First Results of the L-band Digital Aeronautical Communications System (LDACS) Flight Trials in the National German Project MICONAV

ICNS Conference

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How did the LDACS protocol get from an idea to a flying demonstrator?

Previous projects: B-VHF (2004), B-AMC (2007)
Requirements: COCR
Other systems: AeroMACS, P34, 3G, and 4G (2008)

LDACS Design

Rapid prototyping using computer simulations (2011)

Testing in the lab (2018)

LDACS Implementation

Flight Test

LDACS specification update in ICAO and SESAR (since 2016)

Scope of the MICONAV project

The MICONAV flight trials addressed three research questions

Characterization of service, measured in lab and flight trials:

- Achievable data rate
- Communication range

Quality of service, measured in lab and flight trials:

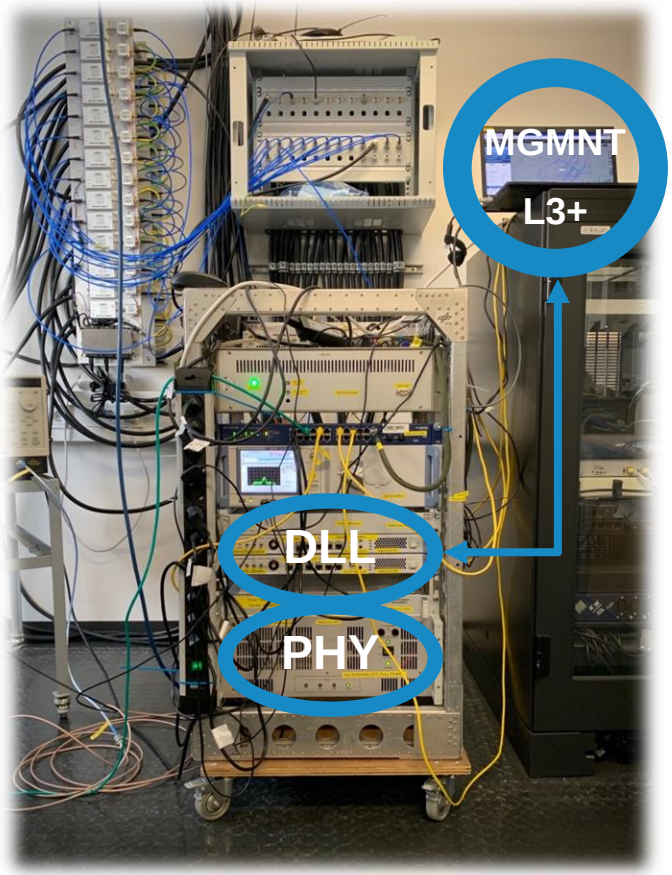
- Priority of access
- Priority of latency

Focus of this talk: Data link layer

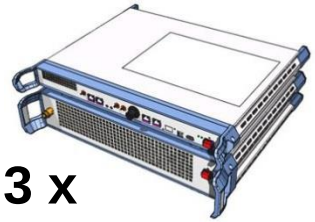
Security of service, demonstrated in flight trials:

- Security for broadcast services: GBAS
- Security for addressed services: ADS-C, CPDLC

The LDACS implementation was split into several hardware components



LDACS ground station “OP” at DLR premises



3 x

BPS

Linux laptop running:

Applications
UDP/IP

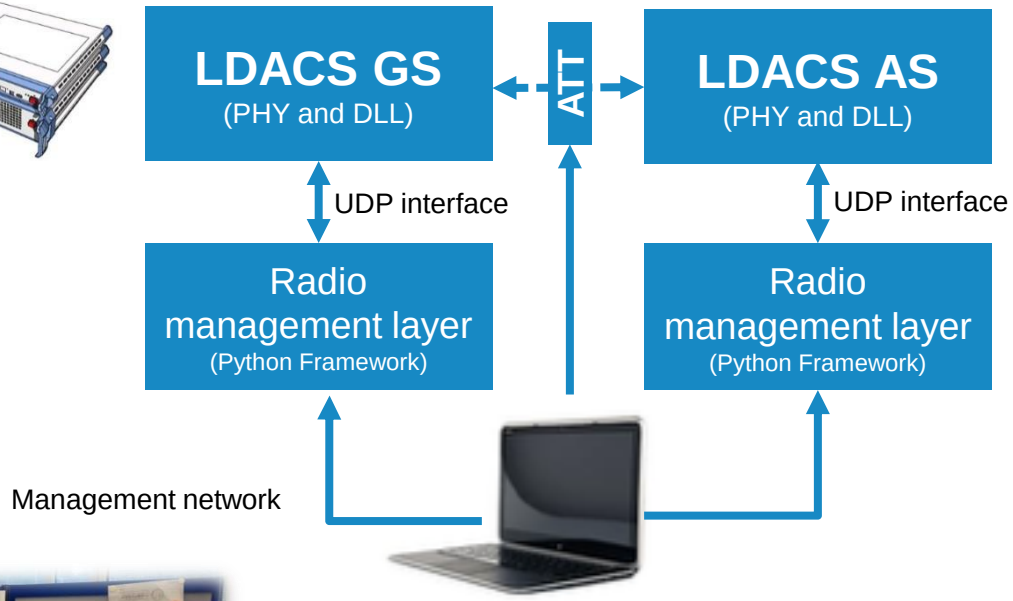
Radio management layer
(Python Framework)

