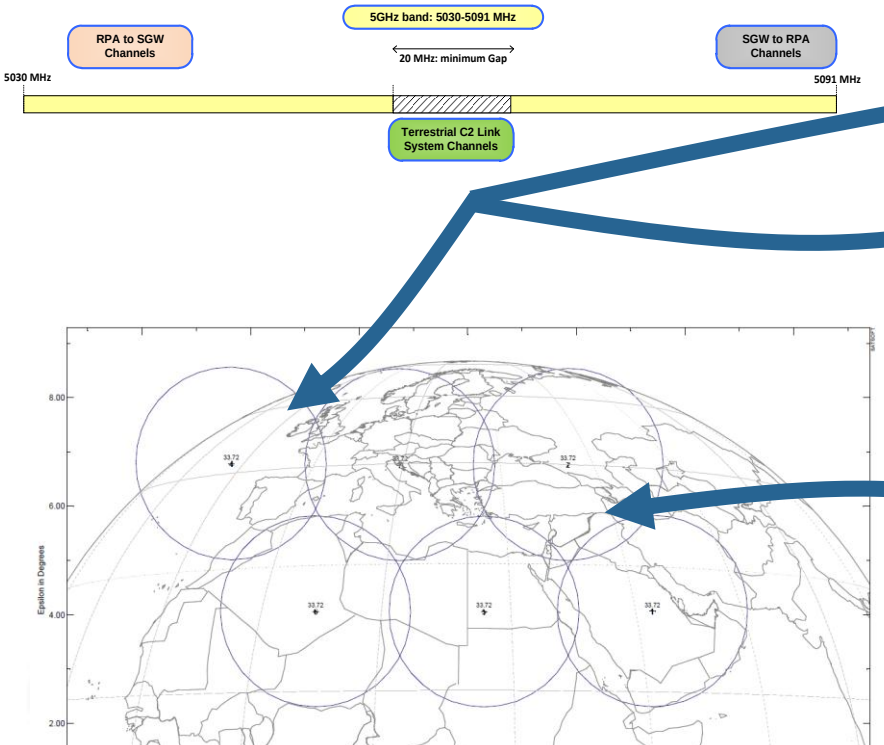
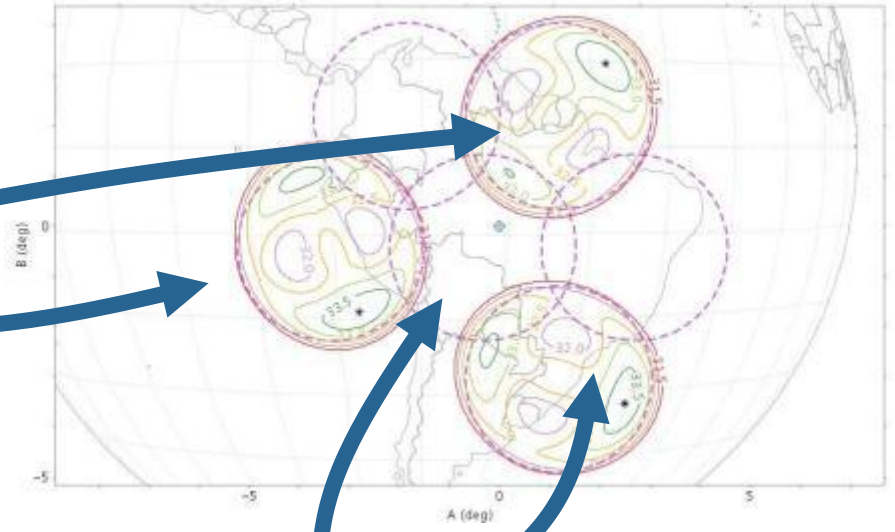
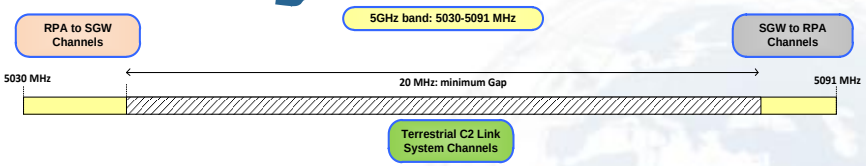
The 5GHz Solution – 5030-5091 MHz frequency band sharing

A sharing that can be flexible depending on the geographical region







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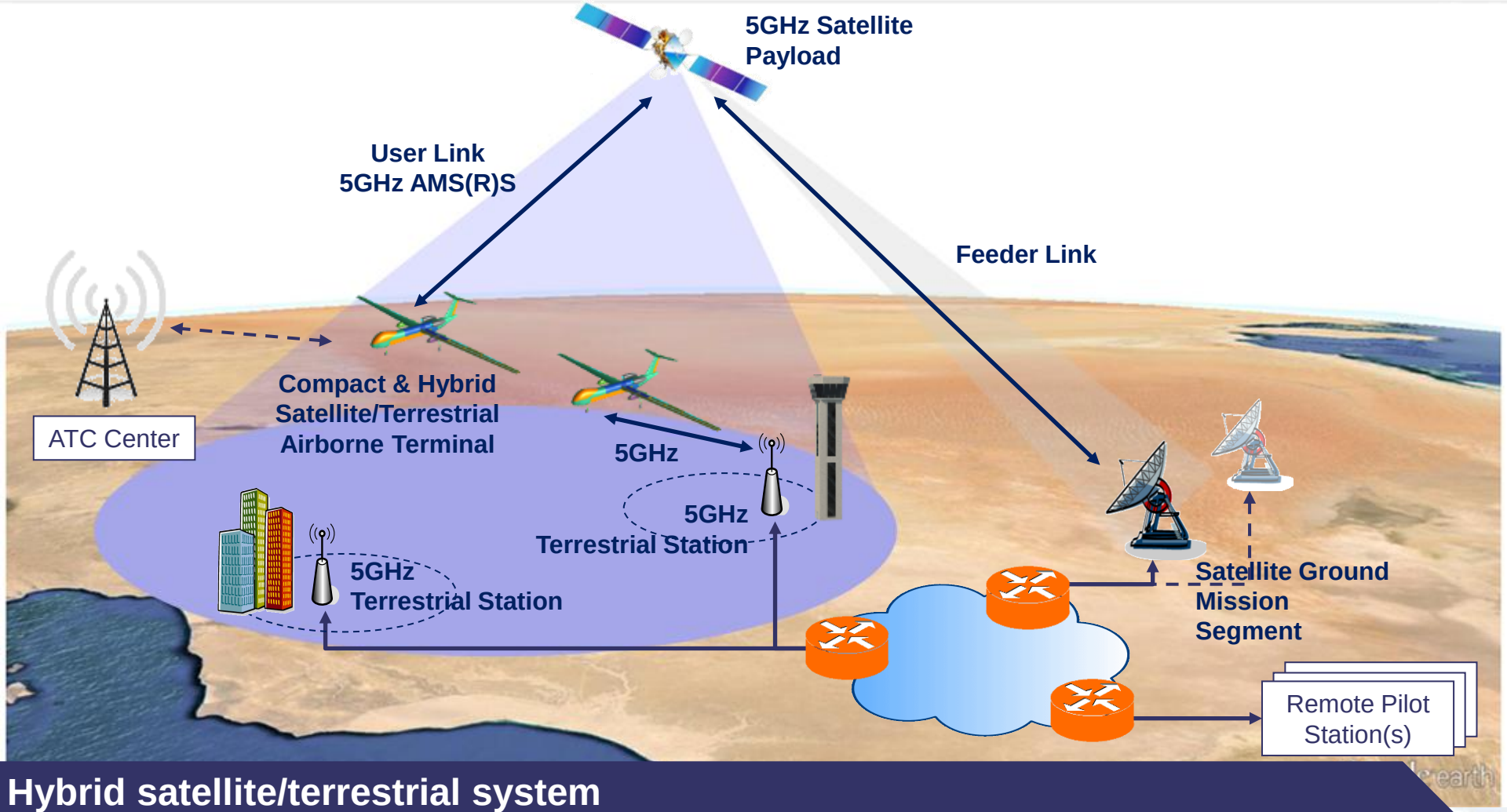
The 5GHz Solution – Ongoing activities

