Auf dem Weg zum neuen weltweiten Flugfunkstandard L-DACS

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German Aerospace Center (DLR)
Institute of Communications and Navigation

Center of Excellence for SoL Communications

SoL
SAFETY OF LIFE COMMUNICATIONS

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

L-DACS: L-Band Digital Aeronautical Communication System

The DLR L-DACS Team:

- Group leader: Michael Schnell
- PHY/MAC design: Sinja Brandes, Ulrich Epple, Snjezana Gligorevic, Michael Walter
- Higher layer issues: Serkan Ayaz, Felix Hoffmann
- Prototyping: Alexander Arkhipov, Niko Franzen, Nikolas Schneckenburger

L-DACS Partners:

- Frequentis, University of Salzburg
- Deutsche Flugsicherung
- iAd, Rohde und Schwarz
- Selex Communications

Content of the Presentation

Some Remarks on DLR – Institute of Communications and Navigation

Motivating the new standard L-DACS

L-DACS PHY/MAC Layer

L-DACS Navigation - an option for APNT

Further Modernisation of Air Traffic Management (ATM) communications

- AeroMacs (aeronautical WiMax) for airports environments
- Networking the Sky

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Oberpfaffenhofen, 20 km west of Munich

Institutes:

- **Communications and Navigation**
- Radio Frequency Technology
- Optoelectronics
- Atmospheric Physics
- Robotics and System Dynamics

Scientific-Technical Facilities:

- Research Flight Operations
- German Space Operations Center (GSOC)
- German Remote Sensing Data Center (DFD)
- Galileo Control Center (GCC)

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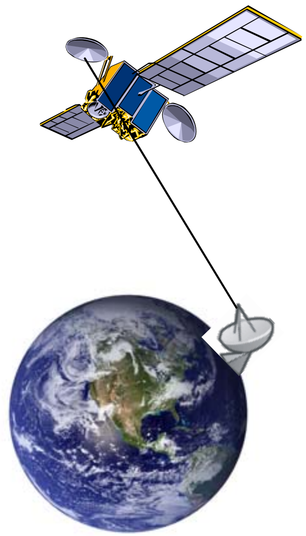
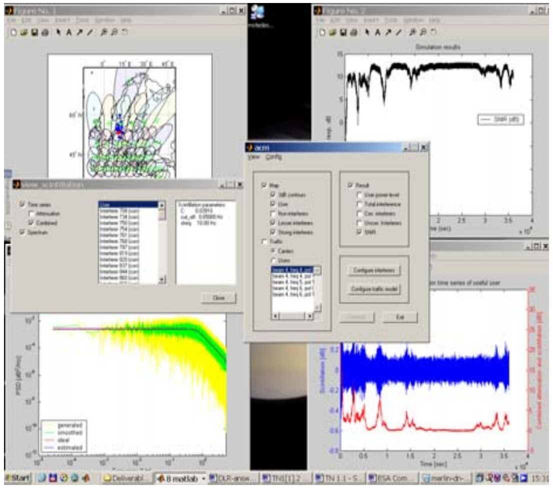
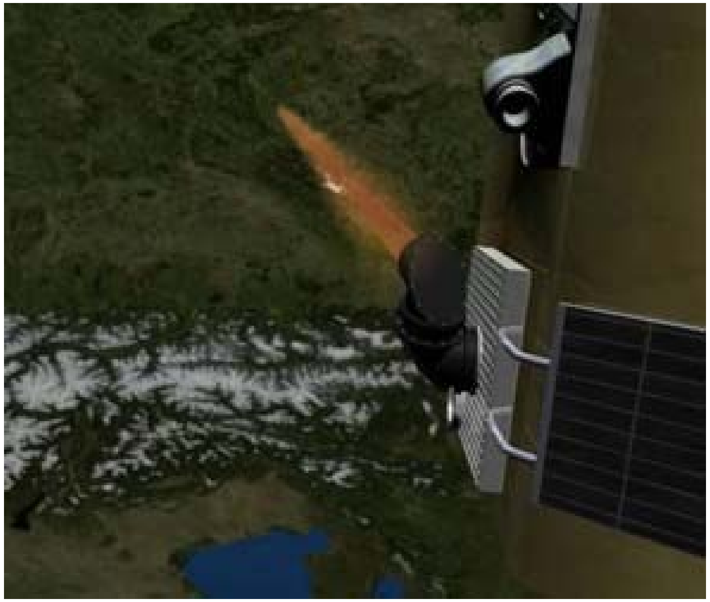
Satellite and Free Space Optical Communications