UDP interface

LDACS GS
(PHY and DLL)

LDACS layer 1 and 2 running on Rohde & Schwarz (WFDU-D) and BPS hardware (WFDU-T, Diplexer) with iAd protocol implementation

In the lab tests the LDACS hardware was embedded into a local IP network



Linux laptop running:
- Radio management software
- Data traffic generators
- Applications
- Logging

In the flight trials LDACS was embedded into an aeronautical IP network

LDACS GS
(PHY and DLL)

UDP interface

Radio management layer
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Linux laptop running:
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LDACS AS
(PHY and DLL)

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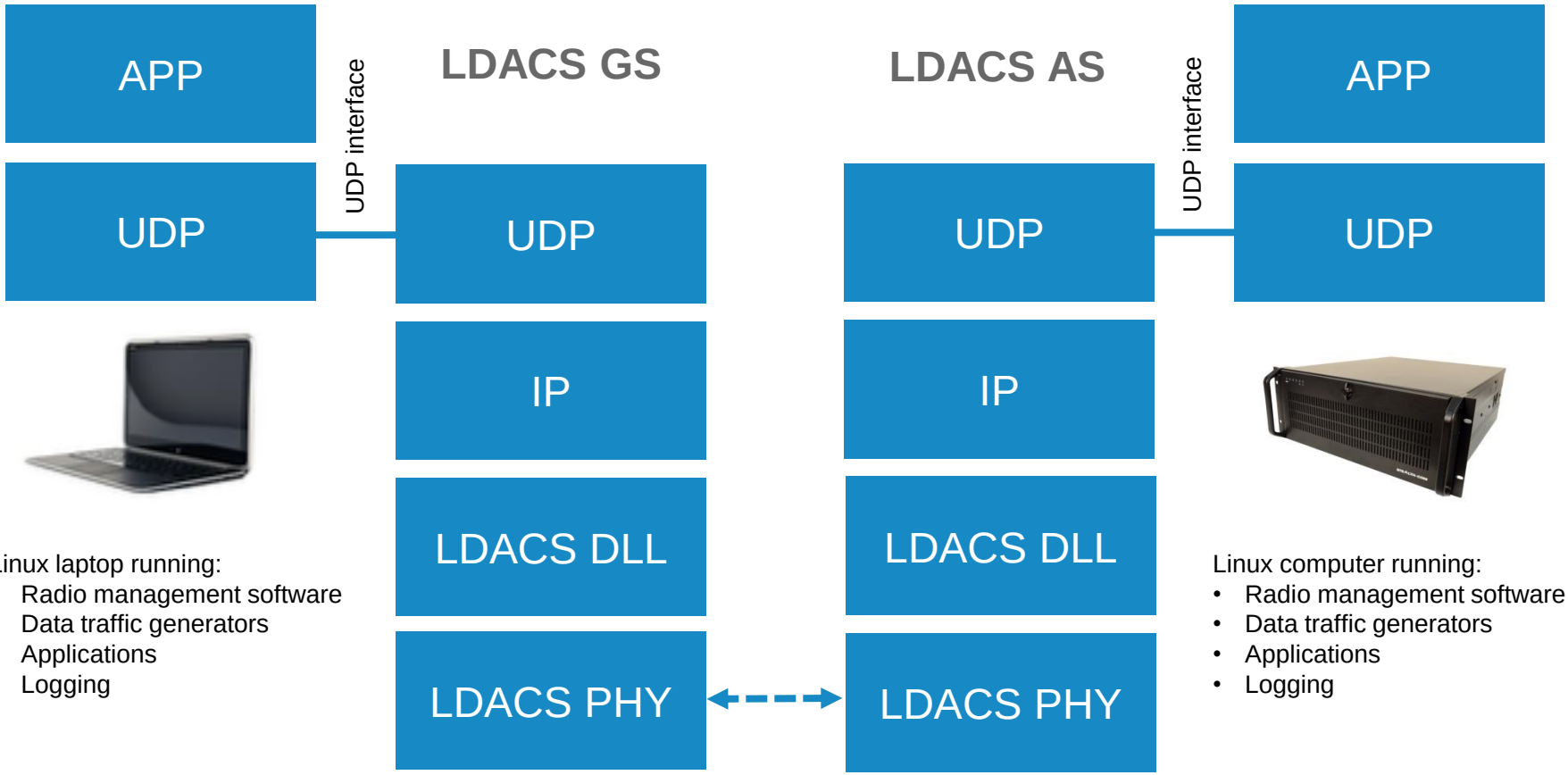
In the flight trials LDACS was embedded into an aeronautical IP network