- **EUROCAE WG-105 (ex WG-73) will continue work on C2 in SG3**
  - **Spectrum management**
    - OSED expected in 12/2017
    - SPR, INTEROP expected by 06/2018
  - **SATCOM data-link**
    - MOPS expected in 09/2017
- 5GHz Band is also considered by **RTCA** SC-228 SATCOM activities

The 5GHz Solution – Overall Architecture



Hybrid satellite/terrestrial system
Large coverage area ensuring very high safety performance where needed

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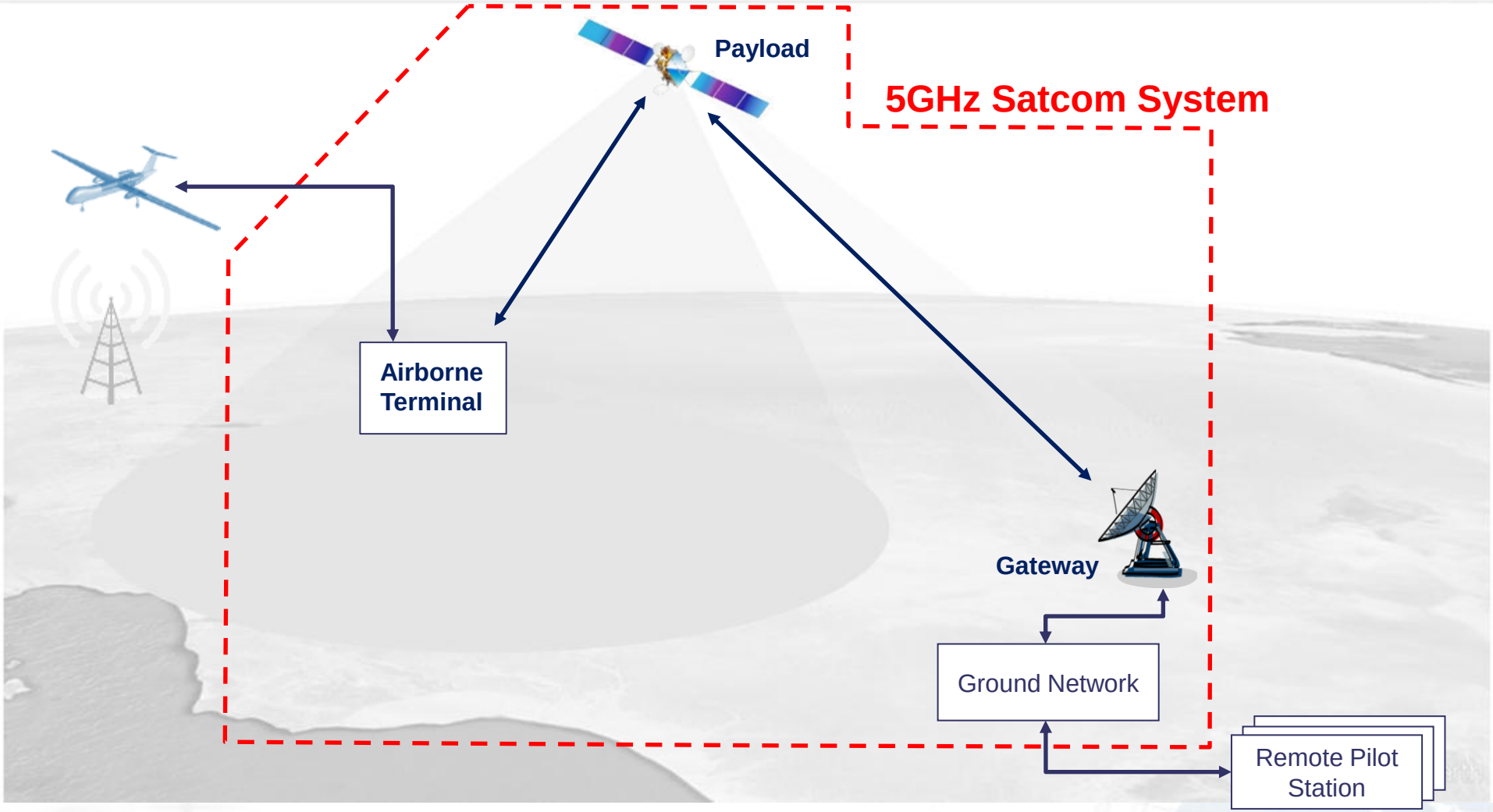
The 5GHz Solution – Perimeter



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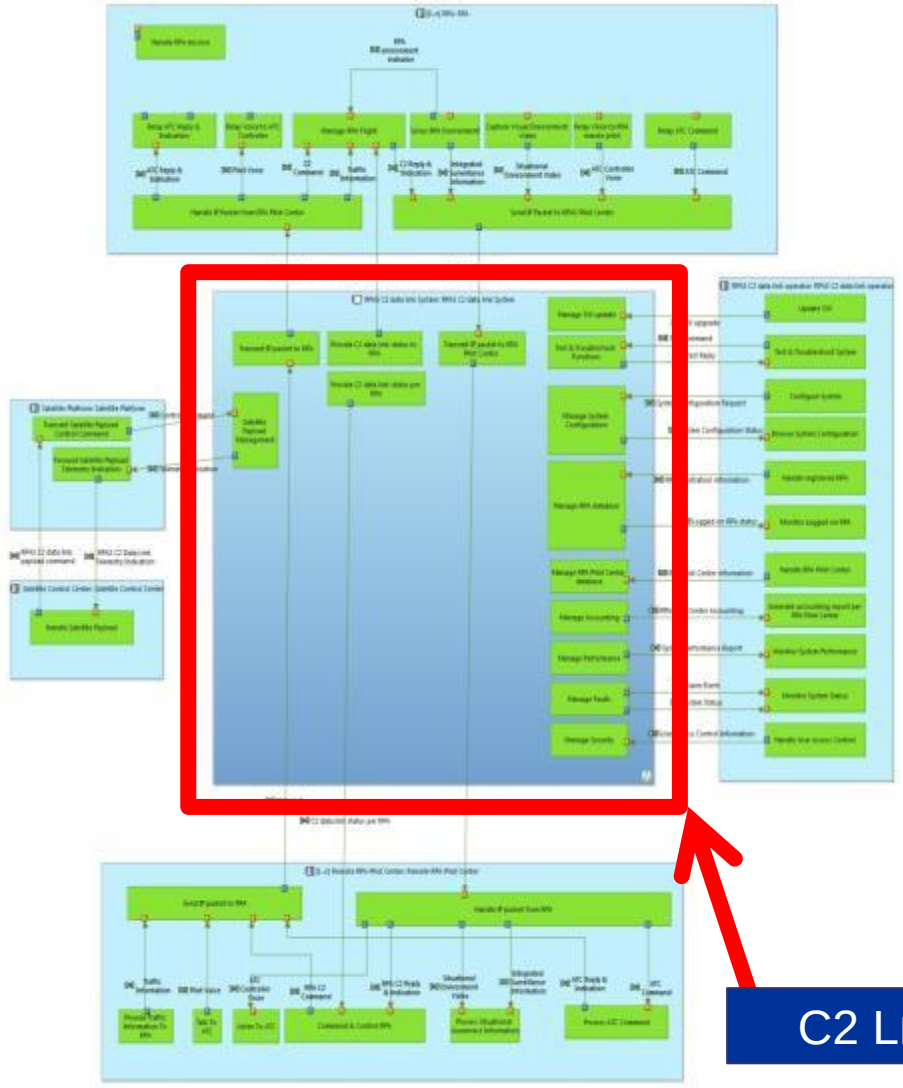
The 5GHz Solution – Functional Perimeter