Free Space Optics:

- Transmission from LEO to Ground (KIODO experiment)
- Optical ground station at OP
- Airborne demonstrations



Satellite Communications:

- Higher frequencies: Ka-band and above
- Involvement in standardization of DVB-S2/RCS
- Adaptive techniques (spot beams, routing etc.)
- Comprehensive simulation tools

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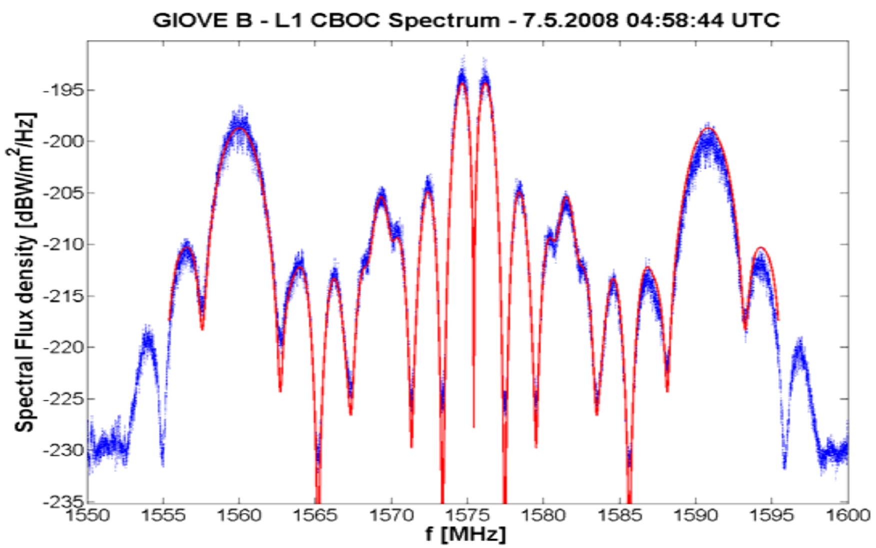
Satellite Navigation



Validation of Galileo signals via Weilheim ground station

Galileo Evolution

Monitoring of the ionosphere

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Ubiquitous Navigation

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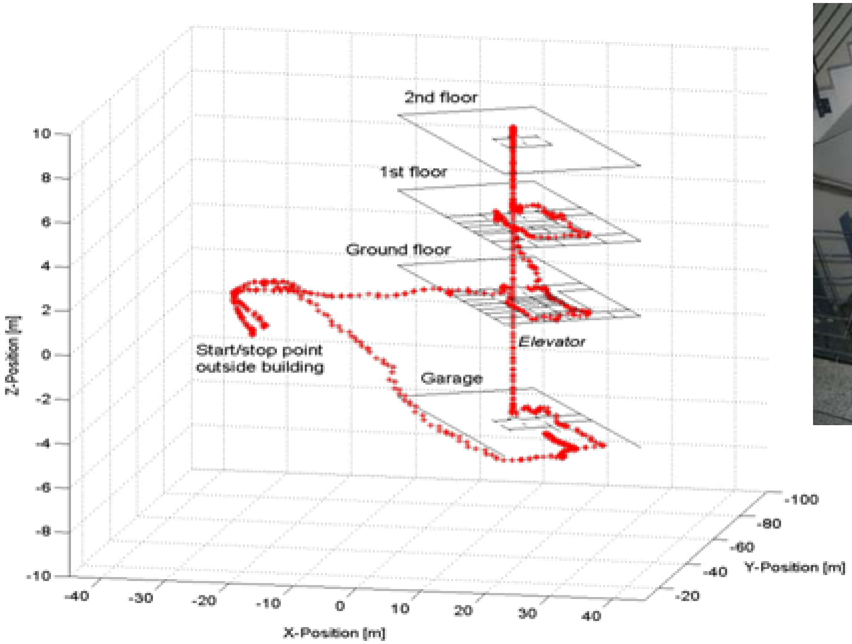
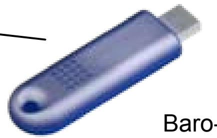
Ubiquitous Navigation

GPS + INS + Altimeter + LTE + WLAN + Maps + …



GPS receiver: ublox EVK-5 (mounted on body)

Electronic compass: OceanServer OS5000-US (mounted on hip)



Baro-Altimeter: Intersema MS5540-C (mounted on laptop)