Linux laptop running:
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Linux computer running:
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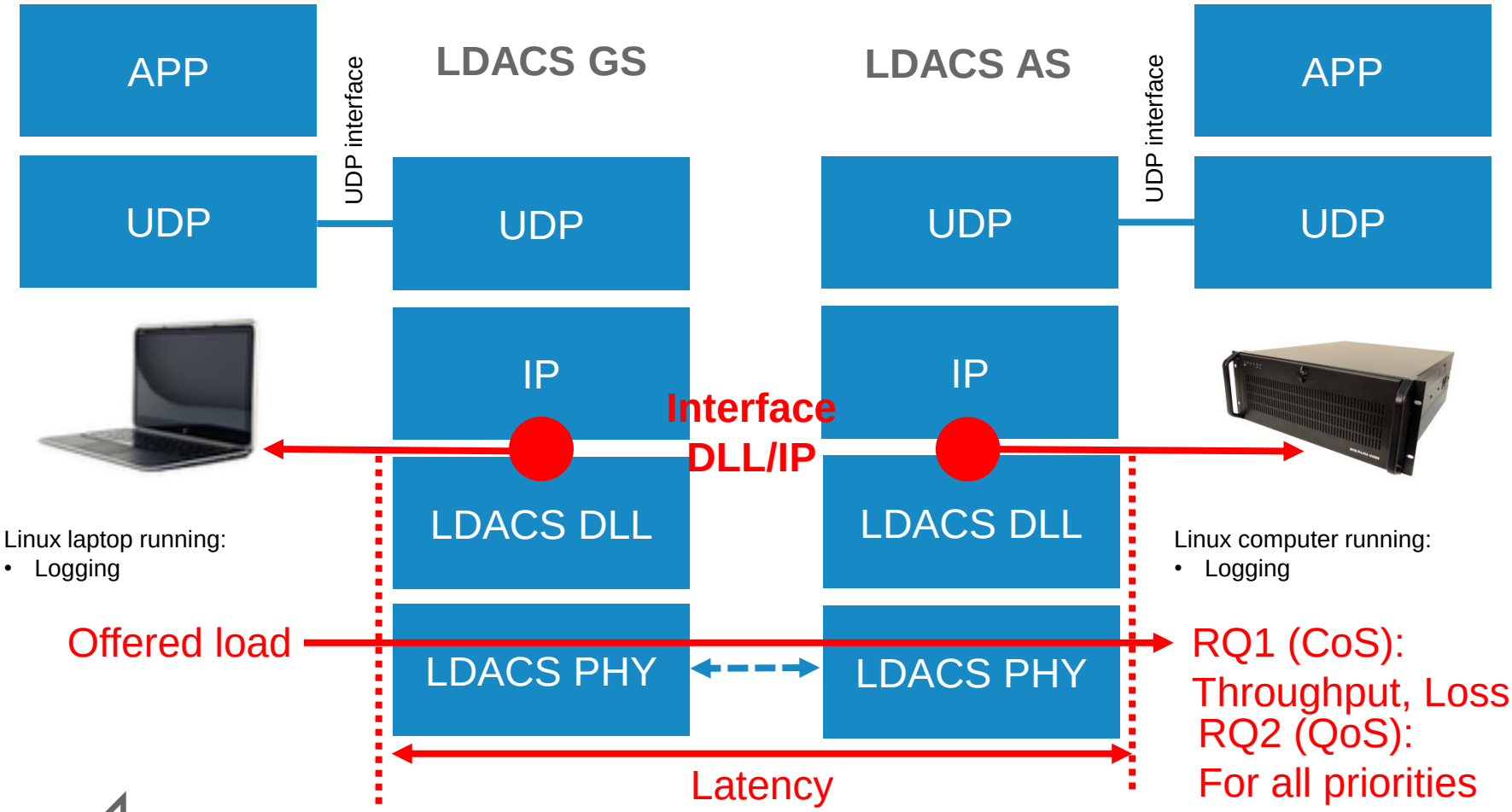
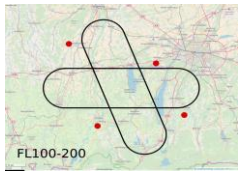
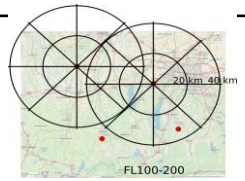
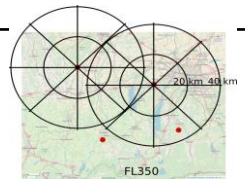
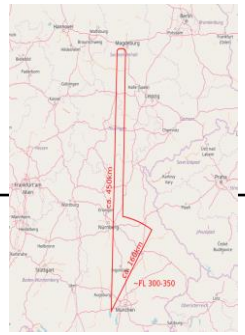
LDACS was measured at the interface between DLL and IP



