



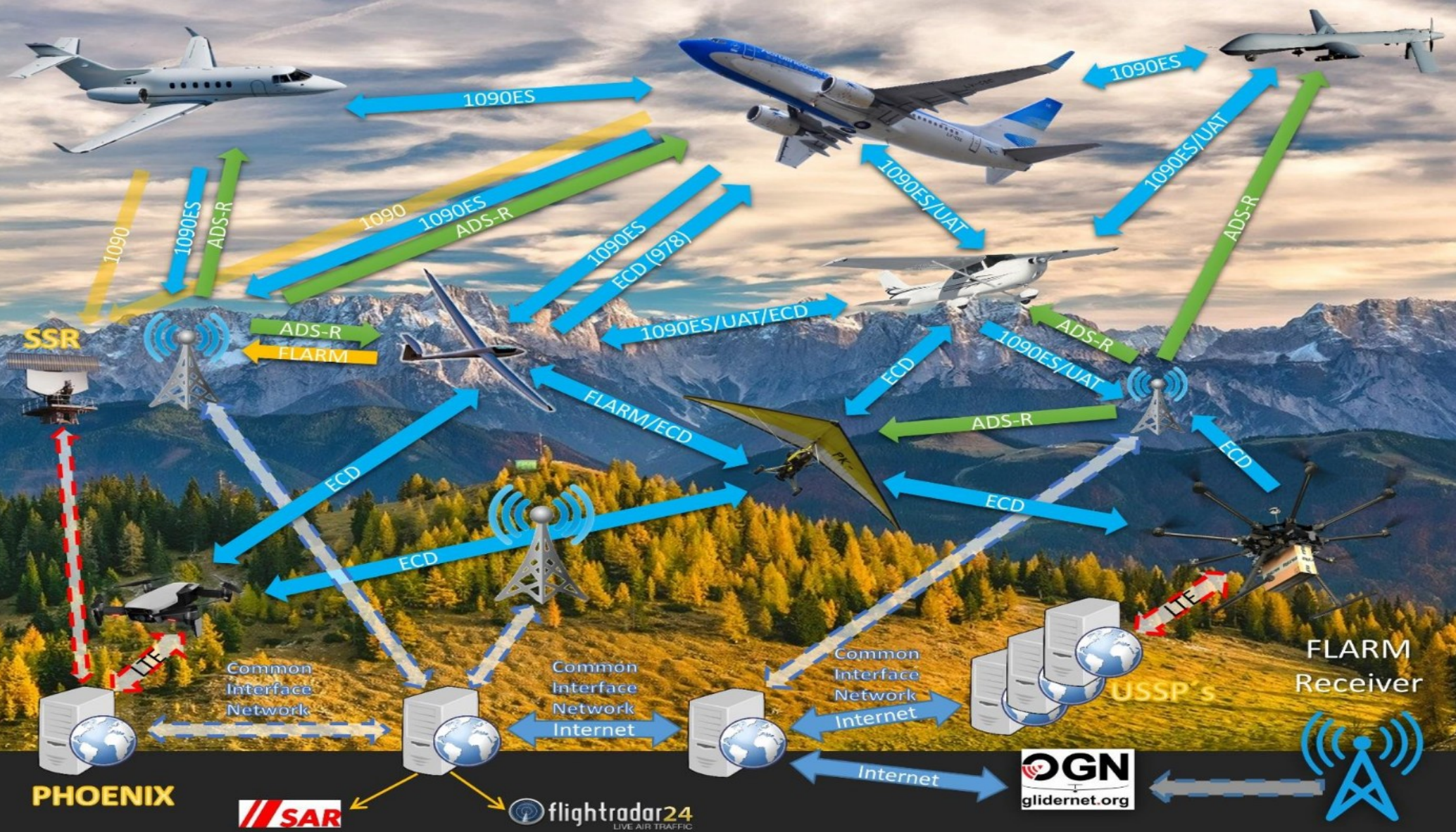
**Co-funded by
the European Union**



**Kofinanziert vom
Land Rheinland-Pfalz**

ADS-G Ground Link Feasibility Study

by ***CHARTERWARE***



PHOENIX

SAR

flightradar24
LIVE AIR TRAFFIC

OGN
glidernet.org

USSP's

FLARM
Receiver

Common
Interface
Network

Common
Interface
Network
Internet

Common
Interface
Network
Internet

Internet

1090

1090ES
ADS-R

ADS-R
FLARM

1090
1090ES
ADS-R

1090ES
ECD (978)

1090ES/UAT/ECD

FLARM/ECD

ECD

ECD

ECD

ADS-R

ECD

ADS-R

ADS-R

ECD

1090ES

1090ES/UAT

1090ES/UAT

1090ES

Designing fully eControlled Traffic Awareness for tomorrows VFR Traffic Warning devices



Incomplete and incompatible Infrastructure on air:
Hidden Objects,
Flarm @ 868 MHz
Mode A/C without position
Full ADS-B in & Out

868 MHz

XPDR + Position
FLARM
Traffic Monitor

XPDR
Mode A/C
only Altitude
No Position

1090 MHz

ADS-B Position

70% detection

Flarm
Position

Quiet hidden

ADS-B
Primary +Sec.
Radar

ADS-B
Secondary
Radar

ADS-B
Secondary
Radar

ADS-L
LTE
868

TELEKOM

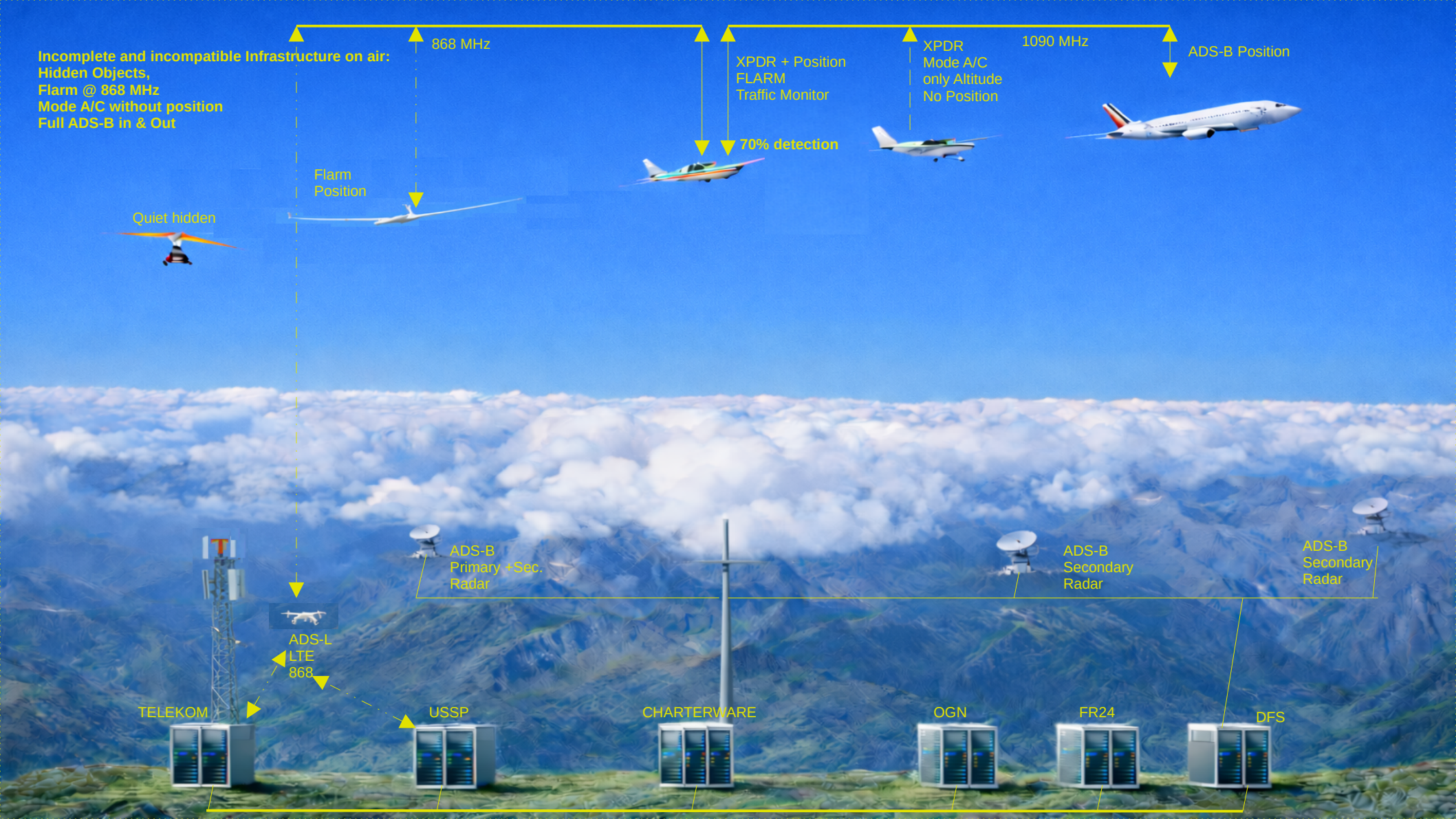
USSP

CHARTERWARE

OGN

FR24

DFS



Incomplete and incompatible Infrastructure on air:
Hidden Objects,
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Full ADS-B in & Out