IMU: XSens MTx-28A53G25 foot-mounted: right and left

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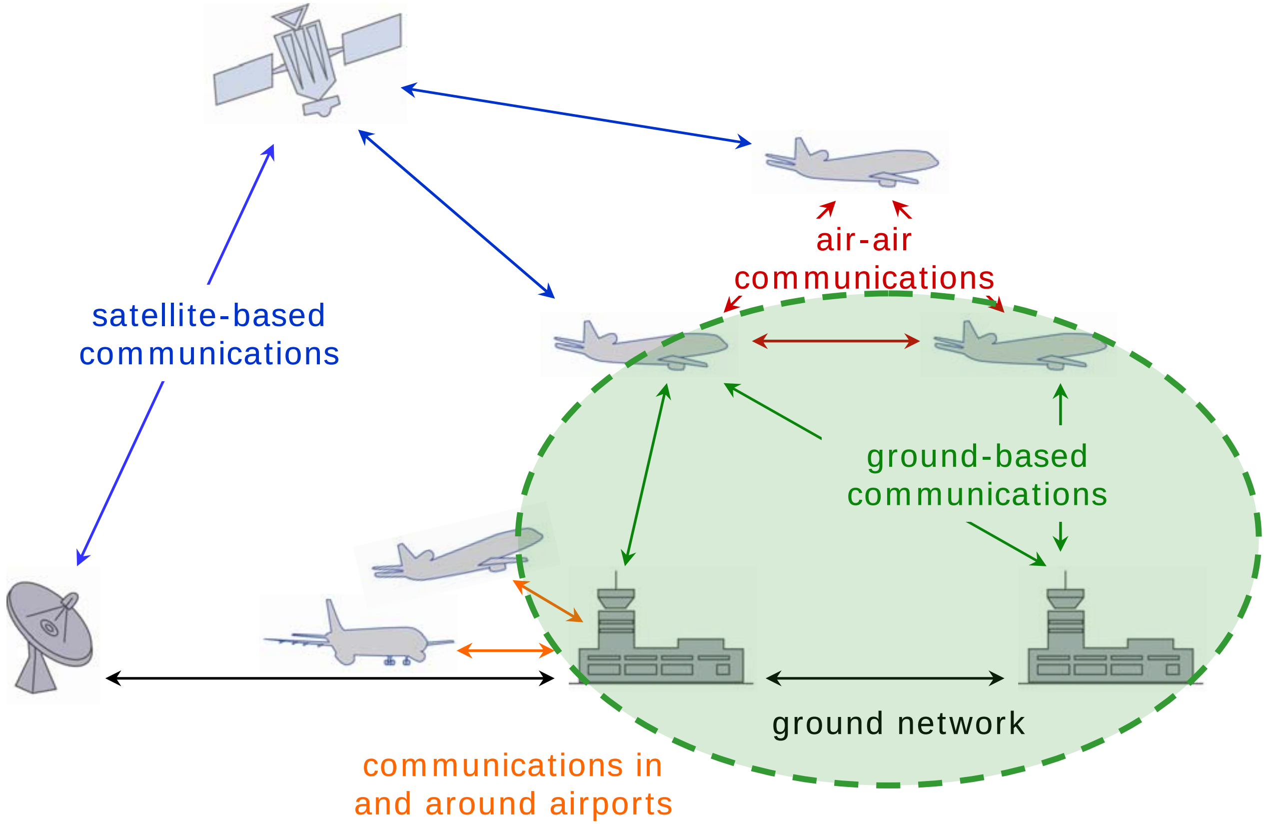
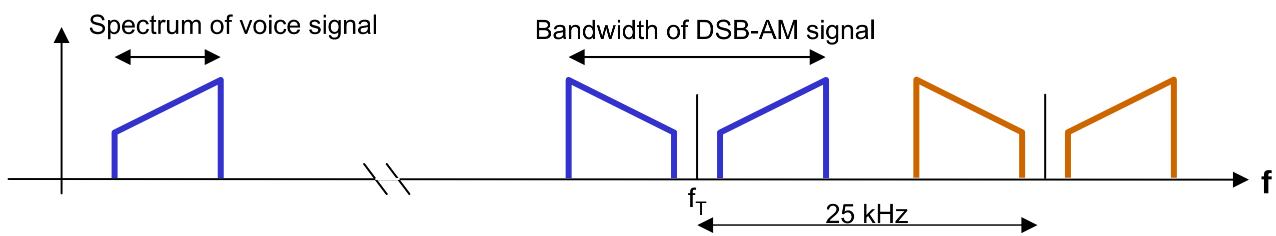
Aeronautical Communications for Air Traffic Management (ATM)