- **Functional system interfaces:**
  - RPA platform (CMU)
  - RPA Remote Pilot Center (RPS)
- **Management Interfaces:**
  - C2 Link Operator
  - Satellite Operator

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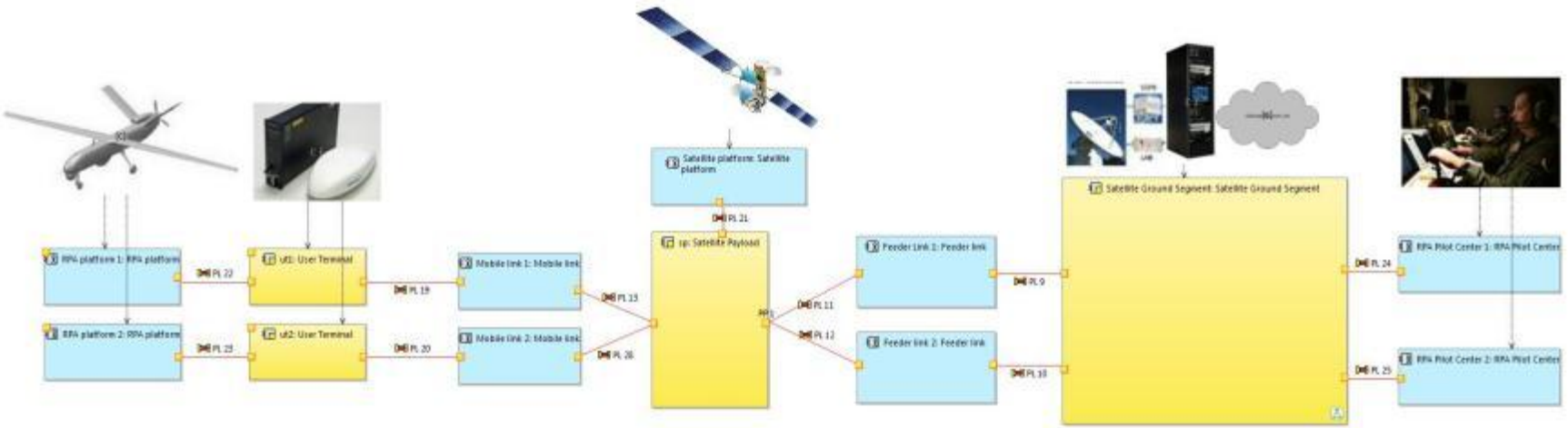
The 5GHz Solution – System Physical Architecture



- **C2 Link Ground Segment**:
  - provides connectivity to the RPA (Remote Piloted Aircraft) pilot centers
- **C2 Link Satellite Payload**:
  - hosted payload onboard a satellite platform
- **C2 Link User Terminal**:
  - onboard the RPA, provides C2 link Connectivity to the RPA Platform

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The 5GHz Solution – C2 Link Ground Segment

- **Communication protocol tailored to the need**
  - **Forward Link – from SGW to RPA:**
    - TDMA, i.e. several RPA are multiplexed over a single carrier
    - Continuous Transmissions using CPM Modulation
    - High efficiency waveform delivering 10^-3 PER
  - **Return Link – from RPA to SGW:**
    - FDMA, i.e. each RPA uses its own carrier
    - Burst Transmissions using CPM Modulation
    - High efficiency waveform delivering 10^-3 PER
- **Redundancy mechanisms between multiple sites – Availability > 99.99%**

A simple and robust ground segment

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The 5GHz Solution – C2 Link Airborne User Terminal

- **Simple:** no diplexer, no antenna pointing mechanism
- **Low Size, Weight and Power** compatible with light drones
- **Small antenna footprint,** limited accommodation constraint
- **Hybrid Satellite/Terrestrial terminal**
- **Dual use :** Civil (5030-5091MHz) & Military (4.4-4.9GHz)

Example of existing aero C-band antenna (ANTCOM)
5cm (W) x 13cm (L) x 8cm (H)
150g

Hybrid terrestrial/satellite airborne terminal + dual use opportunity
➔ Satellite connectivity without any additional hardware

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The 5GHz Solution – System Specifications – Overview (1/2)

Category	Specifications
Interfaces	IP with Remote Pilot Centers IP with Communication Management Unit onboard RPA
Functional	Transmit IP datagrams Indicate the quality of the link Support Remote Pilot Center handovers Implement QoS differentiation
Performances	**Coverage:** regional, extensible to global coverage **Capacity:** from ~ 100 RPAs simultaneously, to up to 10 000 **Latency** (99.9% over 1 month): C2: 0.5s, ATC voice: 0.4s, ATC data: 3s, SA: 0.7s **Availability:** >99.99%

The 5GHz Solution – System Specifications – Overview (2/2)

Parameter	FWD	RTN
Duplexing	Frequency Division Duplex	
Physical Layer		
Channel Bandwidth	300kHz to 1MHz	40kHz to 100 kHz
Modulation	Continuous Phase Modulation (CPM)	Continuous Phase Modulation (CPM)
Offered bitrate	From 150 to 500 Kbps	Up to 35 Kbps
Link Layer		
Access Mechanism	TDMA–terminal listens to 1 shared carrier (Dynamic Timeslot Allocation)	FDMA–1 dedicated RTN carrier per user
Network Layer		
Protocol	IP	IP
Control plane		
Authentication	Strong Authentication during logon phase Source Authentication & Non-Repudiation of control plane exchanges	
Handover	Carrier & Beam handover	

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The 5GHz Solution – Typical Session

Prior Knowledge:
- Security Credentials
- Initial RX frequency

- **RPAS logs on to the system (establishes communication)**
  - Listens to SGW transmissions on initial frequency
  - Discovers the “logon” transmit frequency to use
  - Initiates the logon process on this frequency (random access is used here)
  - Receives a dedicated carrier frequency allocation for TX, optionally, is also given a different frequency for RX

Roles for logon:
- Broadcasts SysInfo
- Assigns channels to RPA
- Authenticates Users

Security Considerations

- UT authenticates the SGW as legit (strong auth)
- SGW authenticates the UT as legit (strong auth)
- All subsequent exchanges are signed:
  - Ensuring source authentication
  - Allowing for non-repudiation