868 MHz

1090 MHz

ADS-B Position

XPDR + Position
FLARM
Traffic Monitor

XPDR
Mode A/C
only Altitude
No Position

Flarm
Position but
had Coverage

70% detection

Dependent
Positioning

Quiet hidden

Dependent
Positioning

MLAT
Positioning

Primary Radar
Positioning

ADS-B
Primary + Sec.
Radar

ADS-B
Secondary
Radar

ADS-B
Secondary
Radar

ADS-L
LTE
868

Ground **knows a lot more** than air
++ Primary. Rad. ++ MLAT ++ OGN ++ ADSL
but still not about low airspace traffic.

TELEKOM

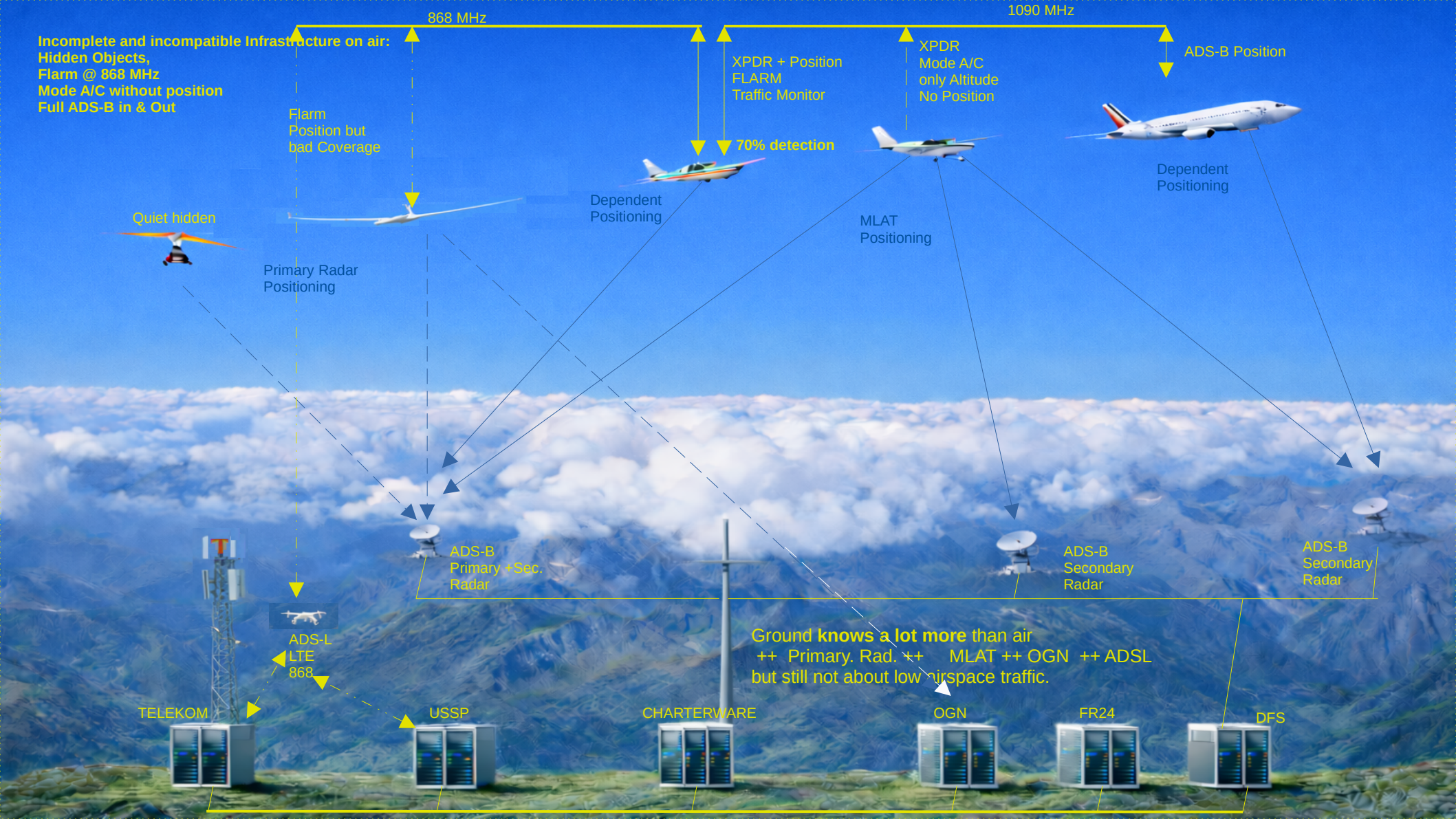
USSP

CHARTERWARE

OGN

FR24

DFS



Incomplete and incompatible Infrastructure on air:
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Position but
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868 MHz

1090 MHz

XPDR + Position
FLARM
Traffic Monitor

XPDR
Mode A/C
only Altitude
No Position

ADS-B Position

~90% detection

~90% detection

Not part of this study: UAT 978 Traffic Repeater
Dual purpose - weather and traffic broadcasting.

ADS-B
Primary + Sec.
Radar

UAT 978
Traffic Repeater

ADS-B
Secondary
Radar

ADS-L
LTE
868

Ground knows a lot more than air,
but it still does **not know** about low airspace traffic.