Aeronautical VHF Communication

- Worldwide assigned frequency band: 117.975 – 137.000 MHz (VHF band)
- Channel spacing: 25 kHz
  - Till 1970: 50 kHz spacing
  - 25 kHz spacing allows for about 760 channels
- Modulation: DSB-AM



- TDD mode; simultaneous transmission and reception not possible
- Cellular system with 11,000 VHF assignments worldwide today
  - Same frequency can be reassigned provided there are no interference problems
  - German speaking area: 67 “25 kHz channels” in use mainly in 122.000 – 123.675 MHz for 200 airports and 300 gliding airfields

Aeronautical VHF Communication

VHF Assignments Munich Airport

CTR/INT		ICAO-Code	IATA-Code
München		**EDDM**	**MUC**
	Sprechfunkfrequenzen		
ATIS	**Tower**	**Apron**	**Ground**
123,125 MHz	118,700 MHz (1) 120,500 MHz 121,975 MHz (2)	121,775 MHz (3) 121,925 MHz (4)	121,725 MHz Initial 121,975 MHz (1) 121,825 MHz (2)
Volmet	**De-Icing**	**Airport-Operations**	**FIS**
	121,650 MHz 121,875 MHz 130,600 MHz	130,650 MHz MAS 131,775 MHz EW 131,800 MHz DBA 131,925 MHz LH	120,650 MHz 126,950 MHz
Approach	**Arrival**	**Departure**	**CVFR-Radar**
118,825 MHz Director	120,775 MHz (2) 128,025 MHz (1)	123,900 MHz (1) 127,950 MHz (2) 128,250 MHz	131,225 MHz

Aeronautical VHF Communication

Capacity Limitations: In crowded flight areas, there are by far not enough 25 kHz channels available to serve all aircraft !!

Solution

- Re-sectorisation (limited)
- Smaller sectors (limited due to interference)
- Optimising frequency re-use (limited)
- More spectrum: 118-136 MHz band increased to 118-137 MHz in 1979
- Signals with smaller bandwidth

The VHF ATM 8.33 kHz Expansion Programme

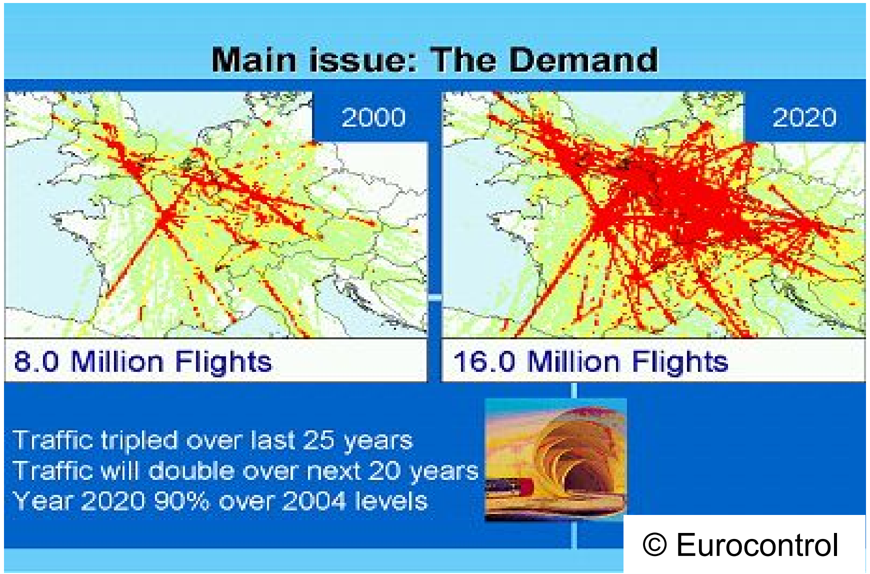
- In 1994 ICAO decided to introduce a channel split from 25 to 8.33 kHz.
- 8.33 kHz spacing was introduced above FL245 (24,000 ft) in the ICAO EUR Region in 1999.
- 8.33 kHz is mandatory above FL195 in the ICAO EUR Region since 15 March 2007.
- These States enforced mandatory carriage above FL 195 from 13 March 2008: Bulgaria, Cyprus, Malta, Portugal, Spain.

