DEMONSTRATION OF AN EXPERIMENTAL 5G GNODEB IN SPACE (MIXELS)

Sandro Scalise, DLR (German Aerospace Center)

ASMS/SPSC 2025 – SITGES (SPAIN), 26-28/02

TABLE OF CONTENTS

PROJECT GOALS AND CONSORTIUM

ThalesAlenia Space
a Thales / Leonardo company

DLR Deutsches Zentrum für Luft- und Raumfahrt

Telefónica

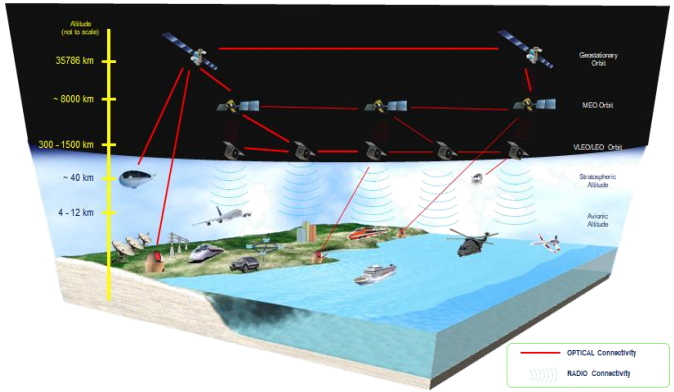
KEPLER

Evoelectronics

MIXELS OBJECTIVES

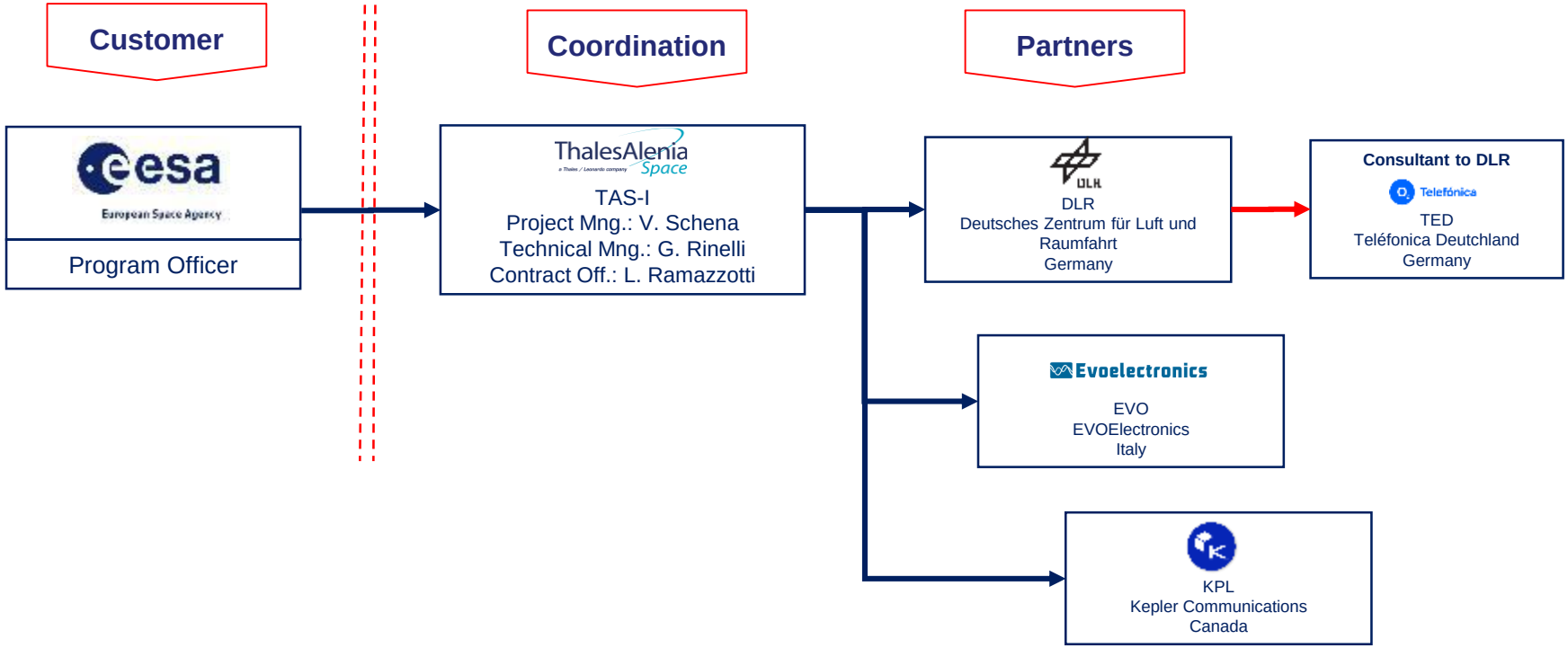
/// The objective of the activity is to develop and demonstrate in orbit an experimental 5G g-NodeB) distributed between a regenerative (processed) payload and a satellite gateway. The demonstration will focus on showing the main functionalities of a gNodeB for New radio Non-Terrestrial Network from LEO.

/// The results of MIXELS in perspective will be able to be extended also towards MEO and GEO in view of the actual implementation of space networks combined and interacting with the terrestrial ones in seamless and transparent way.



/// The target Technology Readiness Level (TRL) for MIXELS is 6, i.e. demonstration in an operational environment.

MIXELS CONSORTIUM COMPOSITION



REQUIREMENTS SUMMARY

ThalesAlenia Space
a Thales / Leonardo company

DLR Deutsches Zentrum für Luft- und Raumfahrt

Telefónica

KEPLER

Evoelectronics

REQUIREMENTS SUMMARY (1/2)

/// **DEMO-REQ-10:** The 5G Satcom regenerative Demonstrator shall include a:

- **SPACE SEGMENT AND ITS SUPPORTING SUBSYSTEM, THE SATELLITE TELECOMMUNICATION PAYLOAD IMPLEMENTING THE REQUIRED ONBOARD REGENERATION,**
- **THE 5G NTN USER TERMINAL(S) ON GROUND,**
- **THE GROUND SEGMENT IMPLEMENTING THE REMAINING 5G GNODEB, INCLUDING THE TELEMETRY AND TELECOMMAND AND**
- **MISSION CONTROL**
- **AND THE NECESSARY 5G CORE NETWORK WITH CONNECTIVITY TO TERRESTRIAL NETWORKS.**

/// **DEMO-REQ -50:** The 5G Satcom regenerative Demonstrator shall demonstrate direct access connectivity based on NTN NR between at least two ground based 5G-enabled user terminals, covering user-to-user (2 hops) and user-to-gateway (single hop) cases.

/// **DEMO-REQ -60:** The 5G Satcom regenerative Demonstrator shall implement at least the Distributed Unit (DU) part of a gNodeB onboard of the space segment.

/// **DEMO-REQ -70:** The 5G Satcom regenerative Demonstrator shall demonstrate connectivity with a user terminal supporting the 5G New Radio (NR) air interface as specified in 3GPP Release 17.

/// **DEMO-REQ -80:** The 5G Satcom regenerative Demonstrator shall be able to support at least a 5MHz channel and to provide a throughput of at least 10 Mbps in downlink and 1Mbps in uplink.

/// **DEMO-REQ -90:** The 5G Satcom regenerative Demonstrator shall operate in user frequency bands to be selected by the Contractor to maximize the success of the demonstration.