TELEKOM

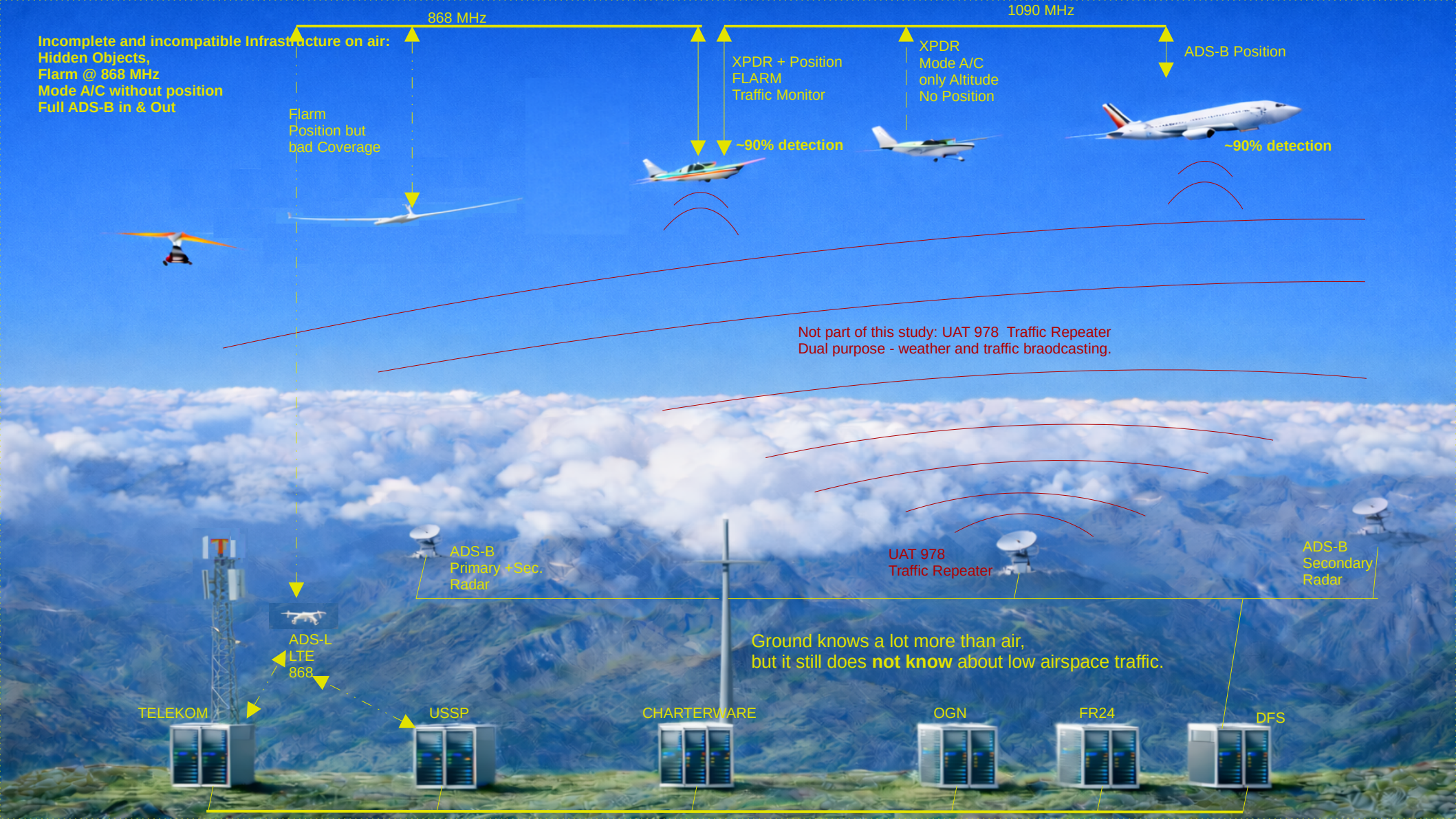
USSP

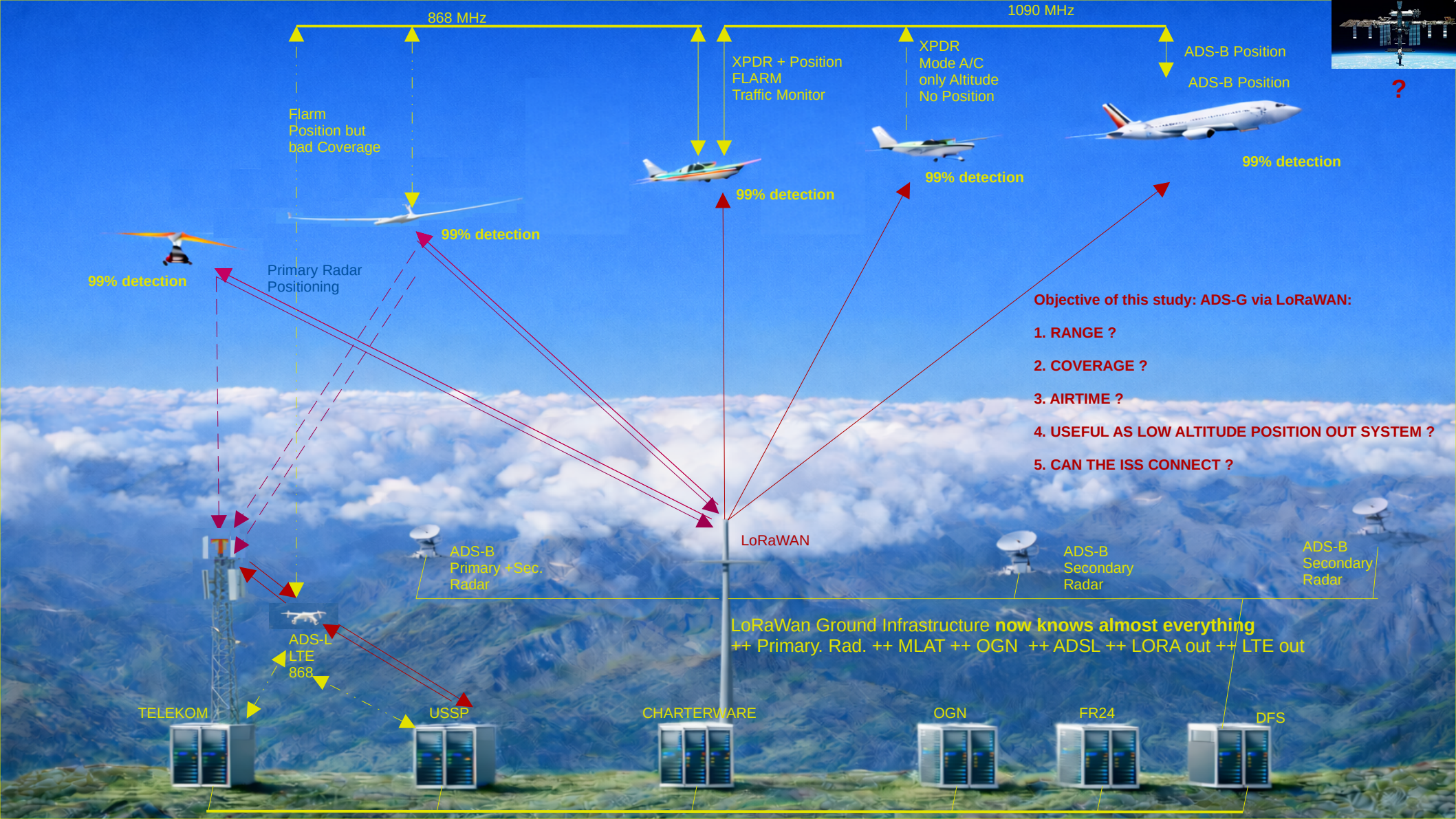
CHARTERWARE

OGN

FR24

DFS





868 MHz

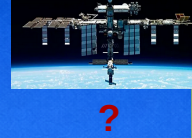
1090 MHz

Flarm
Position but
had Coverage

XPDR + Position
FLARM
Traffic Monitor

XPDR
Mode A/C
only Altitude
No Position

ADS-B Position
ADS-B Position



99% detection

Primary Radar
Positioning

99% detection

99% detection

99% detection

99% detection

Objective of this study: ADS-G via LoRaWAN:

1. RANGE ?
2. COVERAGE ?
3. AIRTIME ?
4. USEFUL AS LOW ALTITUDE POSITION OUT SYSTEM ?
5. CAN THE ISS CONNECT ?

LoRaWAN

ADS-B
Primary + Sec.
Radar

ADS-B
Secondary
Radar

ADS-B
Secondary
Radar

ADS-L
LTE
868

LoRaWan Ground Infrastructure now knows almost everything
 + + Primary. Rad. + + MLAT + + OGN + + ADSL + + LORA out + + LTE out