LDACS QoS and CoS was measured in these measurement scenarios within MICONAV

Lab Measurement Scenarios	Flight Measurement Scenarios
M1: “Simple QoS” 100 kbit/s, packets of same size (1400B) with high/low priorities	**M1: “Simple QoS”** 100 kbit/s, packets of same size (1400B) with high/low priorities
M2: “Realistic QoS” 100 kbit/s, packets of different size (175/1400B) with high/low priorities	**M2: “Realistic QoS”** 100 kbit/s, packets of different size (175/1400B) with high/low priorities
M3: “Preparation of range measurement” 100 kbit/s, packets of different size (175/1400B) with high/low priorities with increasing attenuation	**M3: “CoS: Range measurement”** 100 kbit/s, packets of different size (175/1400B) with high/low priorities with increasing distance to ground-station
M5: “CoS: Maximum Throughput” increasing load, packets of same size (1400B)	

The measurement scenarios were applied in the demonstration & measurement flights

Flight	Measurement Scenario
Flight 0 	Security of service (GBAS, CPDLC, ADS-C)
Flight 1 	Realistic quality of service (M2)
Flight 2  	Simple quality of service (M1)
Flight 3	Characterization of service: Range (M3)

The flight configuration of the LDACS protocol was as follows

- Reduced transmit power:
  - 40 dBm i.e. reduced by 8 dB due to local safety regulations
- LDACS configured with QPSK coding rate 1/2
- Restricted duty cycle:
  - Maximum RL allocation 110/160 tiles i.e. RL data rate restricted to < 70% duty cycle
- 4 ground-stations:
  - Only 2 with full COM capability

First overview of results

Research question: CoS: Achievable data rate?

M5/lab: The achievable data rate of LDACS is approximately 293/236 kbit/s on the FL/RL

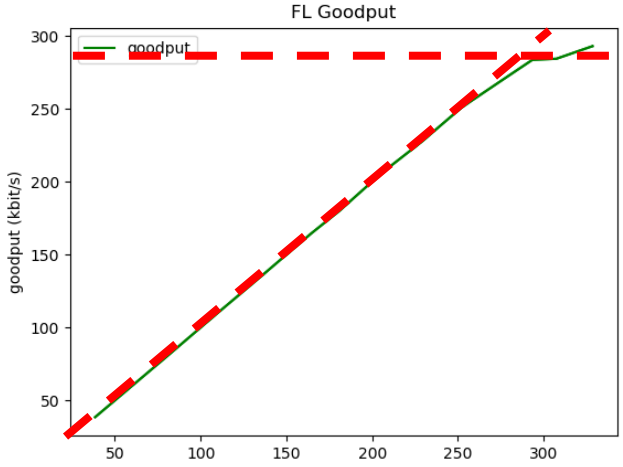
M5: “CoS: Maximum Throughput”