REQUIREMENTS SUMMARY (2/2)

/// **DEMO-REQ -120:** The 5G Satcom regenerative Demonstrator shall demonstrate the following functionalities:

- USER TERMINAL REGISTRATION
- CONNECTION SETUP AND RELEASE
- SESSION MANAGEMENT
- RADIO RESOURCE MANAGEMENT
- DYNAMIC RESOURCE MANAGEMENT
- USER TERMINAL HANDOVER
- MOBILITY MANAGEMENT
- MESH CONNECTIVITY
- ON BOARD ROUTING

/// **DEMO-REQ -130:** The 5G Satcom regenerative Demonstrator shall implement, as a minimum, the following connectivity scenarios:

- USER DATA TRANSFER FROM UE TO GNODEB
- USER DATA TRANSFER FROM GNODEB TO UE
- USER DATA TRANSFER FROM UE TO 5G CORE NETWORK
- USER DATA TRANSFER FROM 5G CORE NETWORK TO UE
- USER DATA TRANSFER FROM UE TO INTERNET
- USER DATA TRANSFER FROM INTERNET TO UE
- USER DATA TRANSFER FROM UE TO UE

DEMO DEFINITION

ThalesAlenia Space
a Thales / Leonardo company

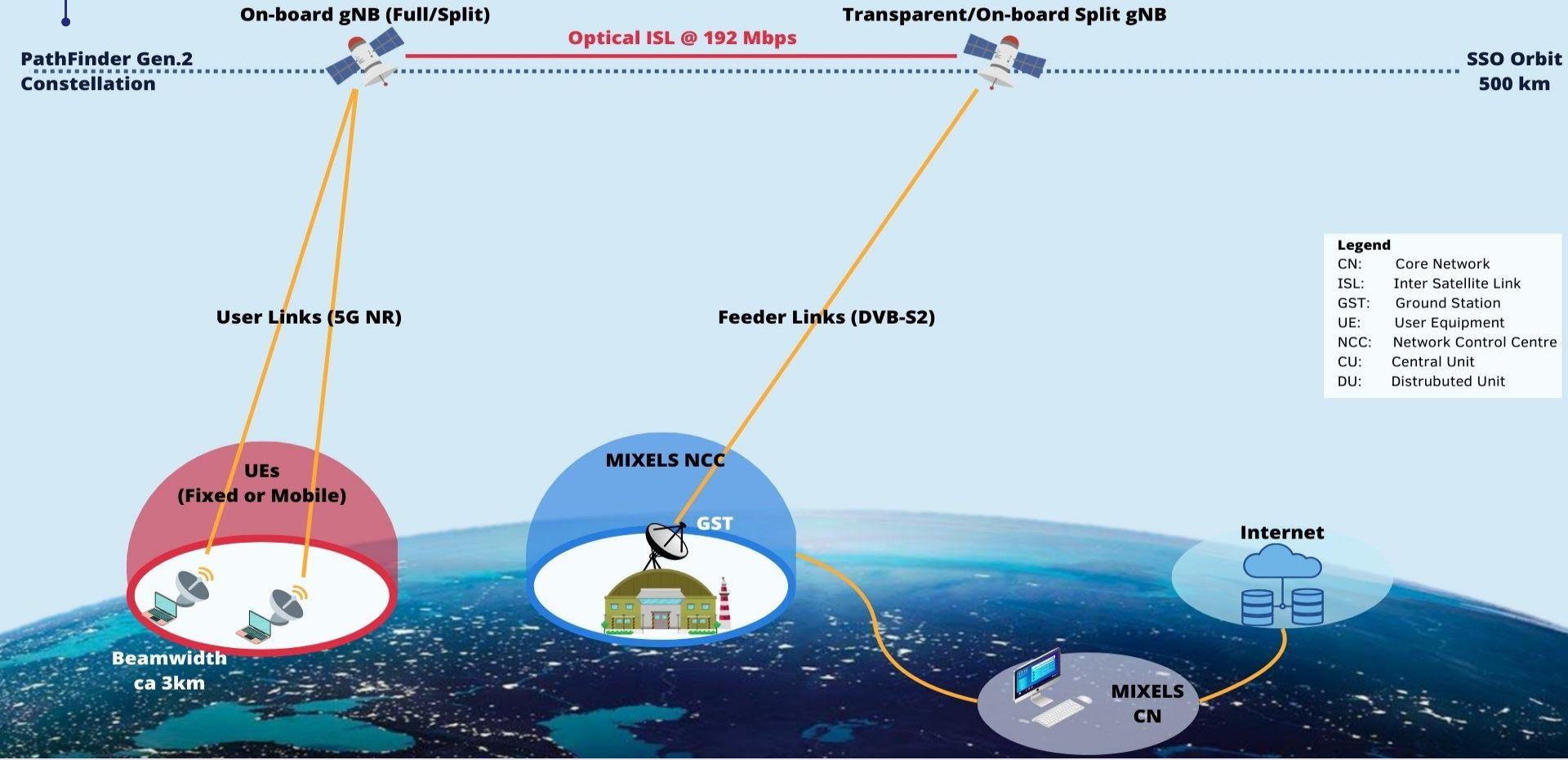
DLR Deutsches Zentrum für Luft- und Raumfahrt