TELEKOM

USSP

CHARTERWARE

OGN

FR24

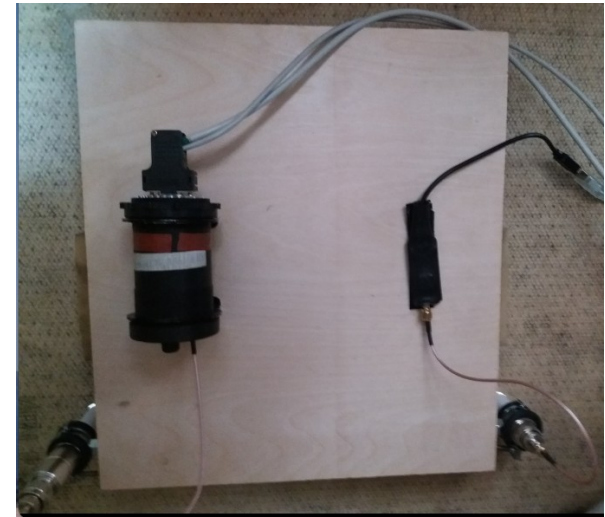
DFS

Test Setup

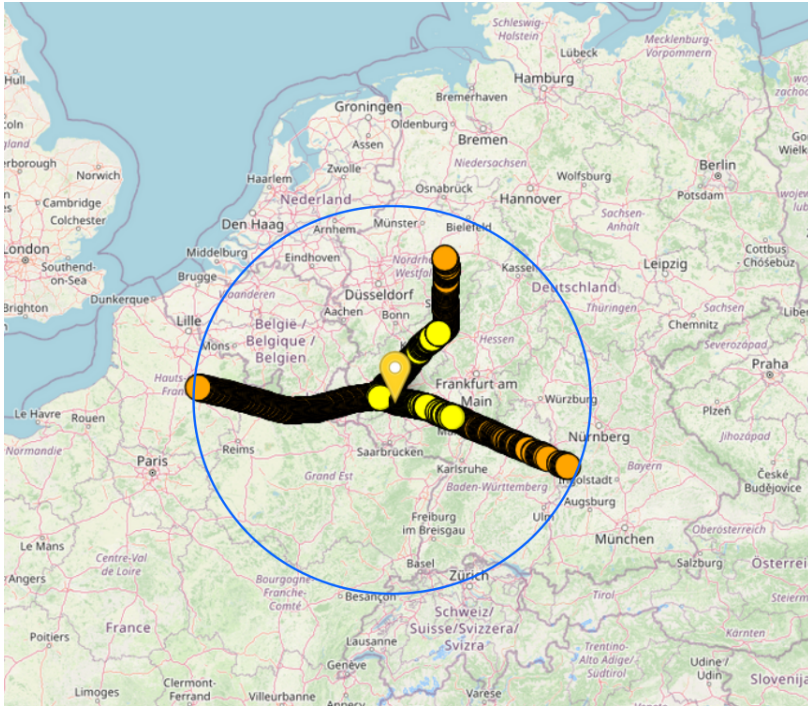
The Base station was setup on a trailer powered by solar & battery located at „Erbeskopf“ the highest hill in Rhineland Palatine (RLP). It was connected by LTE to our network server running our log software.

A C42 Microlight was equipped with a PC controlling a charterware Logger as IOT-NB/LTE interface and a LoRa test PCB.

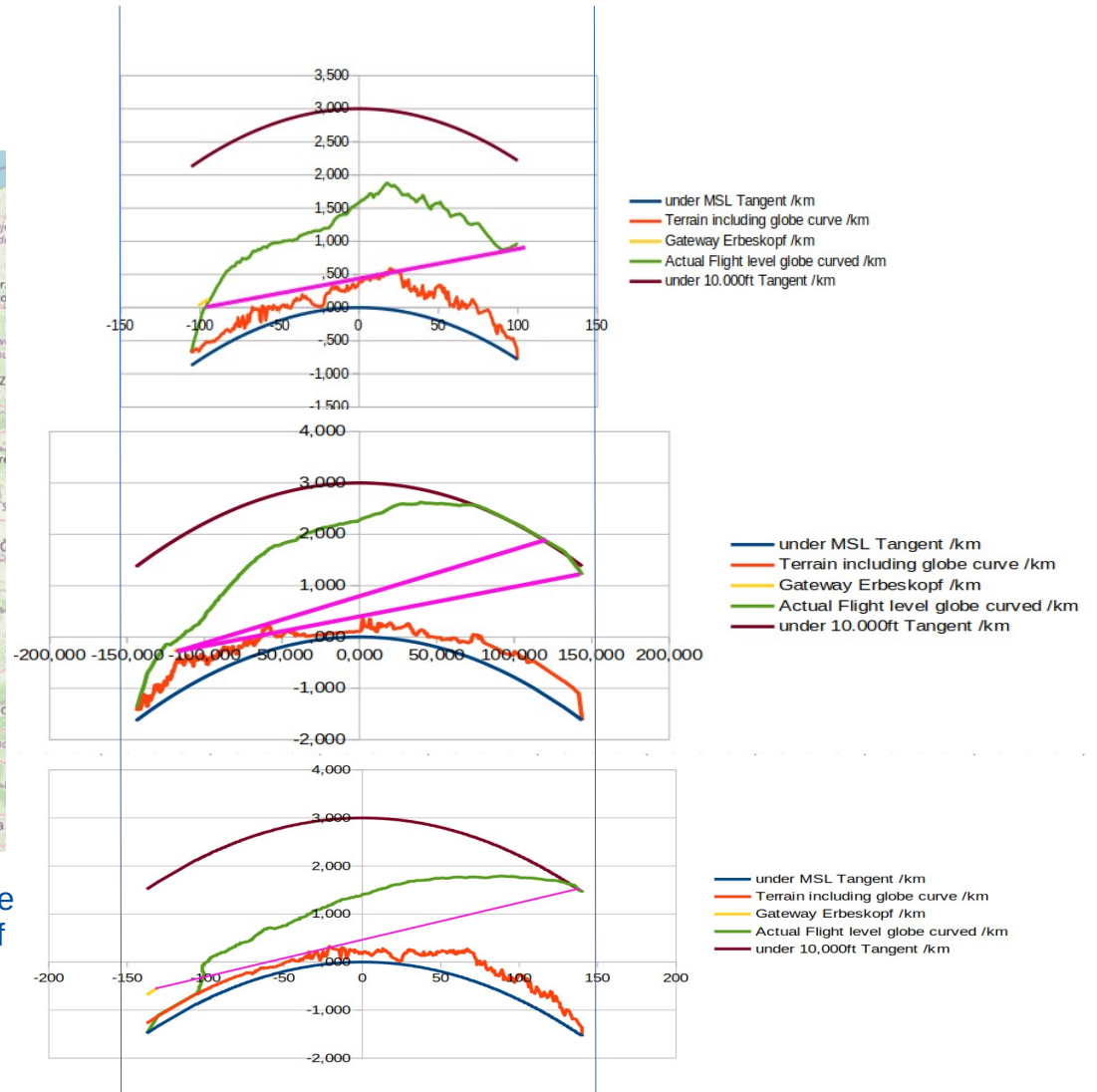
With that setup 3 Range Test Flights and 1 Coverage Test Flights were done.



Range Test Results



➔ The RF link budget of LoRa is not the Limit. The measured RSSI values indicate only the loss of free line of sight is the limit before 300km distance.



Free field range extrapolation 1)

Distance / km	Measured RSSI at Gateway	unused link Budget 139 db-RSSI	Extrapolated free field Range /km = Distance * 2 [^] (unused link budget / 6)
50	-120	19	430
100	-126	13	400
200	-132	7	420

1)
Our current Plane to Ground measurements, Ground to Plane currently only 200 to be optimized in a product



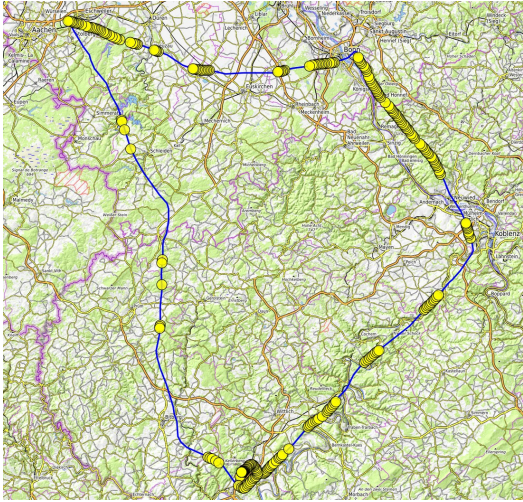
The ISS from it's 400km orbit can connect.

Why is the LoRa range @ 868MHz/14dBm 10 times of FLARM & ADS-L ?