- LDACS configured with QPSK coding rate 1/2
- Lab environment with “no” attenuation

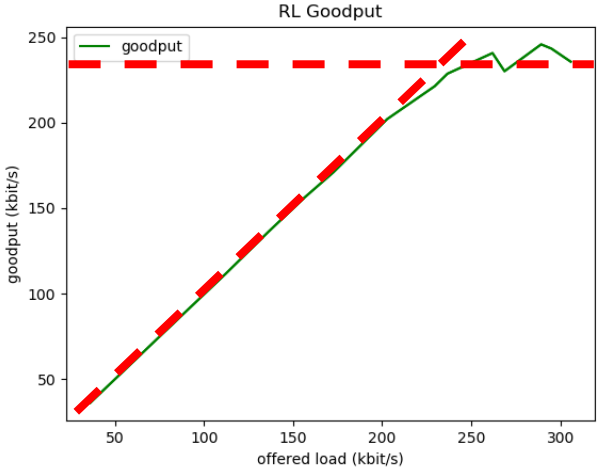
- packets of same size (1400B)
- with exponentially distributed inter-arrival times

- increasing load up to 300 kbit/s,

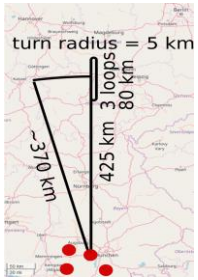
- expected data rate: **291/238 kbit/s**
- measured data rate: **293/236 kbit/s**



293 kbit/s
Expected:
291 kbit/s
CC size 3



236 kbit/s
Expected:
238 kbit/s
max 128 tiles



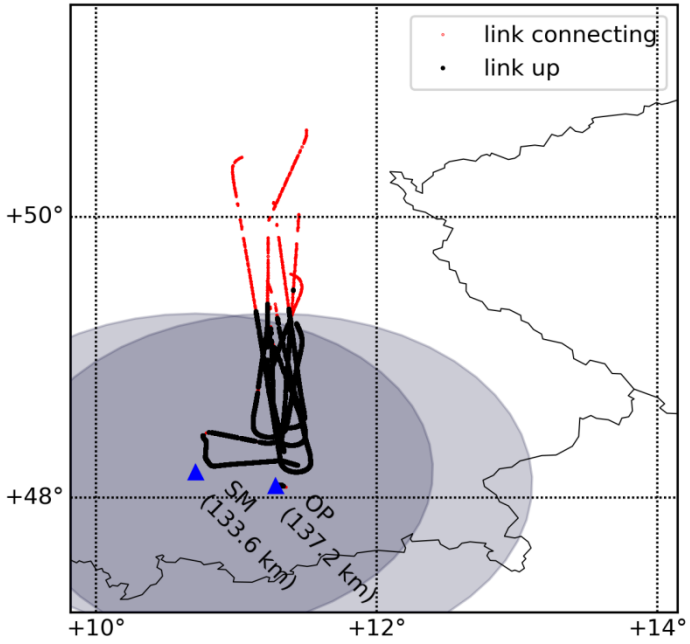
Research question: CoS: Communication range?

M3: The LDACS communication range is approximately 135 km at 40 dBm TX power

M3: “CoS: Range measurement”

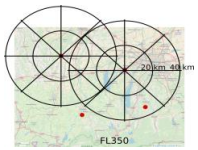
- 100 kbit/s,
- packets of different size (175/1400B)
- with high/low priorities
- with increasing distance to ground-stations OP and SM at 40 dBm TX power
- link up/down measured according to link state reported by radio and cross-checked with RX
- radio management layer configured to re-connect on connection drop
- approximately 12,000 s measurement time in flight
- expected range at 40 dBM TX power is **99,27** km

LDACS communication range, power reduced by 8 dB, FL350, 99% percentile of slant range



- measured range at 40 dBM TX power is **133.6/137.2** km for SM/OP ground-station

Research question: QoS: Priority of access/latency?