O2 Telefónica

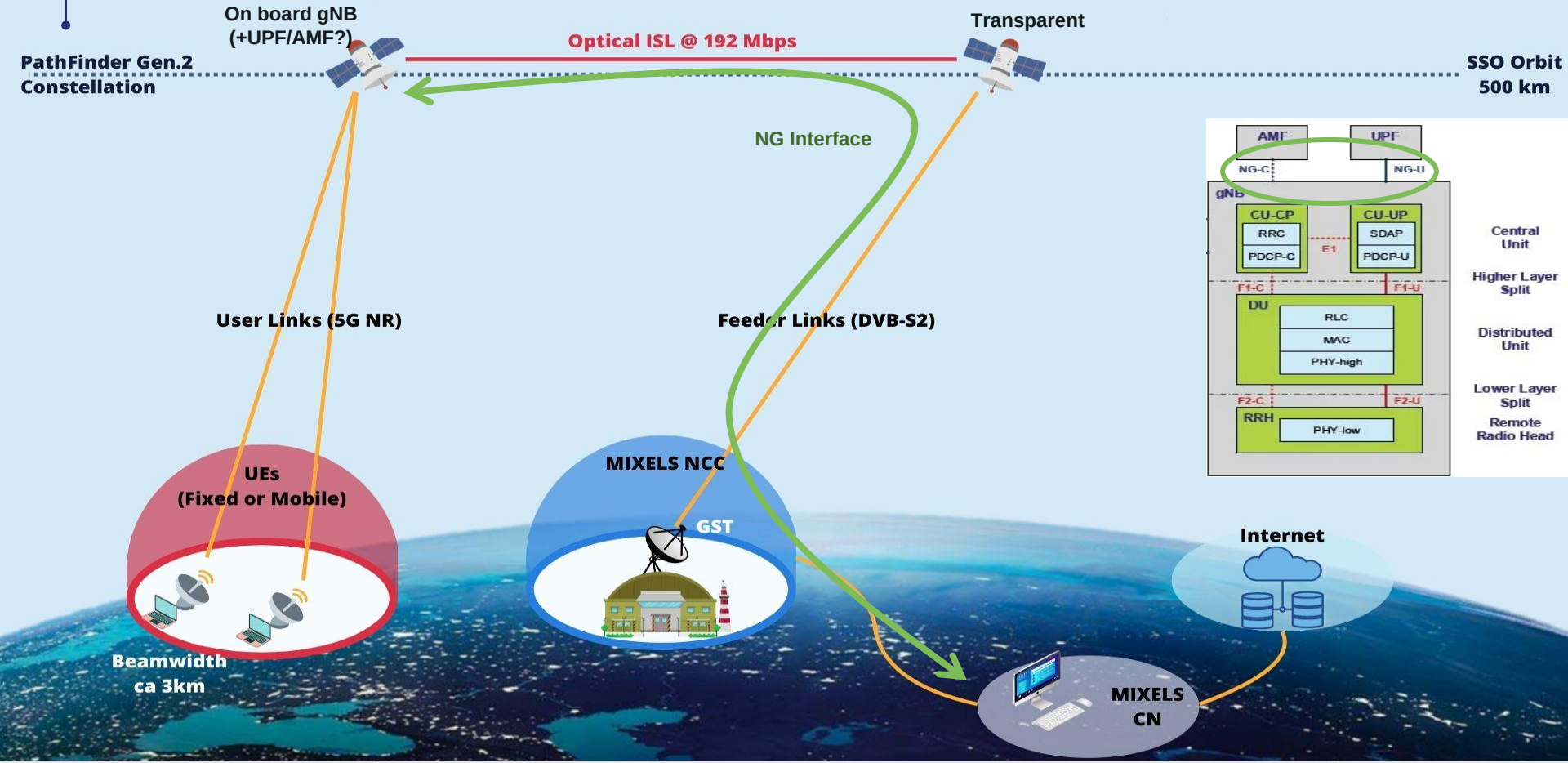
KEPLER

Evoelectronics

DEMO CONCEPT

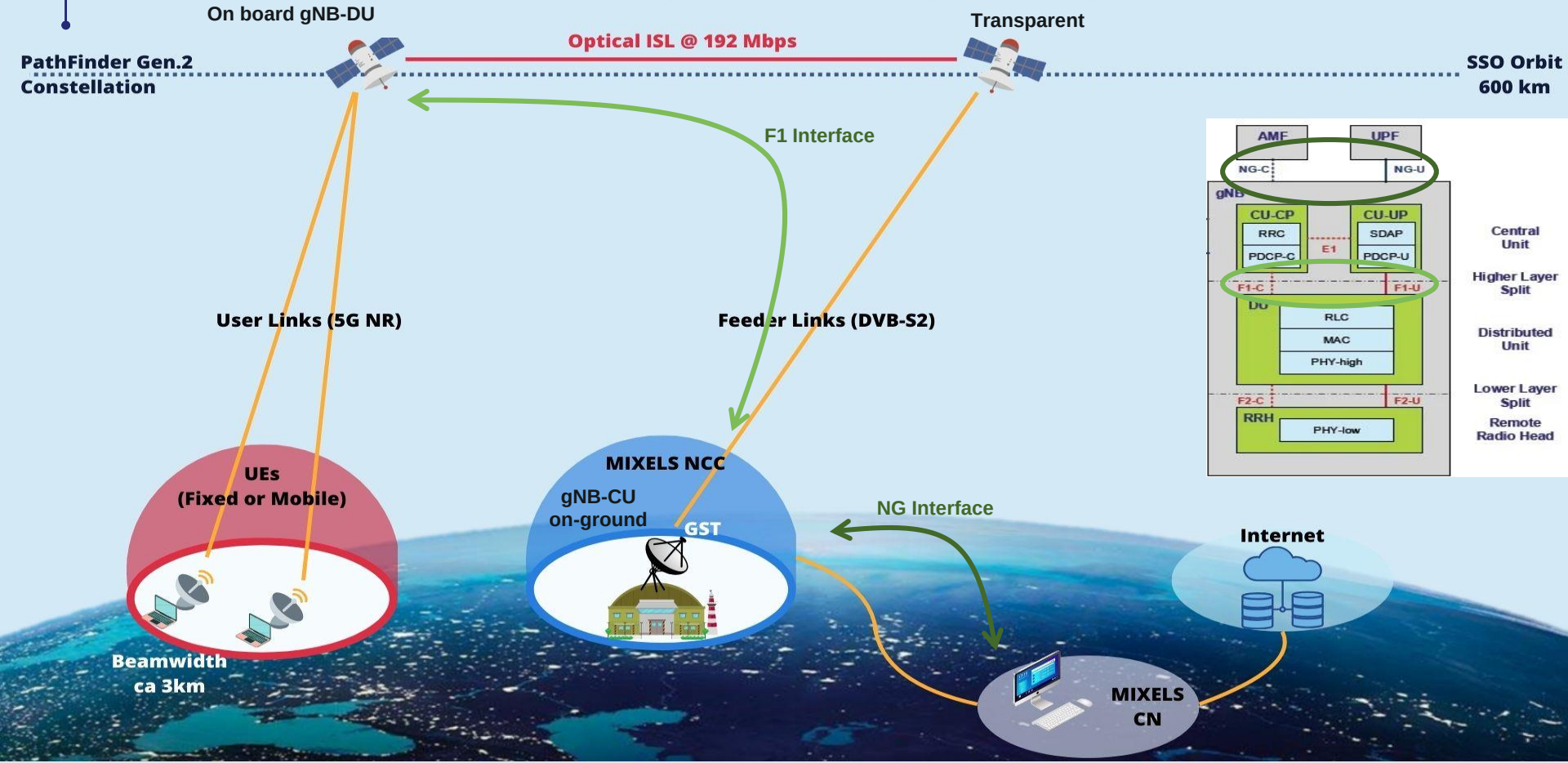


MIXELS DEMO ARCHITECTURE – OPTION #1

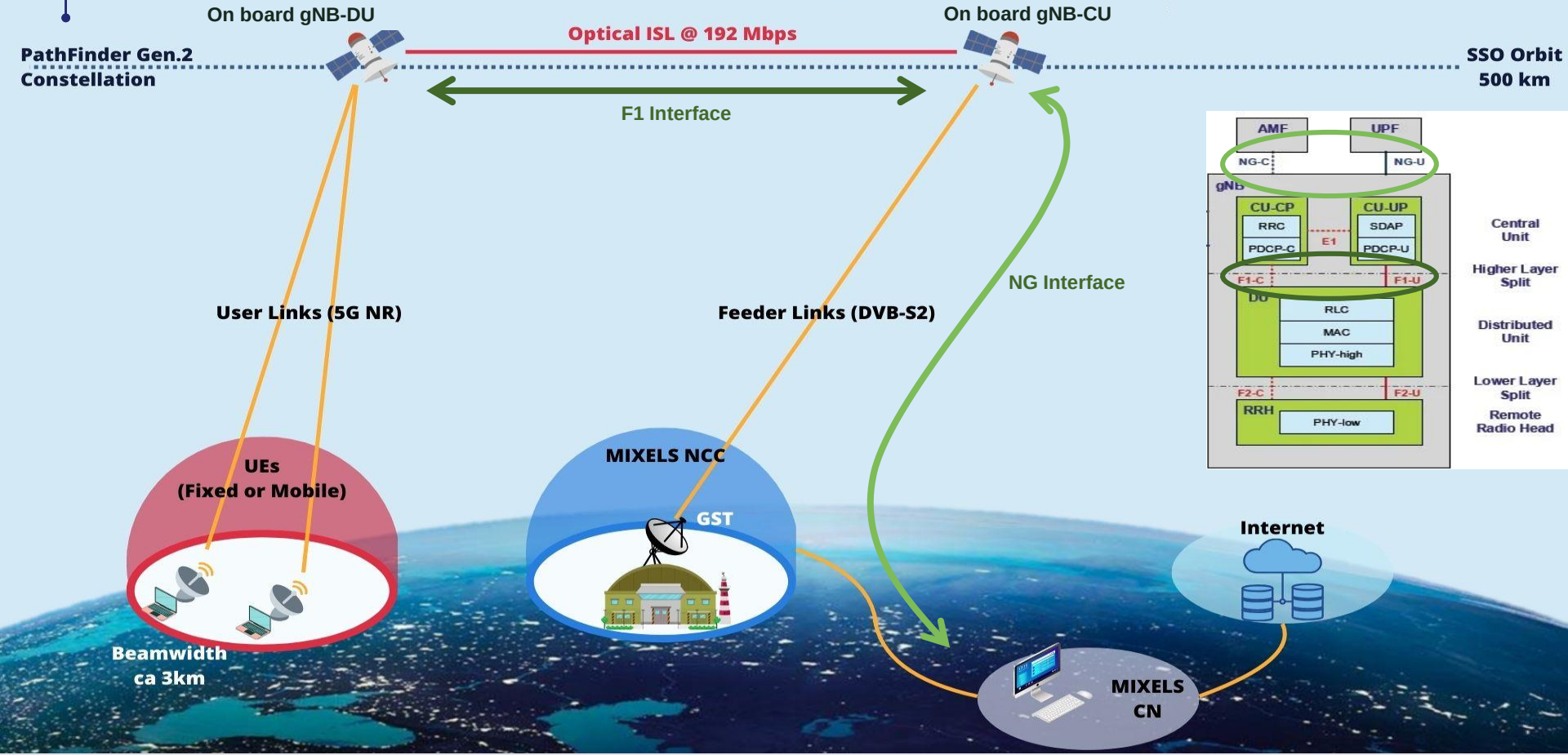


ThalesAlenia Space
DLR Deutsches Zentrum für Luft- und Raumfahrt
Telefónica
KEPLER
Evoelectronics