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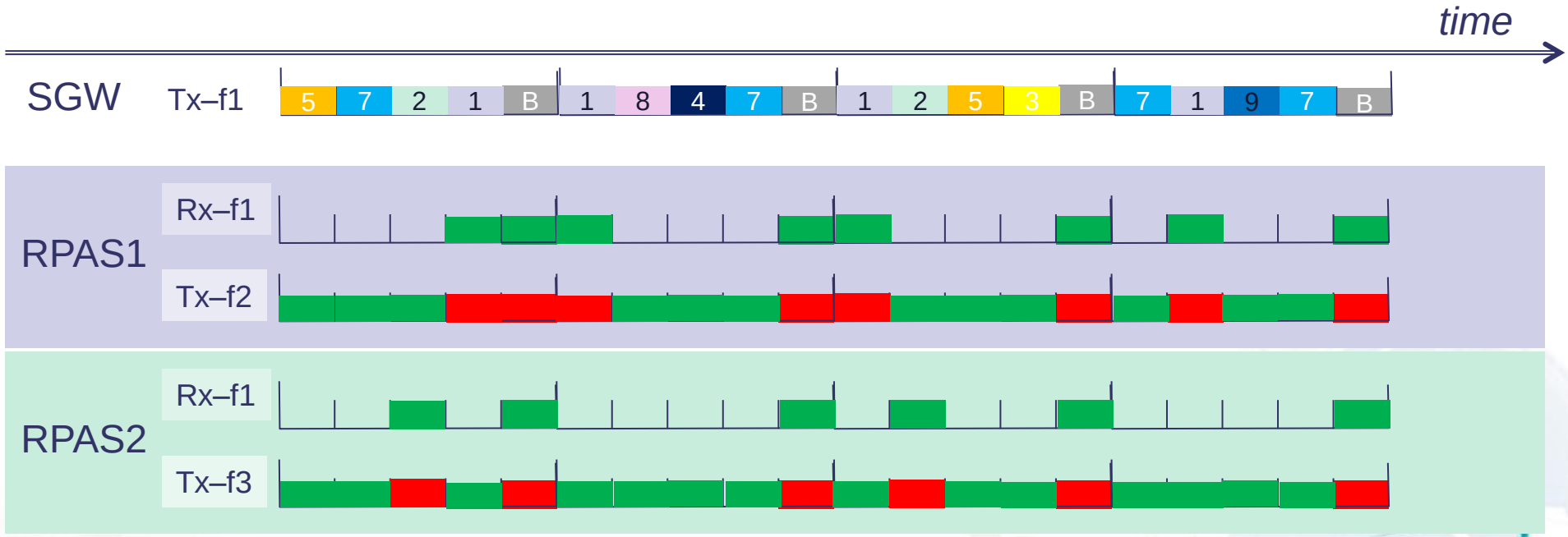
The 5GHz Solution – Multiplexing & Access Scheme

- **Multiplexing & Access Scheme**
  - **Airborne Terminal:** half duplex mode (no diplexer), i.e. sequential Tx/Rx, with a RF filter over the complete band
  - **Satellite payload:** full duplex mode
  - **Satellite Gateway:** full duplex



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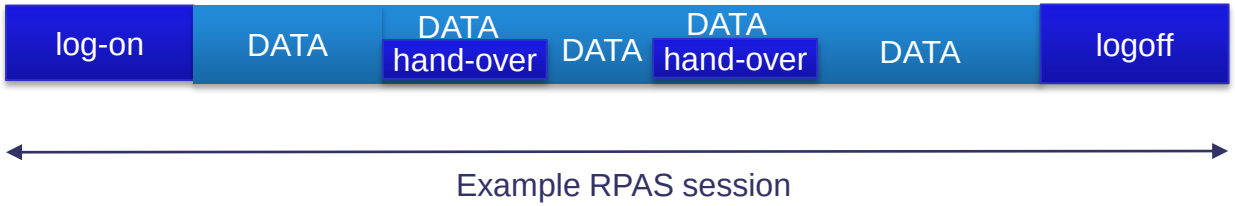
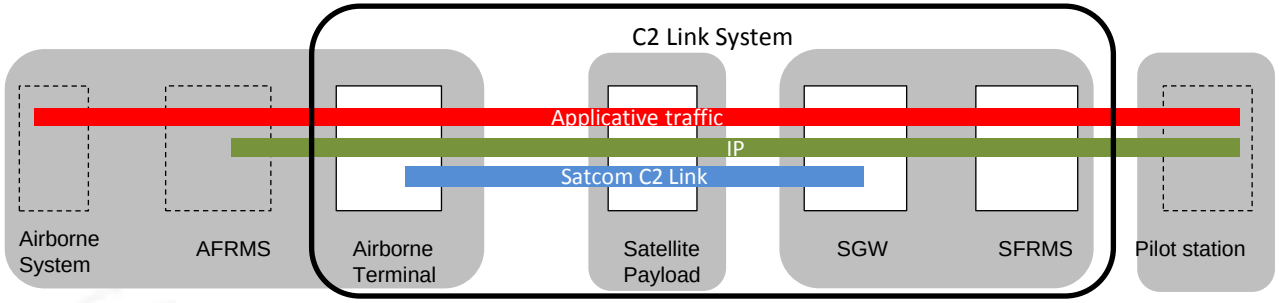
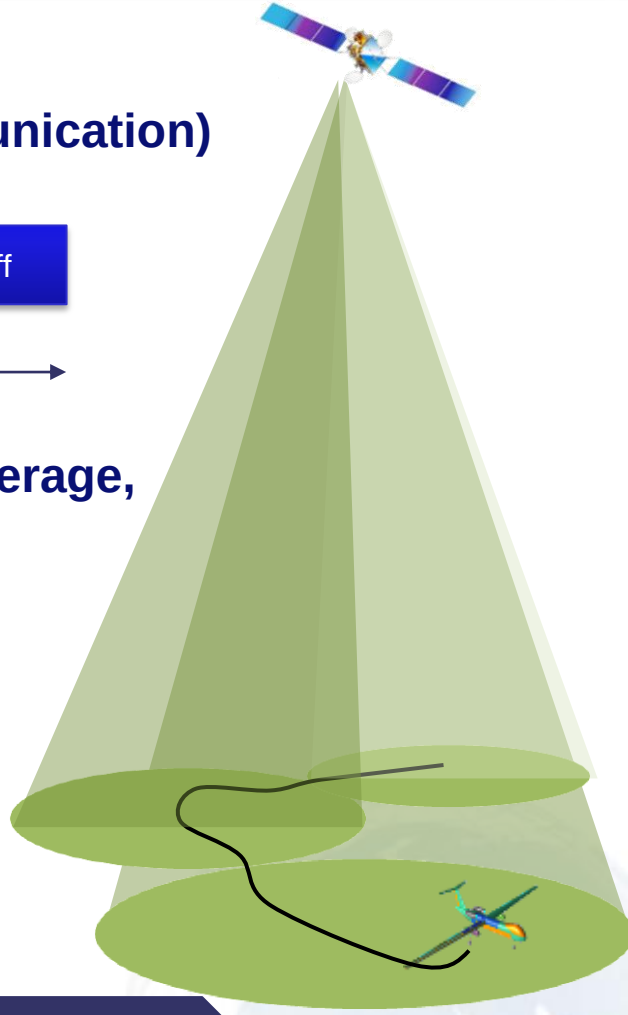
The 5GHz Solution – Typical Session

- **RPAS logs on to the system (establishes communication)**



- **Seamlessly, as the RPAS progresses on the coverage, handover(s) take place to ensure continuity**





Always available end-to-end connection between RPA and RPS

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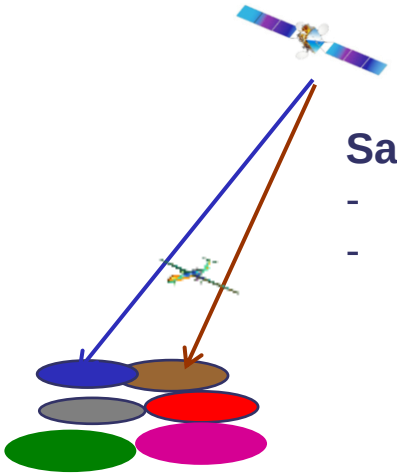
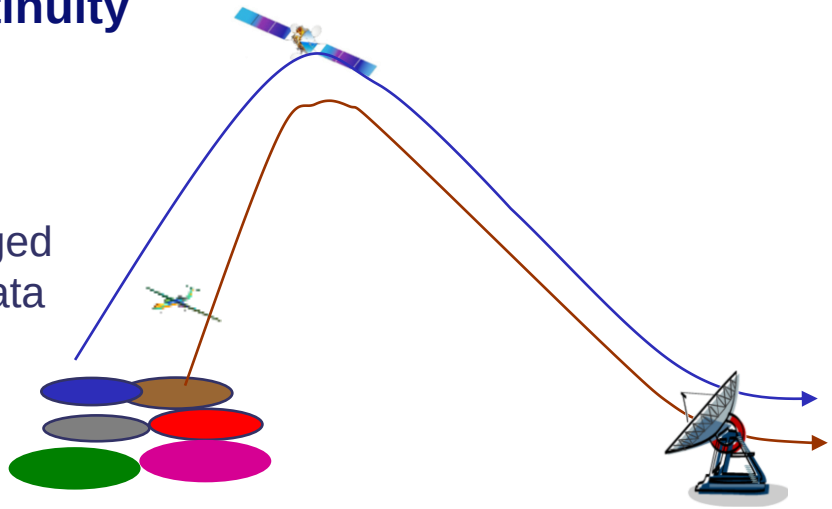
The 5GHz Solution – Typical Session