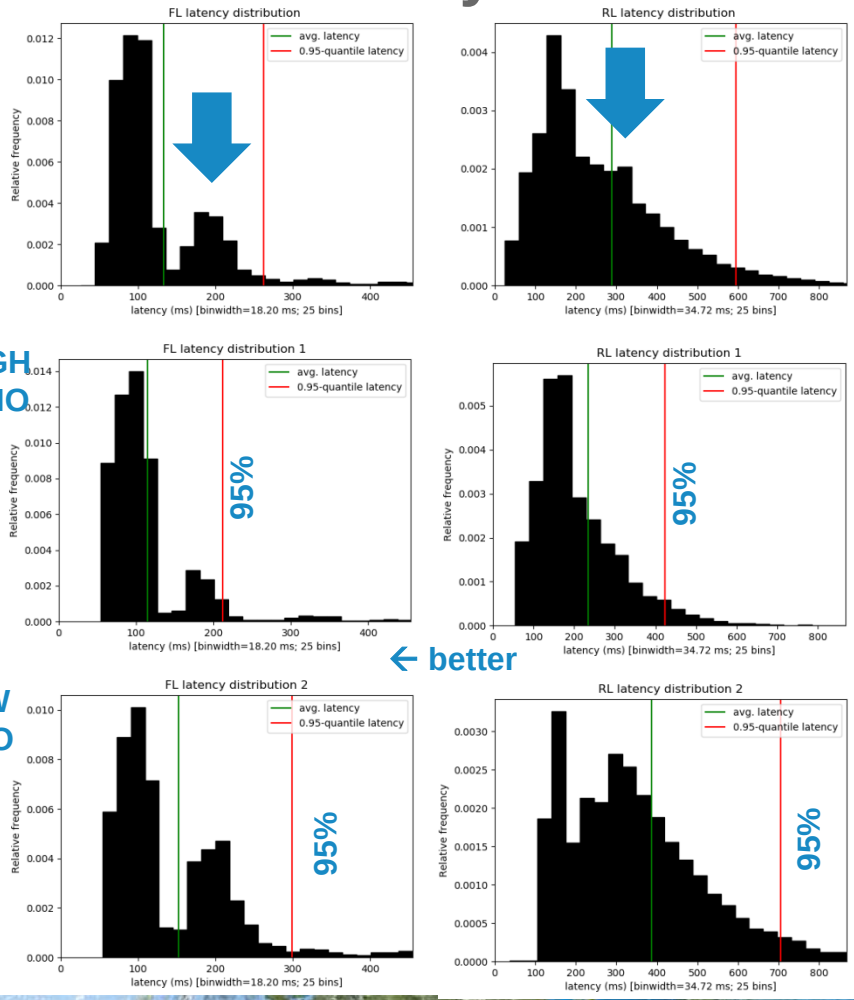


M1/OP: High priority traffic is scheduled first and is therefore transmitted with lower latency

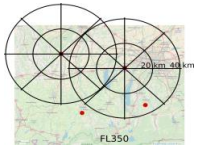
M1: “Simple QoS”

- 100 kbit/s,
- packets of same size (1400B)
- with exponentially distributed inter-arrival times
- with high/low priorities

- LDACS scheduling **prioritizes** high prio traffic over low prio traffic during bursts
  - approximately 5000 s measurement time in flight
- LDACS automatically retransmits corrupted packets
  - Almost no packet loss after retransmission, FL:0.31% and RL:0.82% when link up
  - Retransmission is included in latency measurement



Research question: QoS: Priority of access/latency?



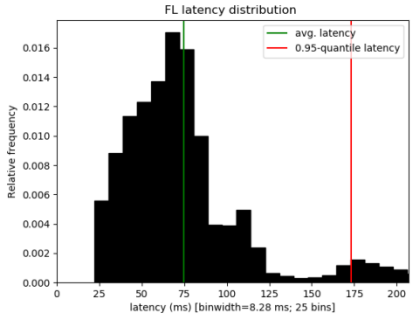
M2/OP: Realistic traffic pattern demonstrates LDACS QoS supports mixed ATS/AOC traffic

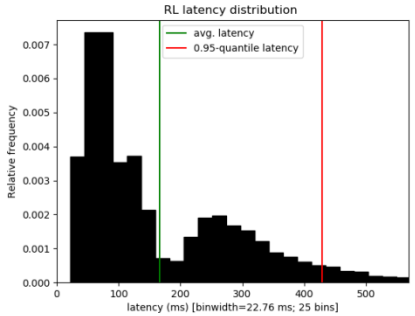
M2: "Realistic QoS"

- 100 kbit/s,
- packets of different size (175/1400B)
- with high/low priorities
- demonstrating ATS/AOC data traffic

- LDACS quality of service **prioritizes** ATC traffic over AOC traffic
  - approximately 3000 s measurement time in flight

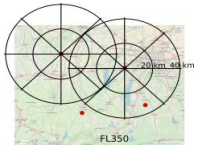
- Always far better than required 95% percentile of $RCTP_{CSP}$ = 10 s for RCP130/A1 from DO-350A.