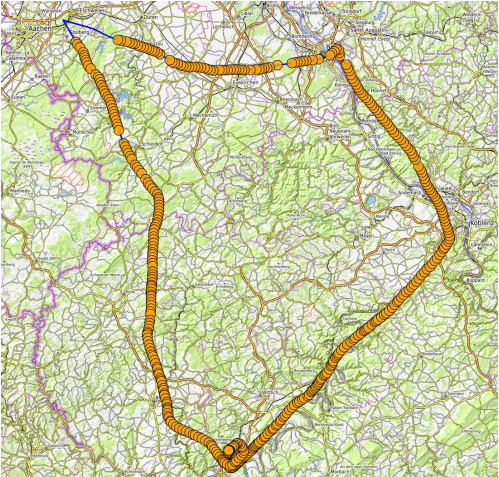
system	Data rate	Modulation	äquivalent
FLARM	300 kbit/s	FSK	30 pages text /s
ADS-L	100kbit/s	GFSK	10 pages text /s
LoRa	0,3-50kbit/s	Chirp Spread Spectrum	distance adaptive, down to 30 character /s



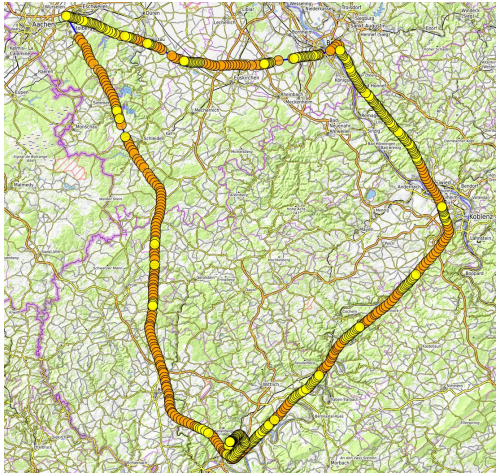
Coverage Test Results



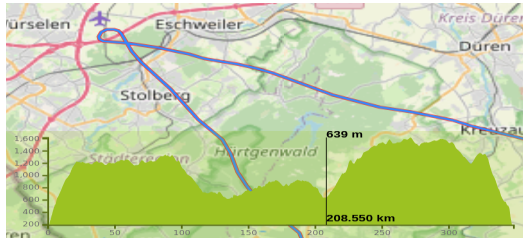
Telekom LTE / NB-IOT



LoRaWAN



Both 97%



carrier	mean delay	max delay	>10s
LTE IOT-NB	9s	58s	25%
LoRaWAN	3s	15s	3%



LTE IOT-NB is only available underneath 3000ft GND and in the areas of cities and highways. If there is only a weak connection, then the delay time of communication increases up to a minute. This explains why mobile phone Apps fail in many situations.

Network planning Germany @ 200km practical radius range circles



6 Basestations will cover Germany.



T-Mobile

<https://www.t-mobile.com>



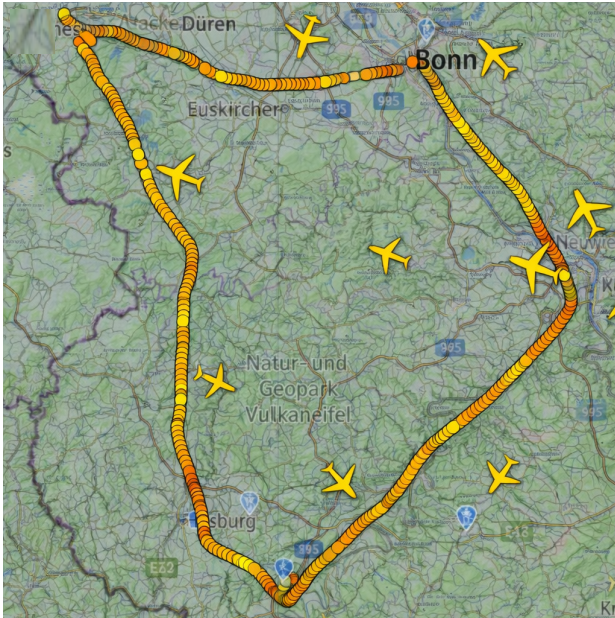
**THE THINGS
NETWORK**

Using 4 networks :

- LoRaWAN by charterware
- LoRaAir by charterware
- LTE IOT-NB
- LoRaWAN by TTN (public)

100% coverage is possible at very low installation cost

Duty cycle Simulation LoRaWAN 868 in Europe



(illustration)

1. Warnings G2A

868 MHz in Europe is limited to 10% Ground2Plane by legal regulation. We assume 1000 planes at 20 Gateways, 50 % of them to be served simultaneously via LoRa.

Is 10% i.e. 360 seconds G2A airtime enough for reliable warnings towards 25 planes ?

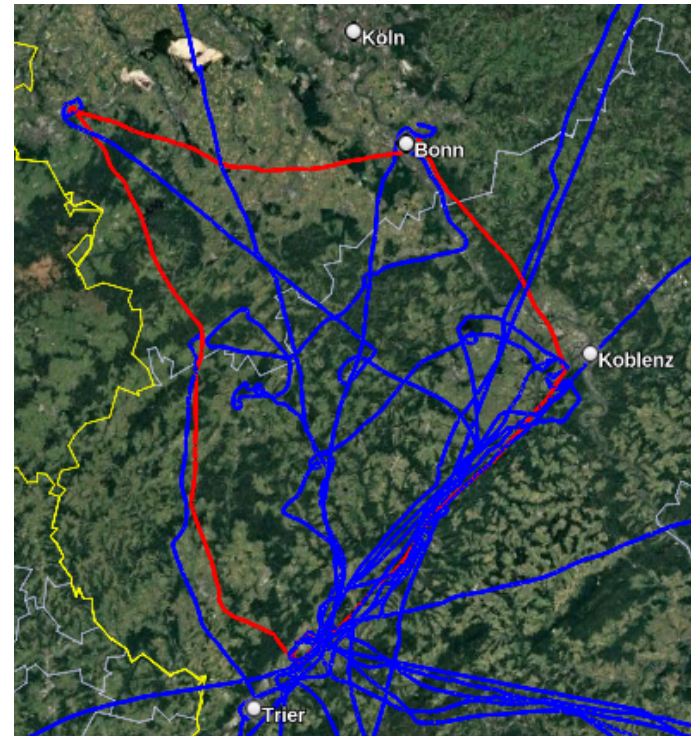
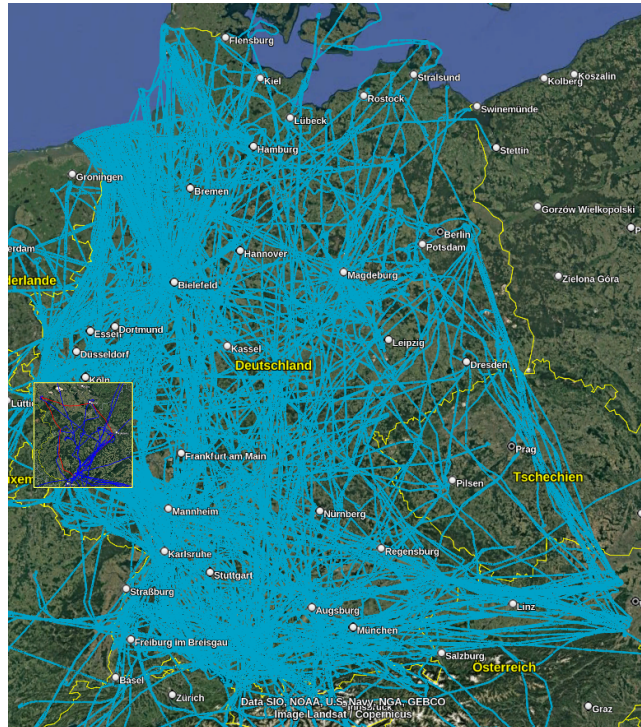
2. Position Out Indications A2G