MIXELS DEMO ARCHITECTURE – OPTION #2

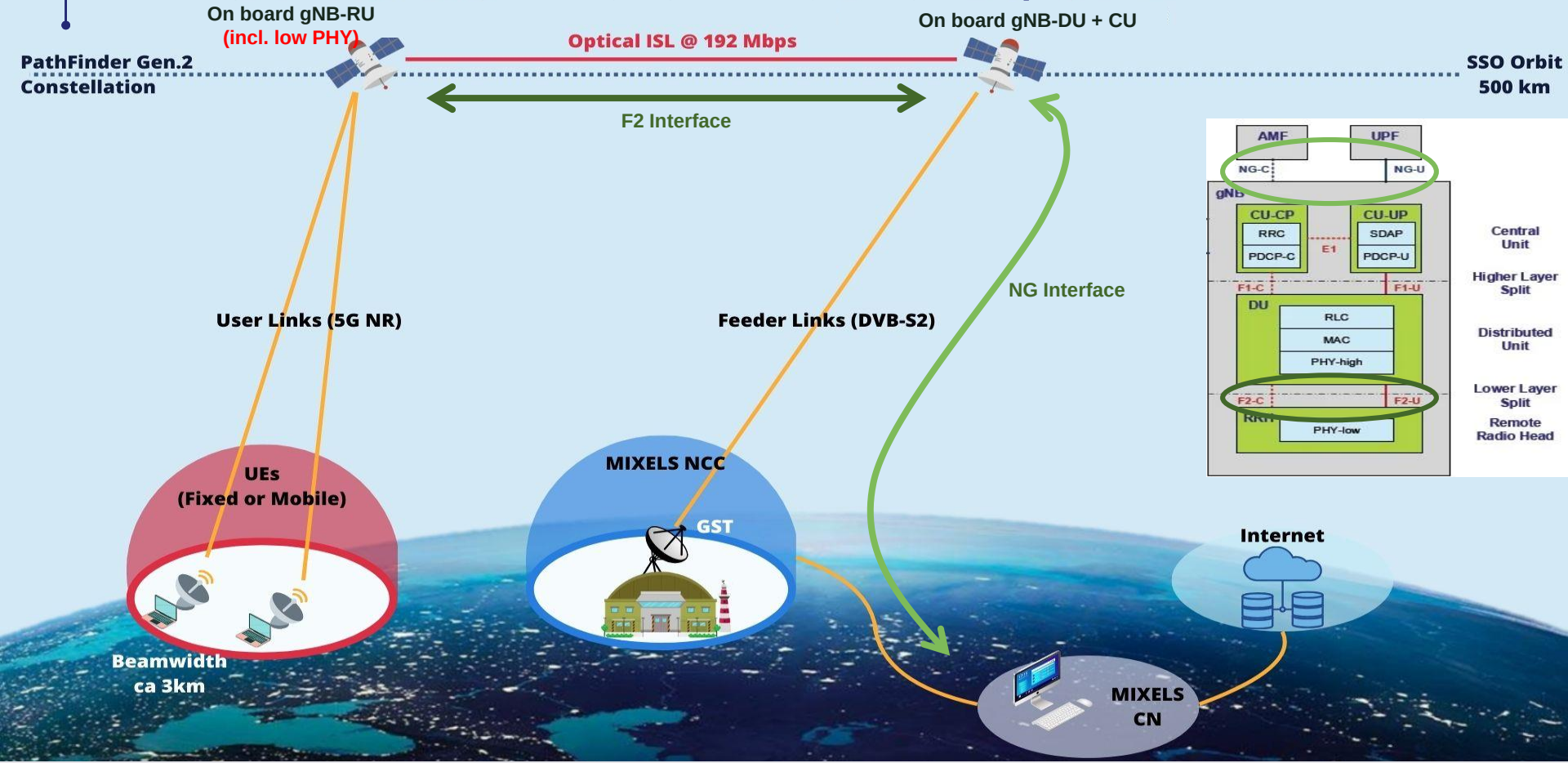


MIXELS DEMO ARCHITECTURE – OPTION #3



ThalesAlenia Space
DLR Deutsches Zentrum für Luft- und Raumfahrt
Telefónica
KEPLER
Evoelectronics

MIXELS DEMO ARCHITECTURE – OPTION #4/#5



ThalesAlenia Space
DLR Deutsches Zentrum für Luft- und Raumfahrt
Telefónica
KEPLER
Evoelectronics

MIXELS DEMO FUNCTIONAL SPLIT OPTIONS

Conf Name	Sat-1	Sat-2	Ground	Optical ISL	DVB-S2 Feeder Links	Comments
#1 (Full gNB in space)	RU, DU, CU	Transparent	CN	NG Interface		▪ Easier implementation ▪ Processing capabilities on Sat-1 to be assessed ▪ Not scalable/optimal for a real system
#2 (Split 2 w/ CU on-ground)	RU, DU	Transparent	CU, CN	F1 Interface (delay critical)		▪ Not in the main focus on 3GPP roadmap for NTN ▪ Unclear whether this split will be widely implemented in 5G / retained for 6G ▪ Delay requirement for the F1 interface (5-50ms) might not be fulfilled
#3 (Split 2 w/ full gNB in space)	RU, DU	CU	CN	F1 Interface (delay critical)	NG Interface	▪ Unclear whether this split will be widely implemented in 5G / retained for 6G
#4 (Split 8 w/ full gNB in space)	RU	DU, CU	CN	F2 Interface (FH - Split 8)	NG Interface	▪ Bandwidth in the downlink depends on the MCS for the F2 interface ▪ Delay/jitter requirements for the F2 interface to be assessed ▪ Potentially representative of a future real system with distributed gNB split in space ▪ Unclear whether current gNB software implementation fully supports these options
#5 (Split 7.2 w/ full gNB in space)	RU, Low-PHY	High-PHY, DU, CU	CN	F2 Interface (FH - Split 7.x)	NG Interface	

DEMO ARCHITECTURE – USER SEGMENT (1/3)