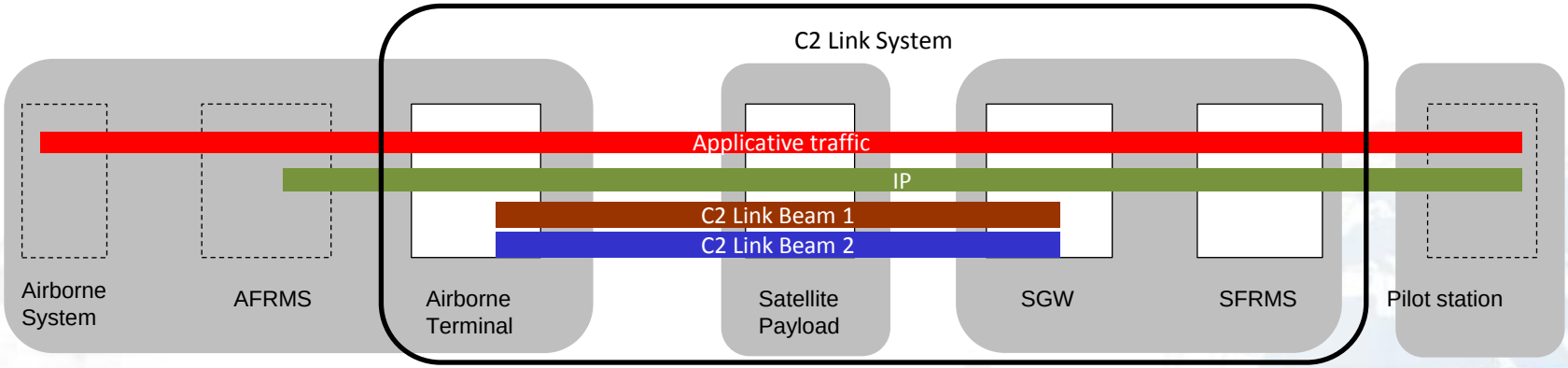
- **Seamlessly, as the RPAS progresses on the coverage, handover(s) takes place to ensure continuity**



Satellite Beam Handover

- RX and TX carriers are changed
- Transparent for end-to-end data





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The 5GHz Solution – Key Advantages

- **Exclusive and global allocation to civil aviation services: AMS(R)S**
- **Unique standards applicable worldwide**
  - ➔ **RTCA DO-362 (and upcoming update) for the Terrestrial Component**
  - ➔ **EUROCAE upcoming ED-XX for Satellite Component**
- **System capacity compatible with mid/long term needs**
- **Hybrid terrestrial/satellite airborne terminal**
  - ➔ Satellite connectivity without any additional hardware
  - ➔ 5GHz is currently sometimes the only option for the terrestrial link (e.g. in Europe)
  - ➔ Possible integration in a **dual use terminal** (Civil 5GHz + NATO 4.4-4.9 GHz)
    - ➔ single equipment for military and civil airspace
- **Small antenna footprint and no accommodation constraint**
  - ➔ compatibility with light drones (<150 kg)
- **Simple system delivering high level safety performances**

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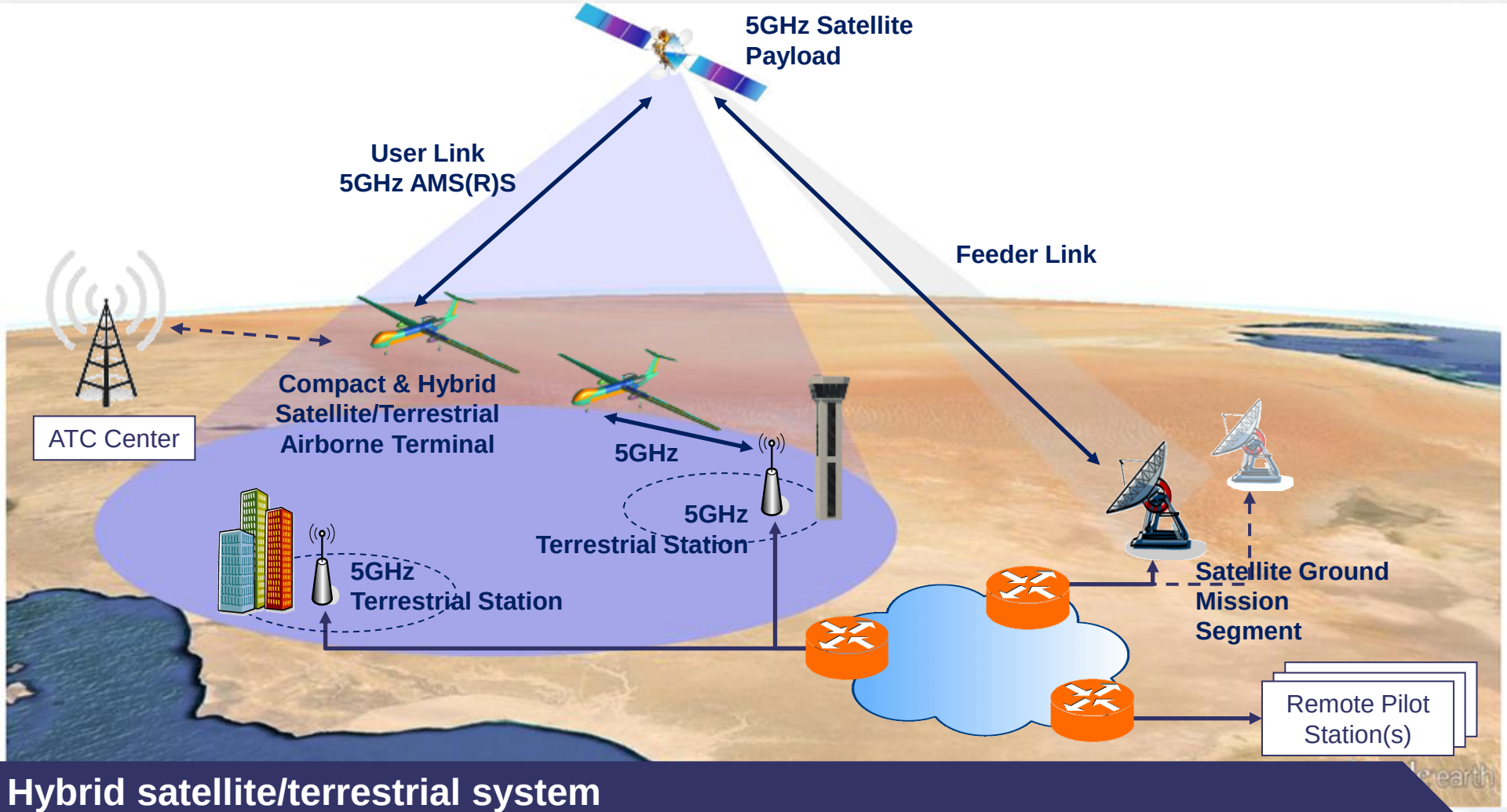
The 5GHz Solution – Overall Architecture