868 MHz in Europe is limited to 2,7% Plane2Gnd airtime if polite spectrum access is implemented. That is 100 seconds /h.

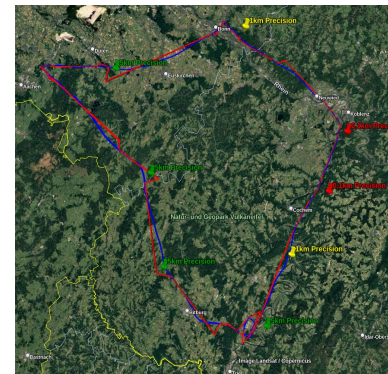
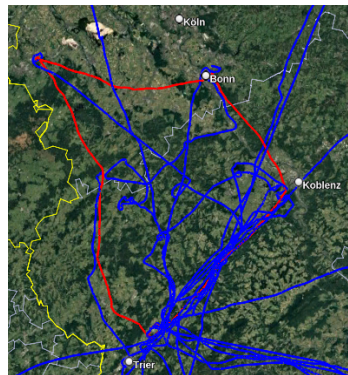
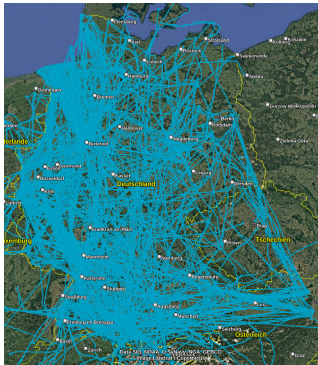
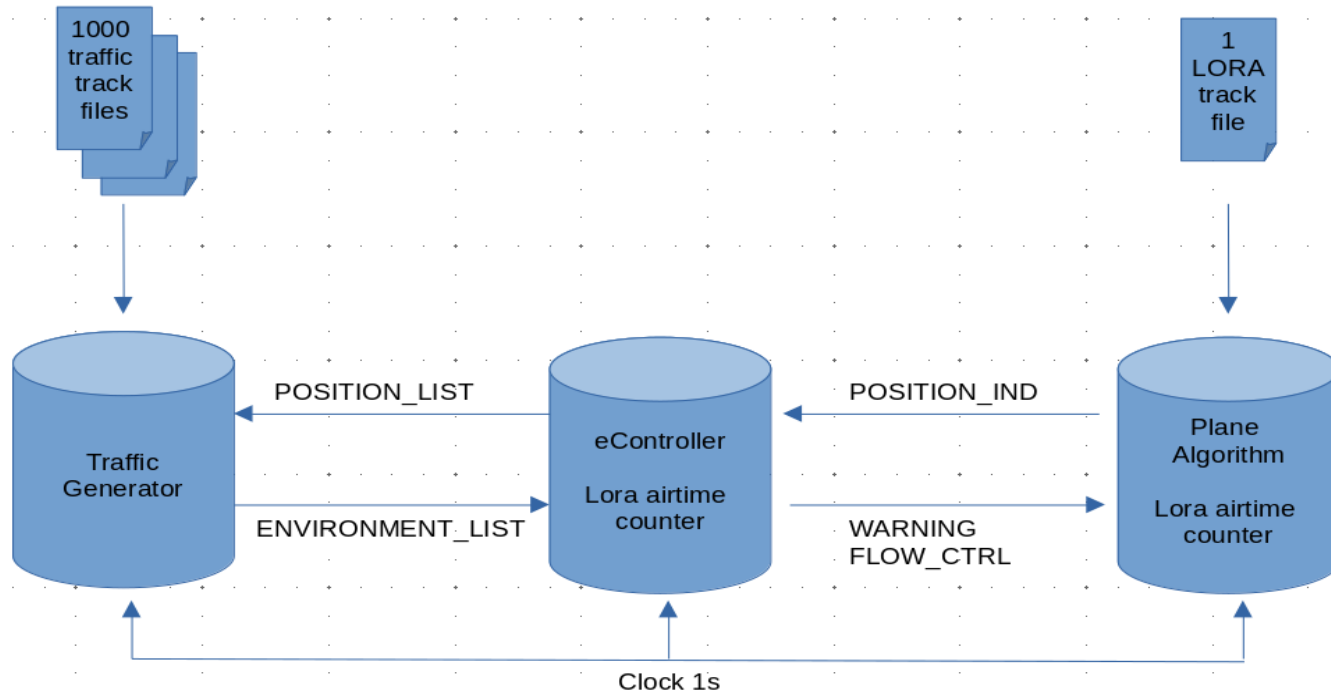
Planes not visible via Pri Radar, Secondary Radar, MLAT or OGN would be asked by the ground to indicate their positions via LoRaWAN.

How long can a plane send permanent indications when legally limited to 100 seconds / h ?

Duty cycle Simulation LoRaWAN 868 in Europe



Total generated traffic and planes in contact.



Duty cycle Simulation LoRaWAN 868

CASE	INPUTS			1 GATEWAY serving 25 planes			# per 2h40 flight times per h		
	PLMN Access	SF	TRA	# WARN PLMN	# WARN LOR	Time WARN LoR *25/h	#POS OUT PLM	#POS OUT LOR	POS time LoR /h
1. BASIC	logs	logs	0	0	0	0	9	22	12s=0,3%
2. SF12	logs	12	0	0	0	0	9	22	14s=0,4%
3. NONET	no	logs	0	0	0	0	0	31	16s=0,4%
4. TYPICAL	logs	logs	1300	13	21	175s=4,8%	15	110	65s=1,8%
5. WORST	no	12	1300	0	34	300s=8,3%	1	124	77s= 2,1%

Table 25: lora airtime depending on environmental conditions



The gateway even under worst case conditions was legally not overloaded to act as a ground to plane warning link

The plane was not overloaded as enduring position out system, certainly it can always fill the low altitude gap

Benchmarks

	ADS-L	ADS-G
Origination	202x	Study only
Prerequisite	Flarm Upgrade	Devices and network
Architecture	Single purpose Airlink	Milti purpose internet link
Ground Coverage	low altitude only	100%
Applications	Traffic Weather	Traffic Private weather radar Flight Logging ELT Black Box Recording Instant Messaging

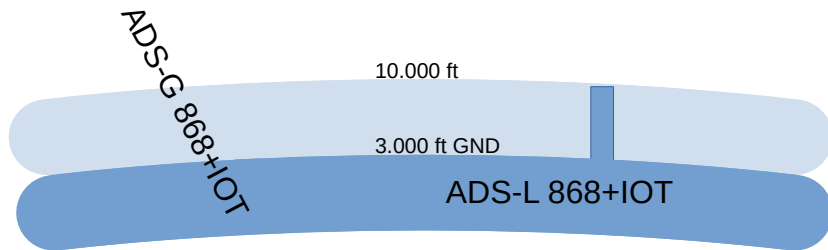
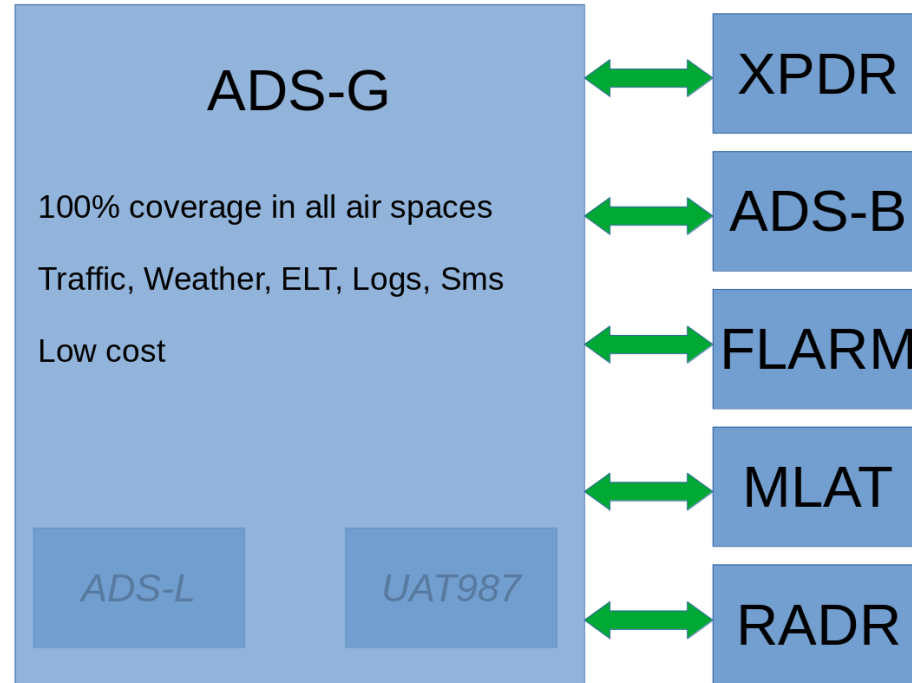