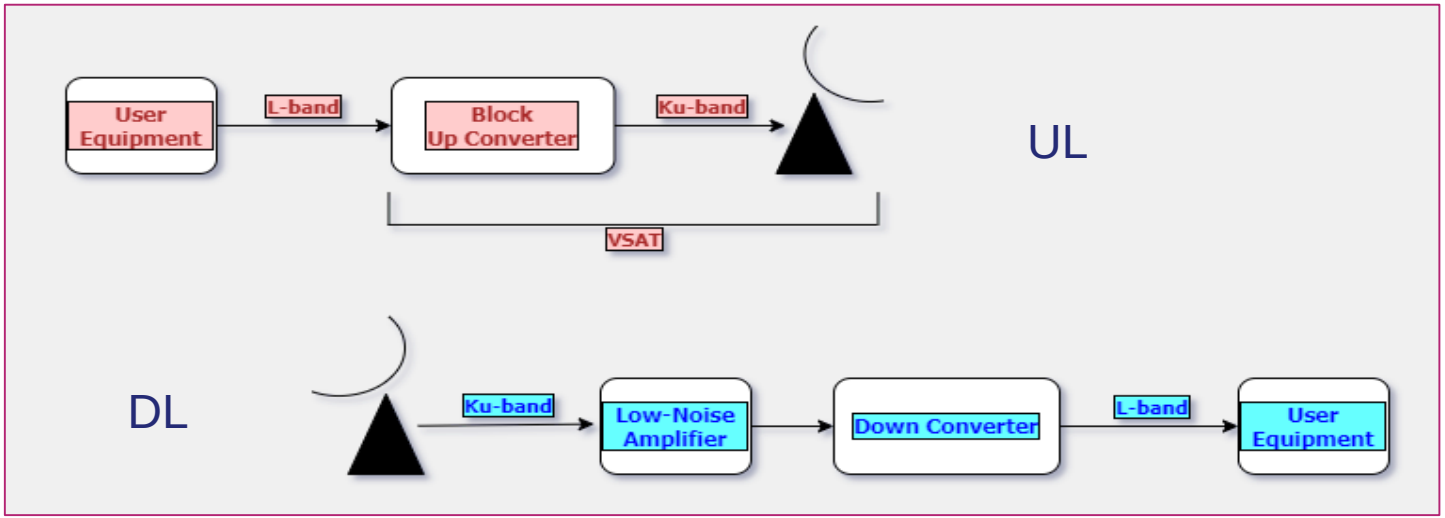
User Terminal

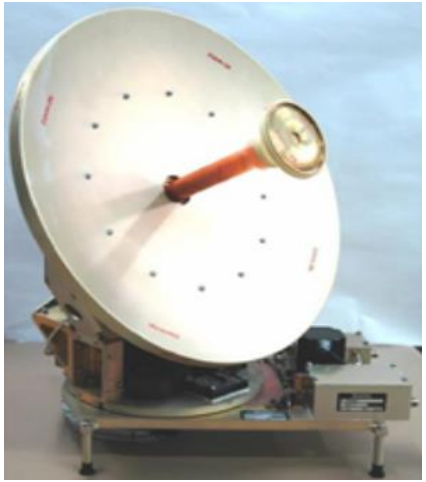
- **Amarisoft UE Simulator**: designed for comprehensive functional and performance testing of 4G and 5G networks;
  - 3GPP compliant for UE 5G NR NTN;
  - capable of simulating numerous UEs operating concurrently within the same spectrum.
- **Functionality**:
  - versatile platform for evaluating the effectiveness and reliability of telecommunications networks;
  - seamless compatibility and performance in various scenarios.
- **Application in the MIXELS Project**: used for testing and optimizing network functionality.
- **Specific Model Used**: **AMARI UE Simbox MBS 064** (testbed and DEMO sessions).

AMARI UE Feature	Simbox MBS 064 values
Frequency range	500 MHz to 6.0 GHz
RF bandwidth	1.4 MHz to 100 MHz
Operation mode	FDD and TDD
MIMO	4x4
ADC/DAC sample rate	122.88 MS/s
Synchronization	Internal clock, PPS signal, GPS, Reference external clock (LVDS)

DEMO ARCHITECTURE – USER SEGMENT (2/3)

User Link

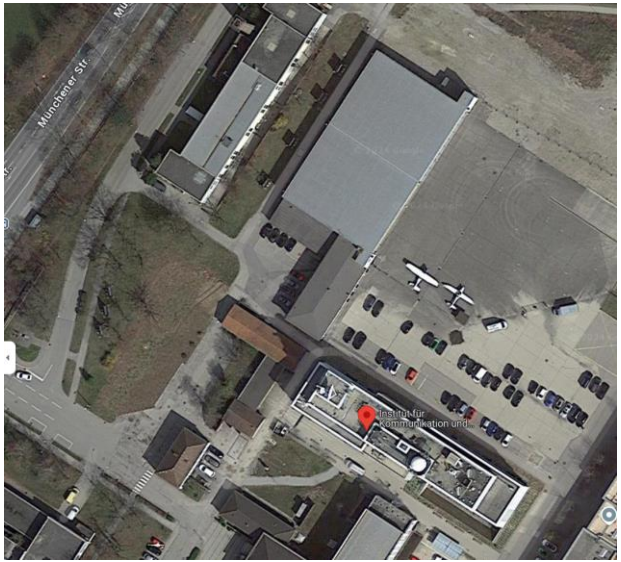




RANTEC 12843-IM

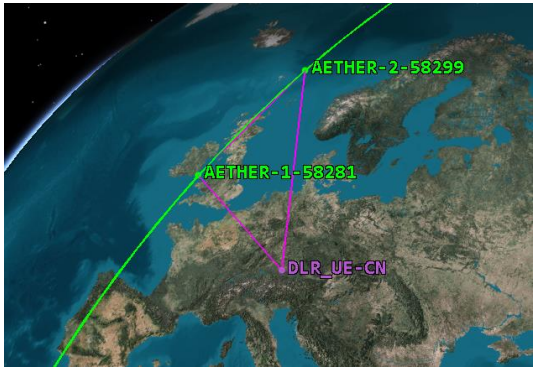
DEMO ARCHITECTURE – USER SEGMENT (3/3)

/// Roof of DLR Institute of Communications and Navigation, Oberpaffenhofen (near Munich)



DEMO ARCHITECTURE – SPACE SEGMENT

Sat Name	NORAD ID	Period	Inclination	Apogee	Perigee
AETHER-1	58281	94.65	97.46	509	494
AETHER-2	58299	94.65	97.46	509	494



Payload block diagramm cannot be shared…

Processing Central Unit (PCU) – Xilinx MPSoC UltraScale ZU15EG.
Capable of taking over the air updates to reprogram as needed

DEMO ARCHITECTURE – TT&C STATIONS

- **TT&C Radio:** operates over S-Band in the frequency ranges of 2200 - 2290 MHz for transmission (Tx) and 2025 - 2110 MHz for reception (Rx).
  - Data Rate capable of 500 kbps throughput
  - DSSS modulation, switched antennas for omnidirectional coverage

- **Ground Stations:** Kepler leverages a network of ground stations through LeafSpace for reliable satellite communication, including data transmission, command uplinks, and telemetry downlinks, ensuring seamless operations across various orbits.

Key Locations:
Awarua, NZ (New Zealand)
Nangetty, WA (Western Australia)
Kandy, LK (Sri Lanka)
Mon Loisir, MU (Mauritius)
Absheron, AZ (Azerbaijan)
Plana, BG (Bulgaria)
Shetland, SCT (Scotland)
Azores / Santa Maria, PT (Portugal)
Blondous, IS (Iceland)
Punta Arenas, CL (Chile)

DEMO ARCHITECTURE – FEEDER LINK STATION

Sweden (65.337090° N, 21.425129° E)

ThalesAlenia Space a Thales / Leonardo company | DLR Deutsches Zentrum für Luft- und Raumfahrt | O2 Telefónica | KEPLER | Evoelectronics

PRELIMINARY DOWNLINK BUDGET (5G NR)

			Downlink			
MCS	Spectral Efficiency [3GPP TS 38.214]	CNR [dB] @BLER 1e-3 [dB]	Link Margin [dB] @BW 5 MHz	Data rate [Mbps] @BW 5 MHz	Required BW to reach 10 Mbps [MHz]	Data rate [Mbps]
0	0,2344	-6	17,9	1,172	45	10,55
1	0,3066	-5	16,9	1,533	35	10,73
2	0,377	-4	15,9	1,885	30	11,31
3	0,4902	-3	14,9	2,451	25	12,26
4	0,6016	-2	13,9	3,008	20	12,03
5	0,7402	-1	12,9	3,701	15	11,10
6	0,887	0	11,9	4,435	15	13,31
7	1,0273	1	10,9	5,1365	10	10,27
8	1,1758	2	9,9	5,879	10	11,76
9	1,3262	3	8,9	6,631	10	13,26
11	1,4766	4	7,9	7,383	10	14,77
12	1,6953	5	6,9	8,4765	10	16,95
13	1,9141	6	5,9	9,5705	10	19,14
14	2,1602	7	4,9	10,801	5	10,80
15	2,4063	7,75	4,1	12,0315	5	12,03
16	2,5703	8,5	3,4	12,8515	5	12,85
18	2,7305	10	1,9	13,6525	5	13,65
19	3,0293	11	0,9	15,1465	5	15,15
20	3,3223	11,5	0,4	16,6115	5	16,61
21	3,6094	12	-0,1	18,047	5	18,05
22	3,9023	13,5	-1,6	19,5115	5	19,51
23	4,2129	14,5	-2,6	21,0645	5	21,06
24	4,5234	15,5	-3,6	22,617	5	22,62
25	4,8164	16,5	-4,6	24,082	5	24,08
26	5,1152	17,5	-5,6	25,576	5	25,58
27	5,332	18,5	-6,6	26,66	5	26,66
28	5,5547	20	-8,1	27,7735	5	27,77
23,2	6,2266	21	-9,1	31,133	5	31,13
24,2	6,5703	22	-10,1	32,8515	5	32,85
25,2	6,9141	23,5	-11,6	34,5705	5	34,57
26,2	7,1602	24,5	-12,6	35,801	5	35,80
27,2	7,4063	25,5	-13,6	37,0315	5	37,03