Hybrid satellite/terrestrial system
Large coverage area ensuring very high safety performance where needed

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Backup

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WRC-15 / FSS & 5GHz

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Spectrum available for C2 links development today

Two potential solutions for satellite C2

- *Ku/Ka-band* solution (mainly military concept) – FSS allocation
- *C-band* solution in the (5030-5091MHz) with AMS(R)S allocation

Our understanding of the current status is the following

- ***C-band has been allocated for UAS C2* link (satcom & terrestrial)**
  - Footnote 5.367 of the ITU Radio Regulations since at least the early 90s (satcom)
  - MOPS for its terrestrial use is ready: DO-362
  - SATCOM was moved to table in the framework of WRC-12 Agenda Item 1.3
  - MOPS for its satcom use is being prepared by EUROCAE

- **WRC-15 opened the door to Ku/Ka band FSS – *work still needed both at ICAO and ITU to determine usability***

A market likely to be segmented

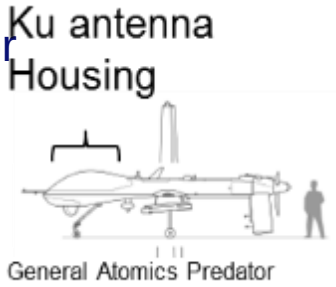
Ku/Ka-bands require heavy and complex airborne equipment

- a large antenna (40-120 cm) to achieve required operation gain
- an agile antenna to manage the satcom beam pointing (mechanically or electronically) esp. during maneuvers
- a strong power source to mitigate rain attenuation on the satcom-UAS link

⇒ derived from proven military technology on heavy UAVs

⇒ but *costly and not fit for small, low-altitude flight*

(25 - 500 kg, < 10 000 ft)



General Atomics Predator

C-band could enable simple and small size terminals

- smaller sized antenna (~ 10 cm)
- lower rain margin requirement, better link budget at all altitudes
- enables the use of a single equipment for terrestrial and satcom link

⇒ *compatible with 25-500kg UAS*


COTS C-band (ANTCOM)
5cm x 13cm x 8cm - 150g

The market will be segmented between those UAS which large size is compatible with Ku/Ka terminals and the smaller ones that will rely on simpler, lighter C-band terminals.

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Conclusions WRC-15 / FSS & 5GHz

- **There are two solutions for the UAS C2 satcom link :**
  - C-band
  - FSS in Ku/Ka-band
- **These two solutions are *not in competition* as they will most likely address different classes of airspace users.**
- **C-band will be hardly avoidable for smaller UAS and at low altitudes**
- **Significant level of European public investment in this domain**
- **Industrials such as TAS, and satellite operators expressed interest in a 5GHz SatCom solution for C2**

Band Sharing

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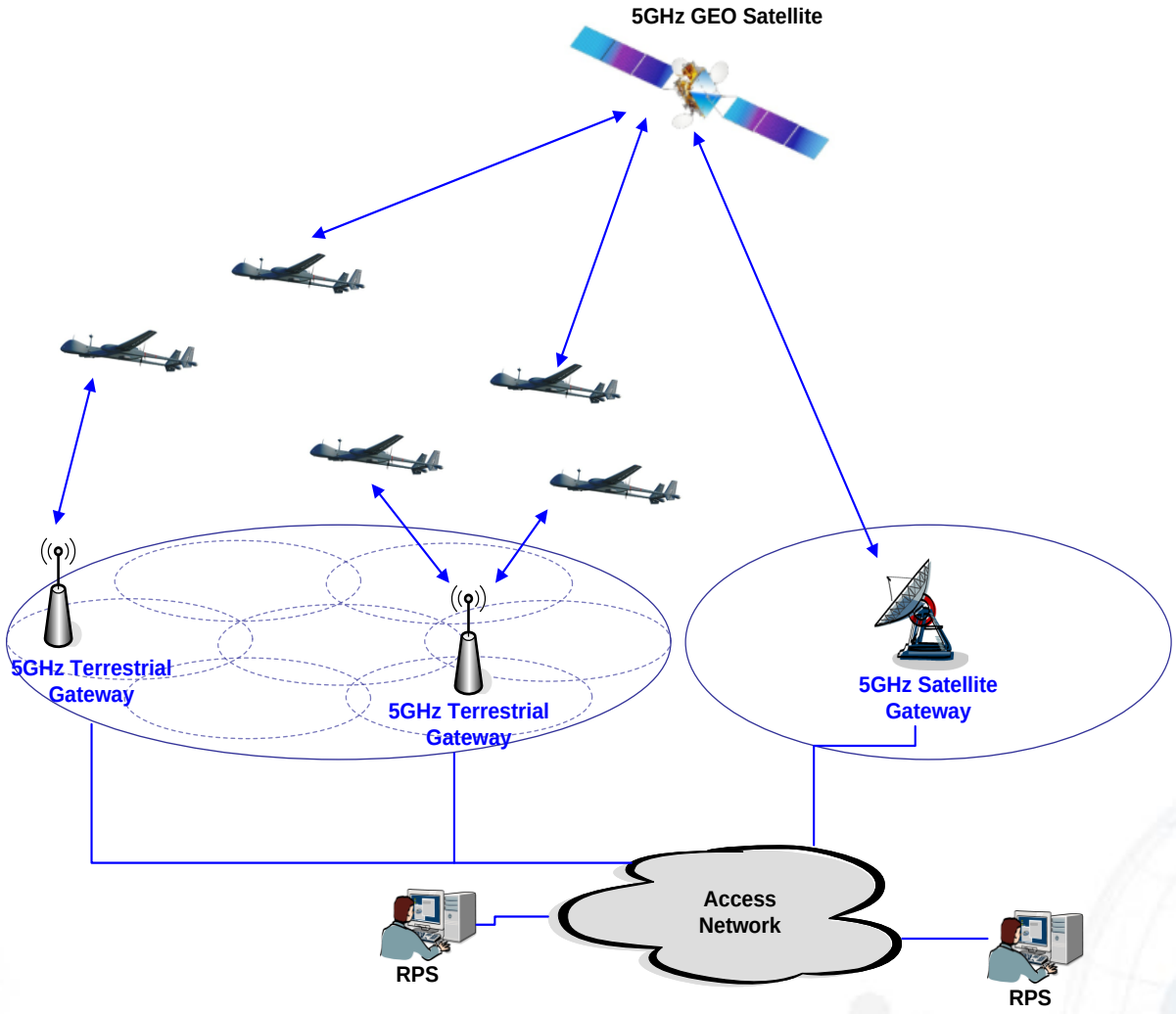
Definition of a reference architecture: High level architecture



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Interference protection criteria

- **Base on ITU-R M-2237 Report « Compatibility study to support the line-of-sight control and non-payload communications link(s) for unmanned aircraft systems proposed in the frequency band 5 030-5 091 MHz", different criteria could be envisaged:**
  - Maximum interference power flux density at receiver antenna input ($dBW.m^{-2}$)
  - Minimum SNIR – Signal to Noise and interference ratio (dB)
  - Maximum INR – Interference to noise ratio
  - Minimum Es/N0+I0 – Symbol energy to Noise and interference density ratio

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System parameters characteristics

- **Transmitter characteristics**
  - EIRP (dBW)
  - TX bandwidth (Hz)
  - TX type of polarization
  - TX mask (cf next slide)
- **Receiver characteristics**
  - G/T ($dB.K^{-1}$)
  - Equivalent receiver noise temperature (T in K)
  - RX bandwidth (Hz)
  - Symbol rate (Bd)
  - RX type of polarization
  - RX mask (cf next slide)