Figure 22: Ground Coverage of ADS-G and ADS-L

	UAT978	ADS-G
Origination	2010 USA	Study only
Prerequisite	Frequency	Devices and network
Architecture	Dual purpose broadcast	Milti purpose internet link
Avionics	ADS-B in and out	New device
Power consumption	>250 Watt power line needed	1,5 Watt solar powered
Link budget Gnd2plane (TXgnd – Rxplane) at 54dBm (250 Watt) free field range: practical range:	54-(-85):~140dbi 300 km 125 km	2 xmit levels 14-(-135): ~ 150 dBi 27-(-135): ~ 160 dBi 3000km 200 km
Ground station spacing	USA: ~125 km radius ~ 25 stations in Germany	200km radius: ~400km, start with 5 stations at saturation 20 station
Cost plane	ADS-B in & out needed	ADS-G box
Display	Traffic Monitor	Eth. / WLAN Display
Cost (source AOPA)	25*10.000€ = €250.000,- + Power supply + fixed Internet + Building	Start 5* 3000 (trailers) @Saturation: 20*3.000€ =€ 60.000,-
Airspace coverage	no low airspace	all airspaces
Applications	Traffic Broadcast weather	Traffic Private weather radar Flight Logging ELT Flight Recorder Instant Messaging

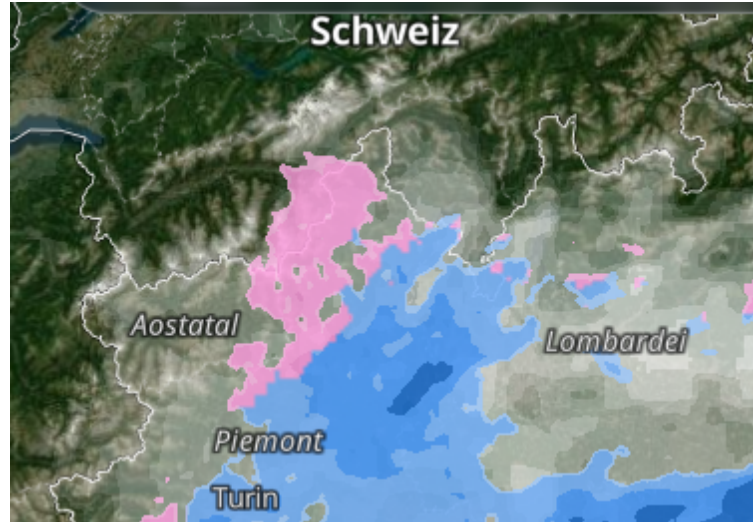
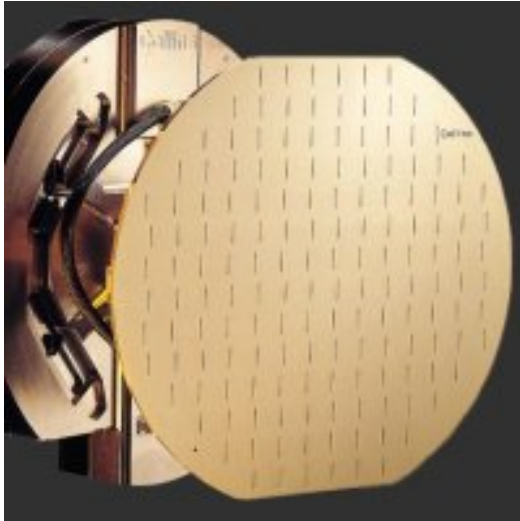
➔ ADS-G provides ful ground coverage and supports multiple applications at lowest cost

Sorting it in ..



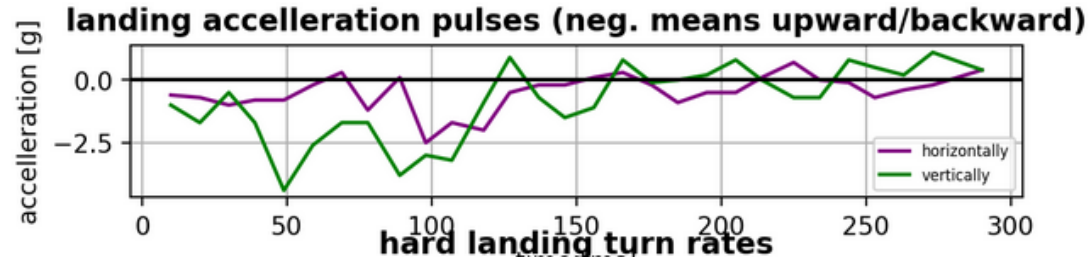
➔ ADS-G is in cooperation with established traffic systems but challenges ADS-L 868 and UAT978

Private Weather Radar



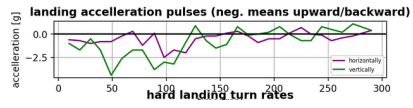
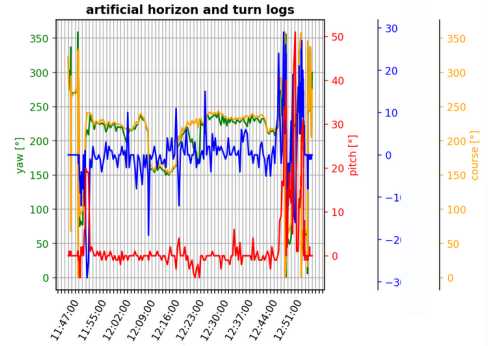
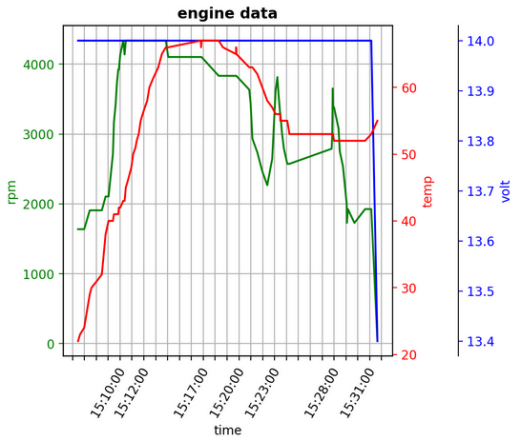
Private weather Radar - with no extra hardware.

Hard Landing detection and ELT



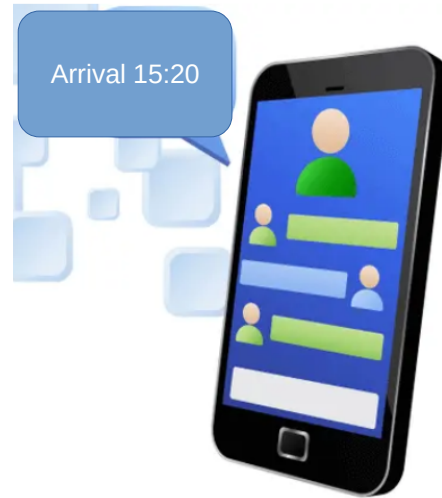
Hard Landing detection available, ELT function can be implemented by a connection to SAR – with no extra hardware.

voice, engine- and flight data recorder



Voice and data Recording can easily be implemented – with no extra hardware.

WhatsApp , SMS & Co



Instant messaging or activation / deactivation of flight plans can be implemented in all Flight levels - with no extra hardware.