PRELIMINARY UPLINK BUDGET (5G NR)

			Uplink for 5 MHz Bandwidth		Uplink for 10 MHz Bandwidth		Uplink for 15 MHz Bandwidth		Uplink for 20 MHz Bandwidth	
MCS	Spectral Efficiency [3GPP TS 38.214]	CNR [dB] @BLER 1e-3 [dB]	Link Margin [dB]	Data rate @ PHY [Mbps]	Link Margin [dB]	Data rate @ PHY [Mbps]	Link Margin [dB]	Data rate @ PHY [Mbps]	Link Margin [dB]	Data rate @ PHY [Mbps]
0	0,2344	-6	29,7	1,17	26,6	2,34	24,9	3,52	23,6	4,69
1	0,3066	-5	28,7	1,53	25,6	3,07	23,9	4,60	22,6	6,13
2	0,377	-4	27,7	1,89	24,6	3,77	22,9	5,66	21,6	7,54
3	0,4902	-3	26,7	2,45	23,6	4,90	21,9	7,35	20,6	9,80
4	0,6016	-2	25,7	3,01	22,6	6,02	20,9	9,02	19,6	12,03
5	0,7402	-1	24,7	3,70	21,6	7,40	19,9	11,10	18,6	14,80
6	0,887	0	23,7	4,44	20,6	8,87	18,9	13,31	17,6	17,74
7	1,0273	1	22,7	5,14	19,6	10,27	17,9	15,41	16,6	20,55
8	1,1758	2	21,7	5,88	18,6	11,76	16,9	17,64	15,6	23,52
9	1,3262	3	20,7	6,63	17,6	13,26	15,9	19,89	14,6	26,52
11	1,4766	4	19,7	7,38	16,6	14,77	14,9	22,15	13,6	29,53
12	1,6953	5	18,7	8,48	15,6	16,95	13,9	25,43	12,6	33,91
13	1,9141	6	17,7	9,57	14,6	19,14	12,9	28,71	11,6	38,28
14	2,1602	7	16,7	10,80	13,6	21,60	11,9	32,40	10,6	43,20
15	2,4063	7,75	15,9	12,03	12,9	24,06	11,1	36,09	9,9	48,13
16	2,5703	8,5	15,2	12,85	12,1	25,70	10,4	38,55	9,1	51,41
18	2,7305	10	13,7	13,65	10,6	27,31	8,9	40,96	7,6	54,61
19	3,0293	11	12,7	15,15	9,6	30,29	7,9	45,44	6,6	60,59
20	3,3223	11,5	12,2	16,61	9,1	33,22	7,4	49,83	6,1	66,45
21	3,6094	12	11,7	18,05	8,6	36,09	6,9	54,14	5,6	72,19
22	3,9023	13,5	10,2	19,51	7,1	39,02	5,4	58,53	4,1	78,05
23	4,2129	14,5	9,2	21,06	6,1	42,13	4,4	63,19	3,1	84,26
24	4,5234	15,5	8,2	22,62	5,1	45,23	3,4	67,85	2,1	90,47
25	4,8164	16,5	7,2	24,08	4,1	48,16	2,4	72,25	1,1	96,33
26	5,1152	17,5	6,2	25,58	3,1	51,15	1,4	76,73	0,1	102,30
27	5,332	18,5	5,2	26,66	2,1	53,32	0,4	79,98	-0,9	106,64
28	5,5547	20	3,7	27,77	0,6	55,55	-1,1	83,32	-2,4	111,09
23,2	6,2266	21	2,7	31,13	-0,4	62,27	-2,1	93,40	-3,4	124,53
24,2	6,5703	22	1,7	32,85	-1,4	65,70	-3,1	98,55	-4,4	131,41
25,2	6,9141	23,5	0,2	34,57	-2,9	69,14	-4,6	103,71	-5,9	138,28
26,2	7,1602	24,5	-0,8	35,80	-3,9	71,60	-5,6	107,40	-6,9	143,20
27,2	7,4063	25,5	-1,8	37,03	-4,9	74,06	-6,6	111,09	-7,9	148,13

LAB TESTBED

ThalesAlenia Space
a Thales / Leonardo company

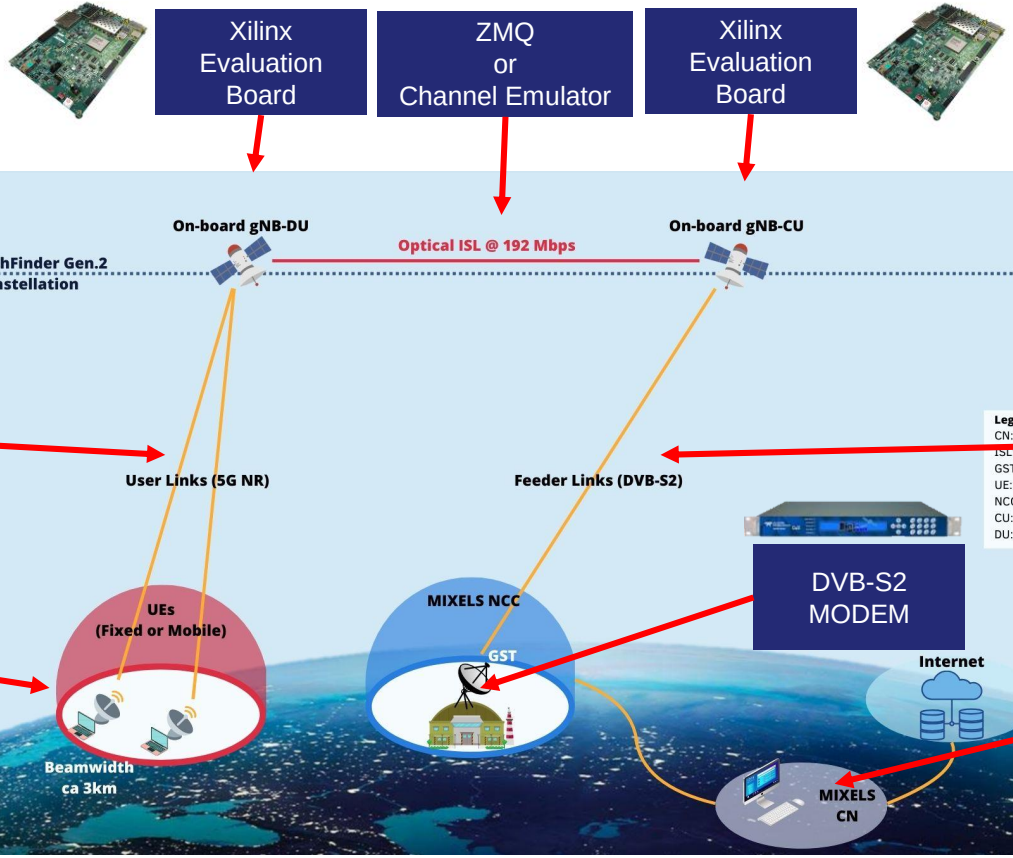
DLR Deutsches Zentrum für Luft- und Raumfahrt