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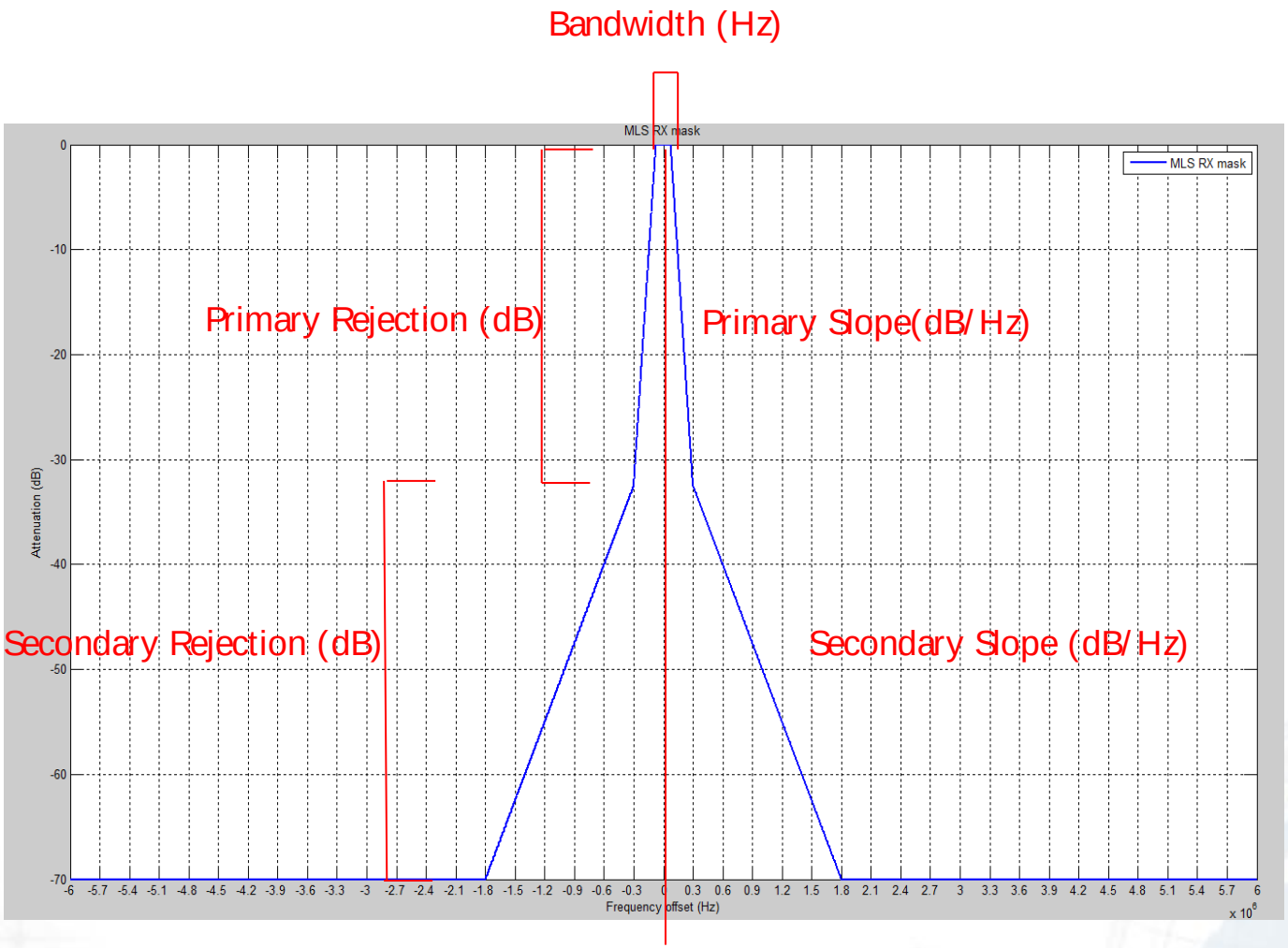
TX Mask parameters



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Interference rejection analysis output

- **For each adjacent carrier frequency**
  - When receiver and interferer are not the satellite payload: minimal distance required between interferer and receiver to meet the interference protection criteria
  - When the receiver or the interferer is the satellite payload, the distance is fixed to 38000 km (GEO satellite). The output is the margin compared to the interference protection criteria

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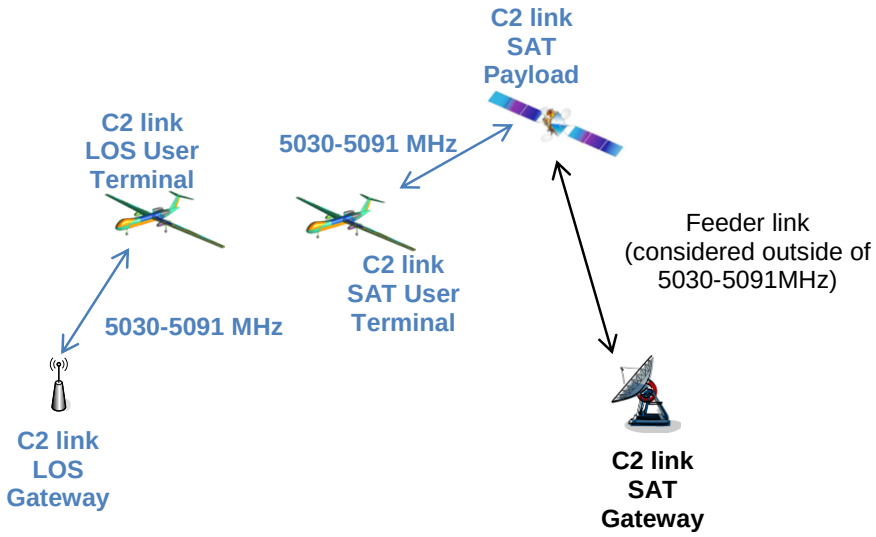
The 5GHz Solution – 5030-5091 MHz frequency band sharing

UAV to Satellite	LOS Band	Satellite to UAV
Satellite RTN		Satellite FWD
5030		5091



Considered Elements

- C2 Link SAT User Terminal
- C2 Link LOS User Terminal
- C2 Link SAT Payload
- C2 Link LOS Gateway

Interference caused by each element on all others is analyzed

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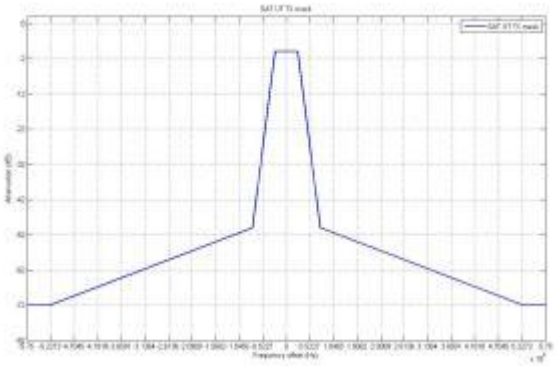
The 5GHz Solution – 5030-5091 MHz frequency band sharing

SATELLITE C2 SYSTEM

SAT UT transmitter characteristics

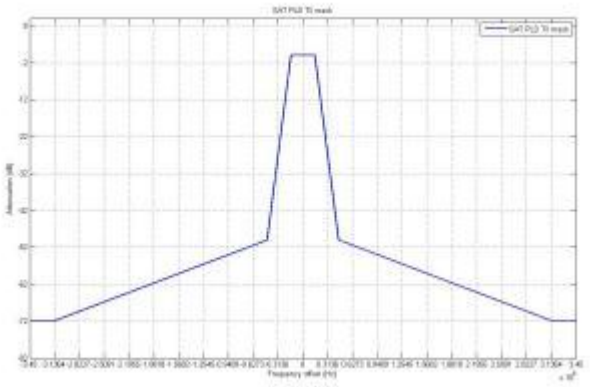
EIRP(dBW)	17.00
TX bandwidth (Hz)	40000.00
Mask type	Linear Gabarit