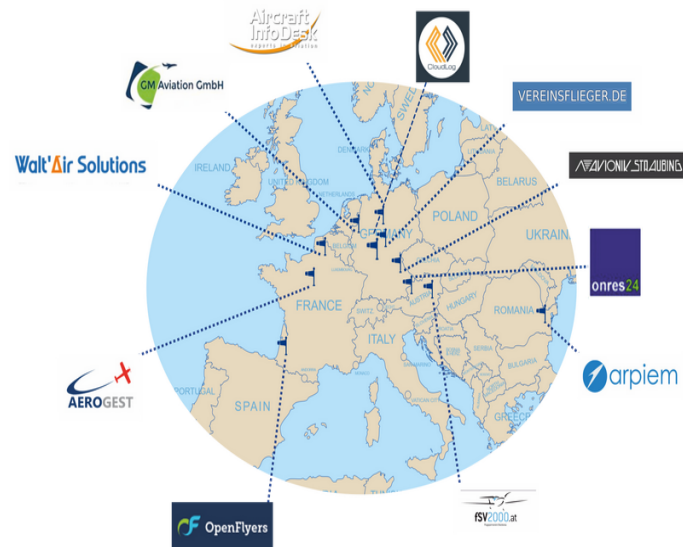
Flight Logs

PILOT's LOG BOOK FOR Charterware UG haftungsbeschränkt

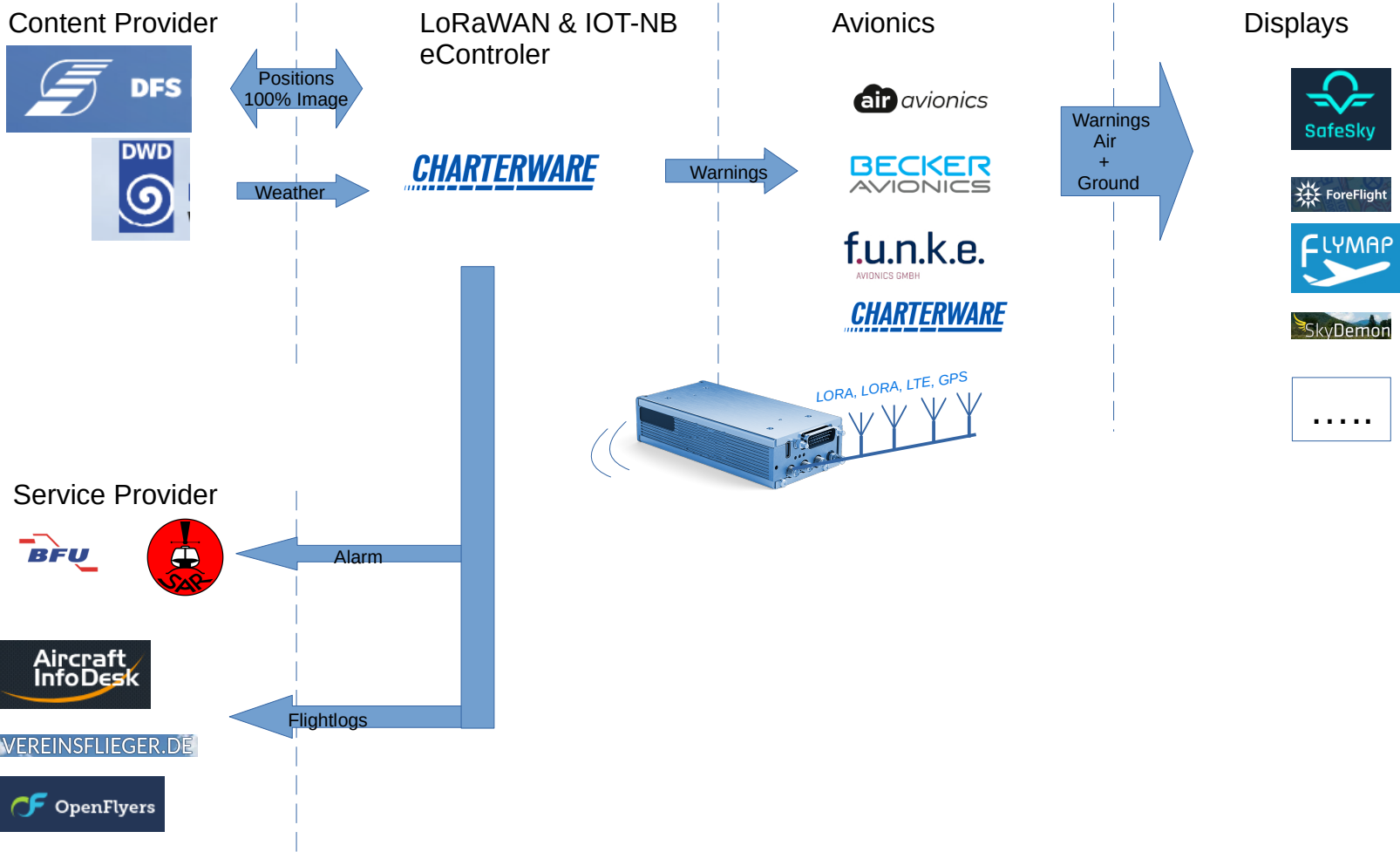
Serial No.	Date 2022	Registration Type	Single-Engine	Flight from	Pilot in charge	Attendant(s)	Off Block	Total Flight Time	Take-off	Total Time Airborne	No. of Landings	Flight Rules	Special Times	Purpose	Remark
			Multi-Engine	Flight to	Duty	Duty	On Block		Landing						
1	14.05.15	D-MABT		EDRT EDKA	Charterware UG haftungsbeschränkt		12:32:14 13:35:31	01:03:17	12:38:54 13:35:31	00:56:37	1				
2	14.05.15	D-MABT		EDKA EDRT	Charterware UG haftungsbeschränkt		15:08:02 16:19:48	01:11:46	15:13:47 16:17:15	01:03:28	1				



Flight Logs to many partners - with no extra hardware.



Applications and Data Flow of Internet on Air

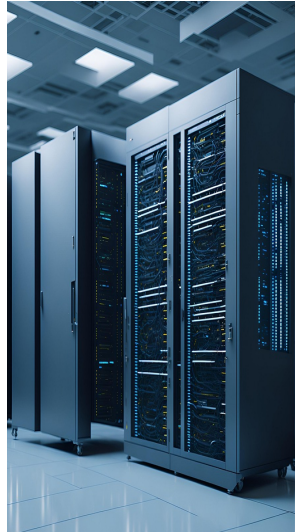


Possible Field Test Setup Germany 2027/28

Traffic Provider
Service Provider



eController
Network Server

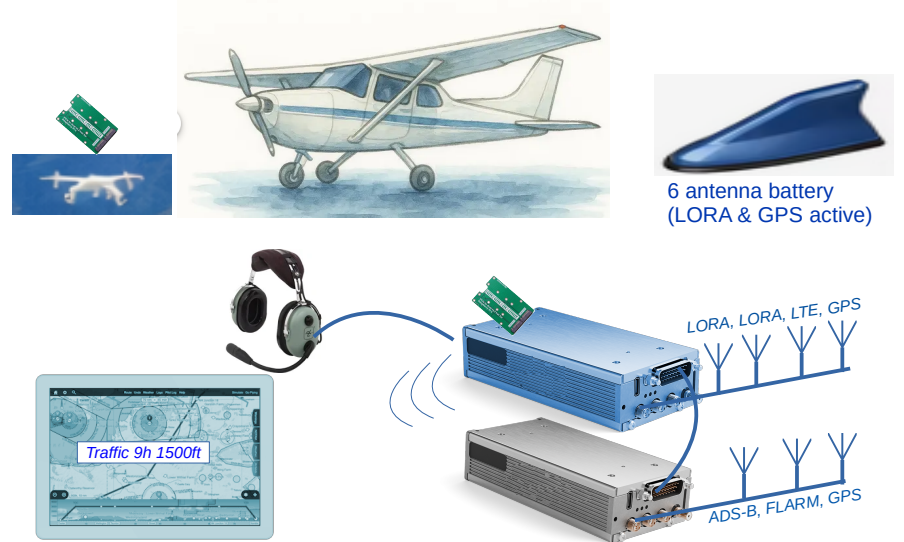


6 LoRaWAN
Gateways



CHARTERWARE

Inside Planes



70% detection with today's air2air devices

90% detection stand alone with new ground supported device

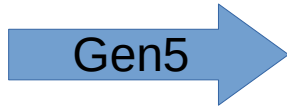
99% detection both technologies air2air + ground supported

Charterware Device Gen5 :

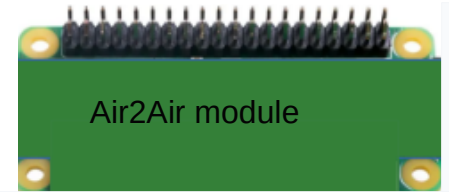
Our Gen5 hardware will not be a single purpose panel device but an Antenna device + a General Aviation Box. That will be based on a rugged Industrial single board system

- Basic board 110*70mm, -40 / 85°, Linux , WLAN
- modular enhanced

Gen4:
Panel Device



Gen5:
Antenna Device
and
Module Stack



6 outdoor Antenna device active GPS + 2 LoRa + Telekom antenna (ADSB / FLARM / for other devices)