Telefónica

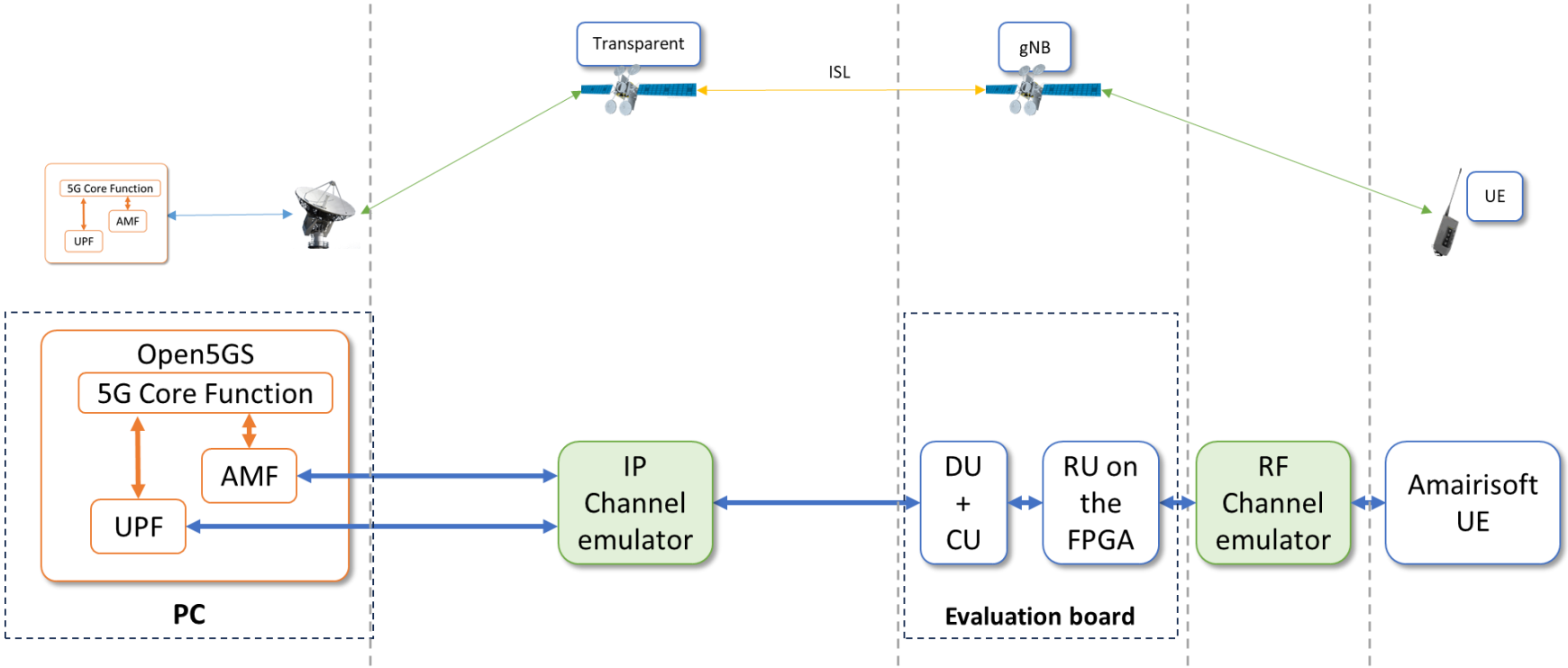
KEPLER

Evoelectronics

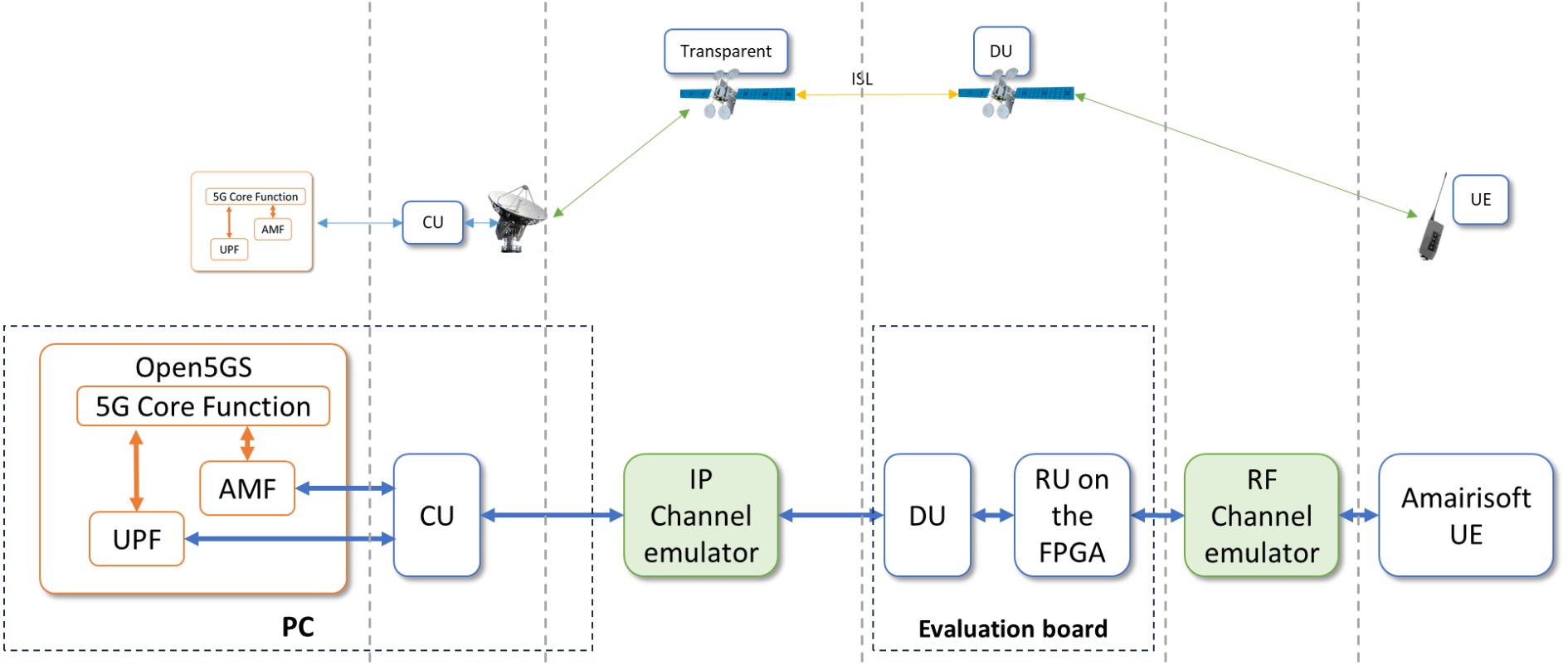
PRELIMINARY GROUND TESTBED SET-UP



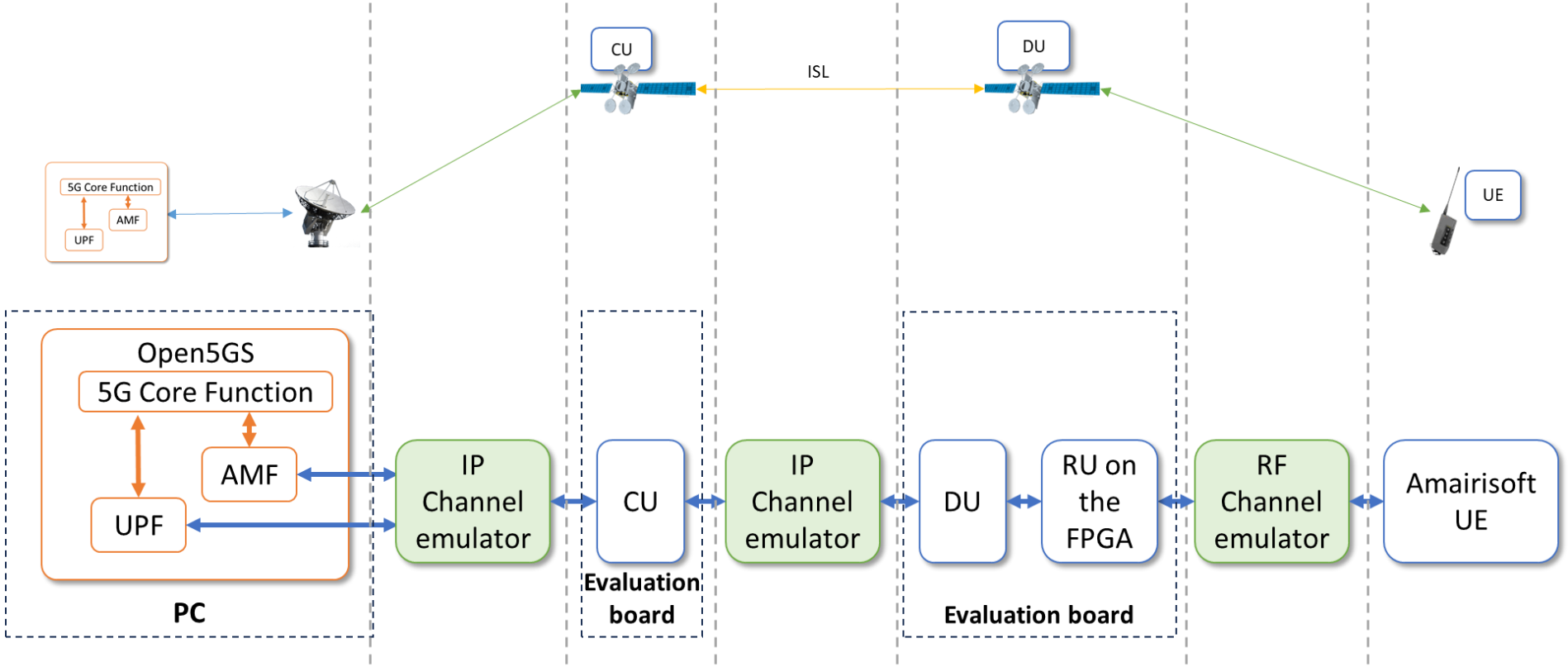
#CONF1 (FULL GNB IN SPACE)