Satellite User Terminal TX mask

SAT Payload transmitter characteristics

EIRP(dBW)	51.00
TX bandwidth	800000.00
Mask type	Linear Gabarit



Satellite Payload TX mask

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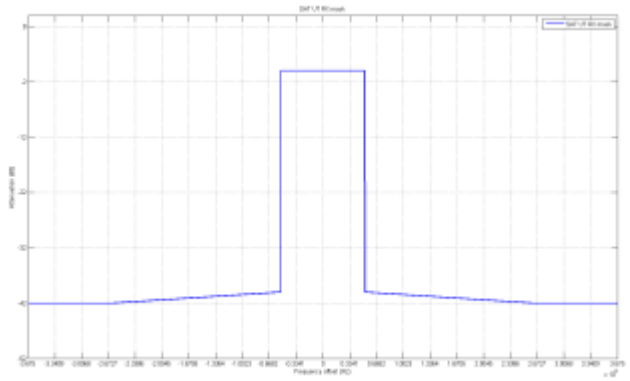
The 5GHz Solution – 5030-5091 MHz frequency band sharing

SATELLITE C2 SYSTEM

SAT UT receiver characteristics

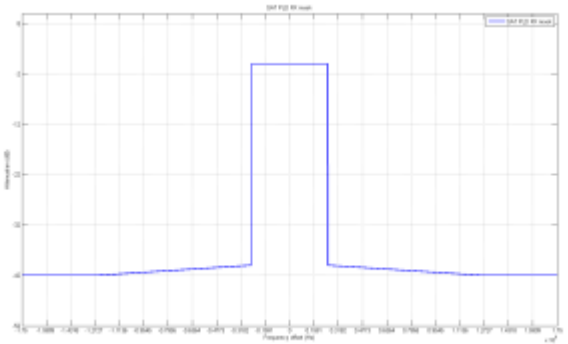
G/T (dBpK)	-19.00
Antenna gain (dBi)	5.00
Equivalent antenna temperature (K)	251.19
RX bandwidth	1050000.00
Mask type	Linear Gabarit



Satellite User Terminal RX mask

SAT Payload receiver characteristics

G/T (dBpK)	2.50
Antenna gain (dBi)	30.50
Equivalent antenna temperature (K)	630.96
RX bandwidth	50000.00
Mask type	Linear Gabarit



Satellite Payload RX mask

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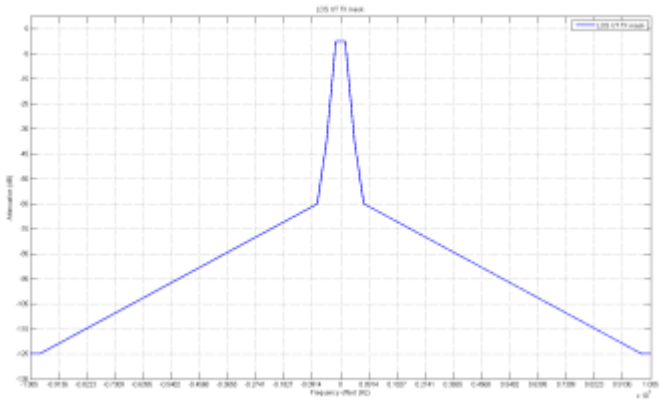
The 5GHz Solution – 5030-5091 MHz frequency band sharing

TERRESTRIAL C2 SYSTEM

LOS UT transmitter characteristics

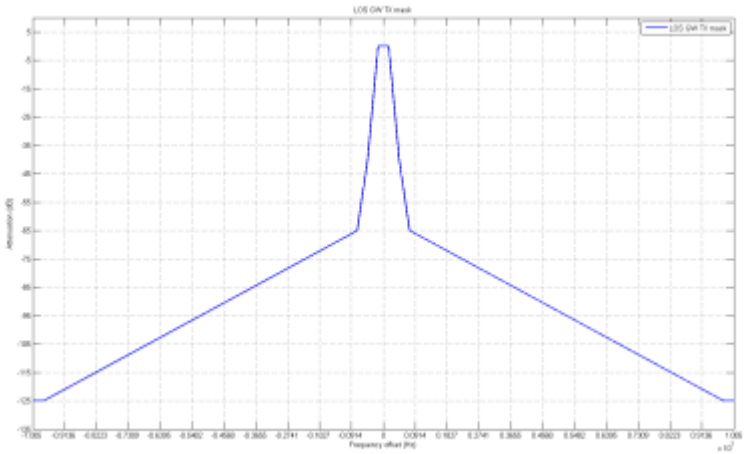
EIRP(dBW)	10.00
TX bandwidth	300000.00
Mask type	Linear Gabarit



LOS User Terminal TX mask

LOS GW transmitter characteristics

EIRP(dBW)	37
TX type of polarization	Vertical
TX bandwidth	3.75E+04



LOS Gateway TX mask

OPEN

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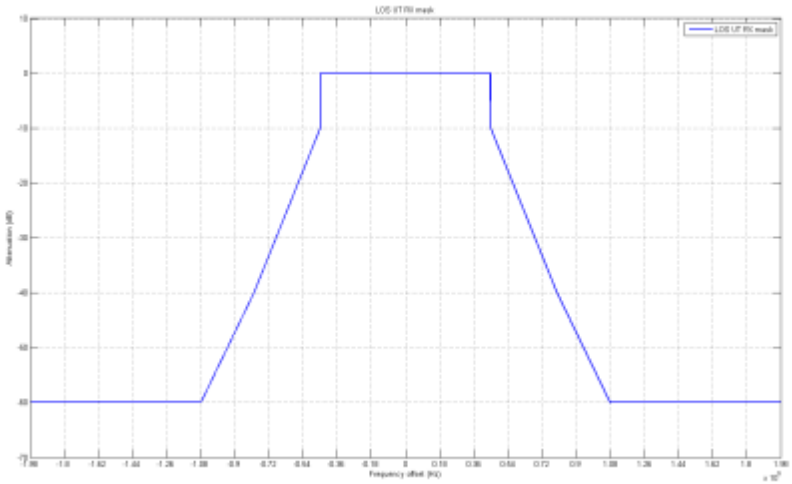
LOS UT receiver characteristics

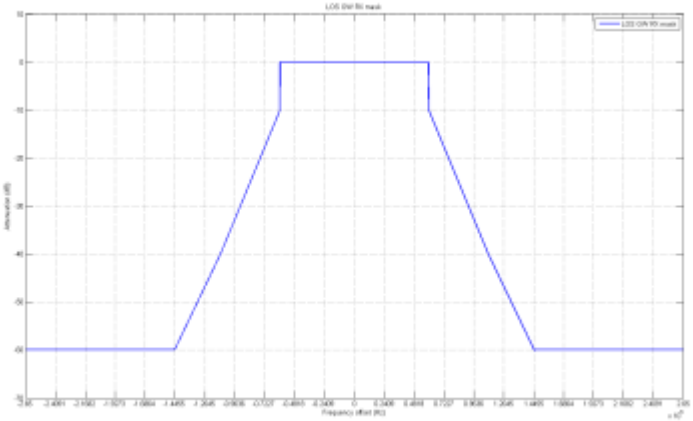
G/T (dBpK)	-24.00
Antenna gain (dBi)	2.00
Equivalent antenna temperature (K)	398.11
RX bandwidth	90000.00
Mask type	Linear Gabarit



LOS User Terminal RX mask

LOS GW receiver characteristics

G/T (dBpK)	9.00
Antenna gain (dBi)	38.00
Equivalent antenna temperature (K)	794.33
RX bandwidth	120000.00
Mask type	Linear Gabarit



LOS User Terminal RX mask

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