Priority	Avg. Latency (ms)		95% percentile Latency (ms)	
	FL	RL	FL	RL
All	74	166	173	429
ATC	57	96	**81**	**229**
AOC	114	330	**200**	**537**

Research question: QoS: Priority of access/latency?



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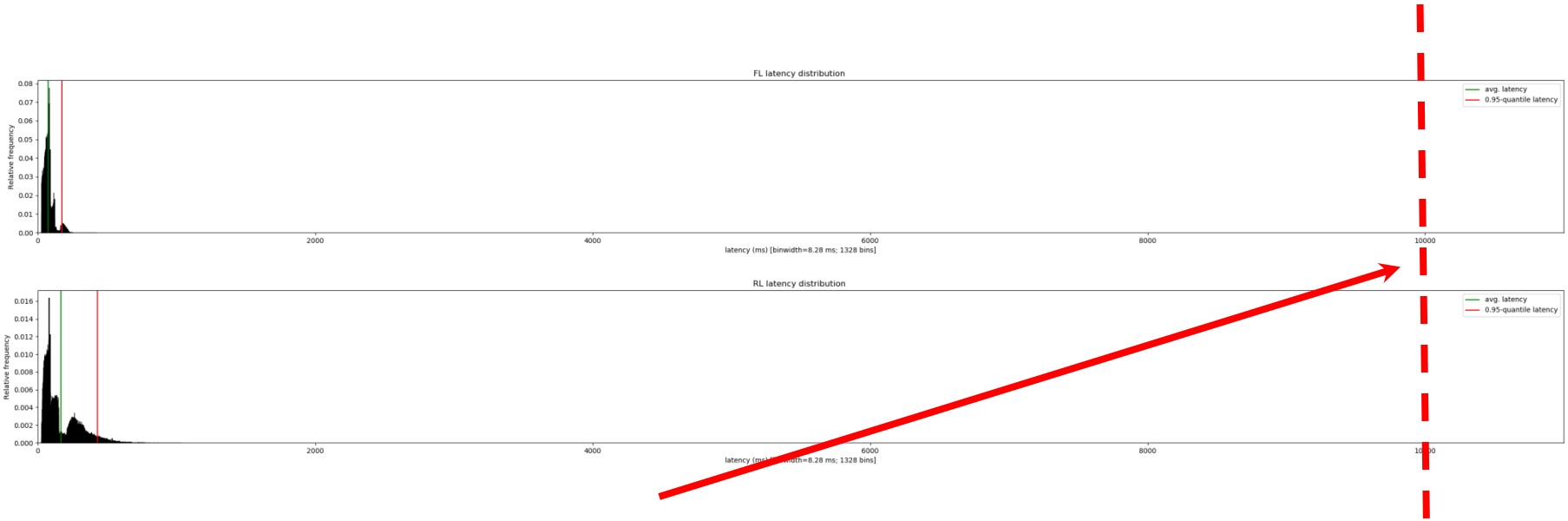

- Always far better than required 95% percentile of $RCTP_{CSP}$ = 10 s for RCP130/A1 from DO-350A.

Instead of a conclusion…

- This talk provided an overview of the evaluation of the LDACS data link layer in the MICONAV flight trials
  - The LDACS protocol behaves **as predicted or better** and truly provides next generation data link capabilities

… next steps:

- Our results will provide the basis for the further development of LDACS:
  - SESAR: Update of specification, and Wave 2/3
  - ICAO: Update of SARPS, development of “manual”

Thank you for your attention!

- T. Gräupl, N. Schneckenburger, T. Jost, M. Schnell, A. Filip, M. A. Bellido-Manganell, D. M. Mielke, N. Mäurer, R. Kumar, O. Osechas, G. Battista, T. Bögl, and T. Richter, "L-band Digital Aeronautical Communications System (LDACS) Flight Trials in the National German Project MICONAV," in Proc. Integrated Communications Navigation and Surveillance Conf., Herndon, VA, 2018.
- T. Gräupl, and M. Ehammer, “L-DACS1 Data Link Layer Evolution of ATN/IPS,” in *Proc. 30th Digital Avionics Systems Conf.*, Seattle, WA, 2011.