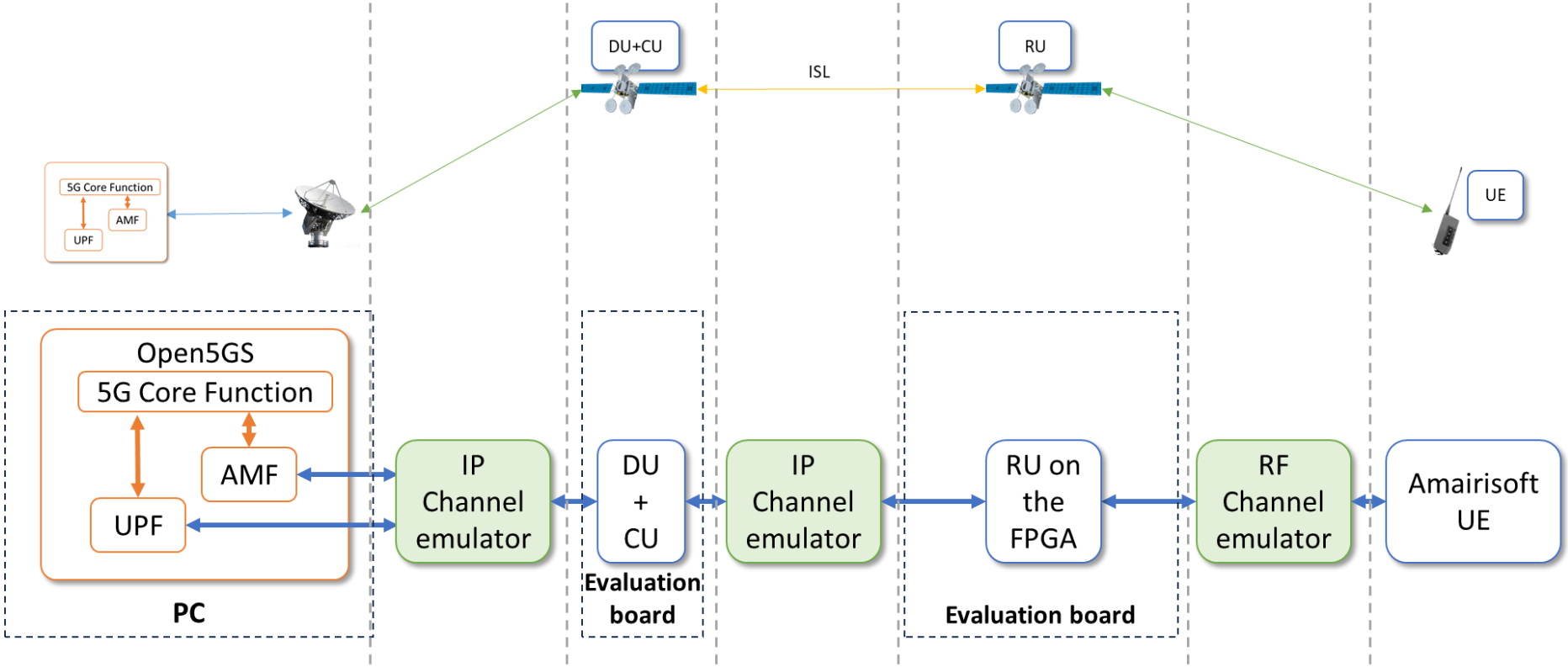
#CONF2 (SPLIT 2 W/ CU ON GROUND)



#CONF3 (SPLIT 2 W/ FULL GNB IN SPACE)



#CONF4 (SPLIT 8 W/ FULL GNB IN SPACE)



CONCLUSION

/// The MIXELS project will demonstrate the functionalities of a regenerative gNB in space using two experimental LEO satellites interconnected by optical ISL

/// Different functional split scenarios between space and ground and in space will be tested in the lab

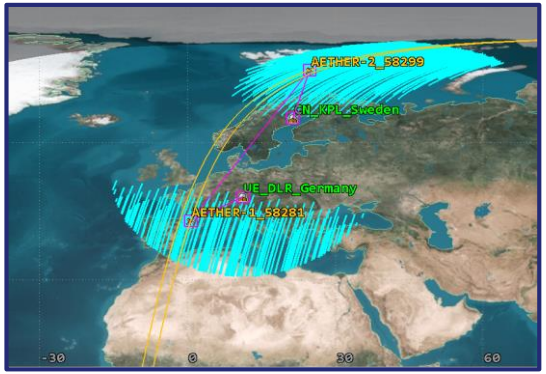
- **ONLY A SUBEST WILL BE RETAINED FOR SATELLITE TESTS**

/// Results are expected to provide valuable insights about NTN functionalities envisged in 3GPP Rel. 17 and could be used for future standardisation activities

DEMONSTRATION OF AN EXPERIMENTAL 5G GNODEB IN SPACE (MIXELS)

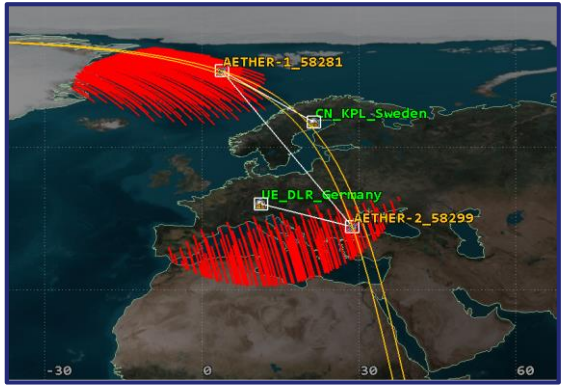
Thanks for your attention!!!

MIXELS VISIBILITY ANALYSIS



Parameter	Description	Value
Maximum Visibility Time	The maximum duration for which both satellites remain visible from the ground during a single pass.	4.684 min
Average Visibility Time	Average visibility duration per satellite pass, indicating the typical communication window available for data exchange.	2.734 min
Number of Accesses per Day	Average number of daily access windows, representing the frequency of communication opportunities between the user, satellites, and ground station.	2
Access Time Window	Approximate time range during which satellite visibility is typically available each day, indicating the usual periods for data exchange.	UTCG 08:45 – 12:15

Chain 2: UE – AETHER-2 – AETHER-1 - CN



Parameter	Description	Value
Maximum Visibility Time	The maximum duration for which both satellites remain visible from the ground during a single pass.	3.921 min
Average Visibility Time	Average visibility duration per satellite pass, indicating the typical communication window available for data exchange.	2.074 min
Number of Accesses per Day	Average number of daily access windows, representing the frequency of communication opportunities between the user, satellites, and ground station.	2
Access Time Window	Approximate time range during which satellite visibility is typically available each day, indicating the usual periods for data exchange.	UTCG 19:30 – 22:30