Today's ATM Communication Systems are at Capacity Limits

8.33 kHz spacing will not solve problems of 2020 ++

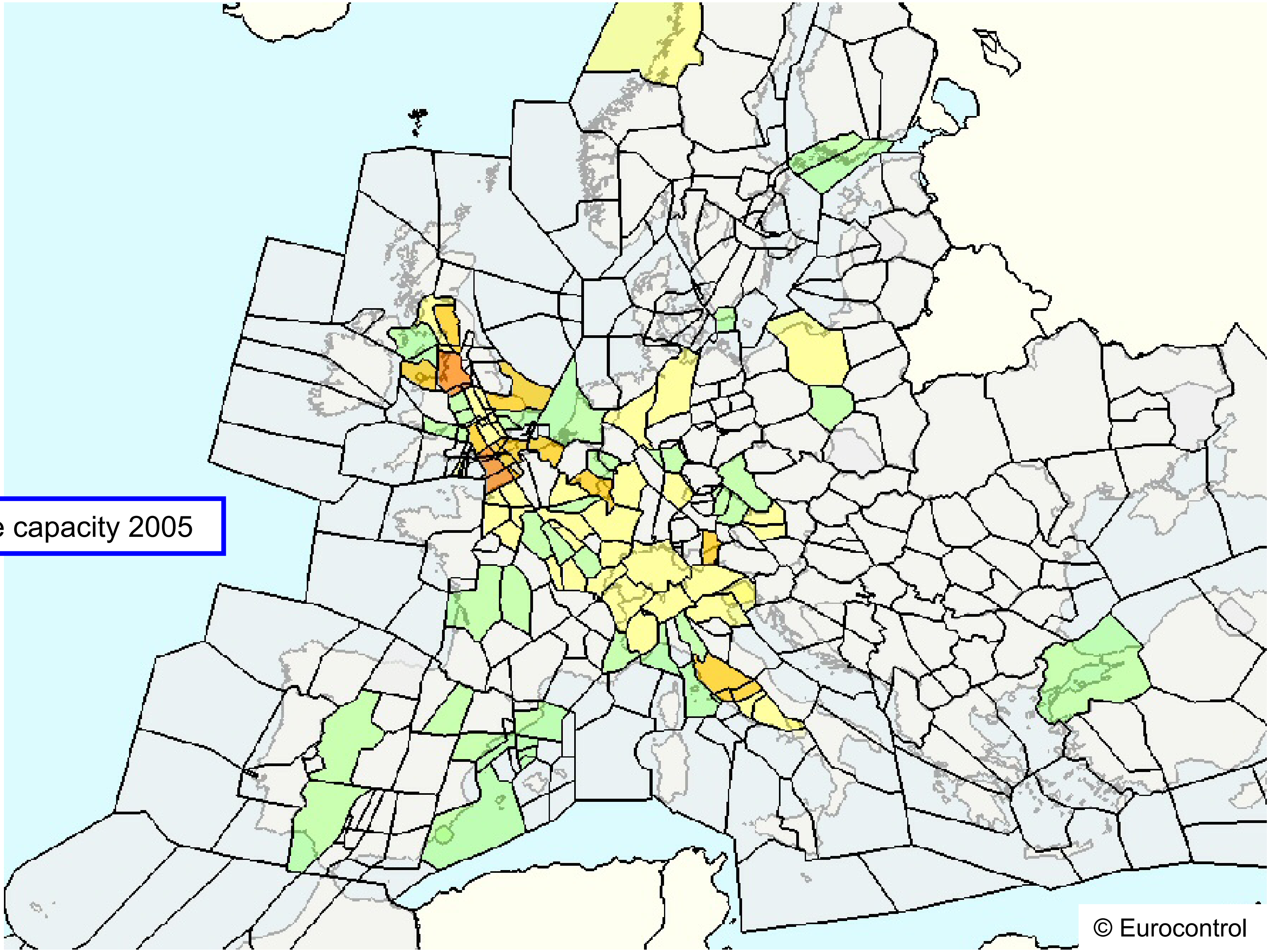
Situation in Europe:

- Traffic in 2004:
  - 8 million flights per year
  - Number of flights on peak days:
    - 30,000 by commercial airlines
    - 200,000 by general aviation
    - Numerous military aircraft
- Estimated traffic in 2020:
  - 16 million flights per year
- Estimated traffic in 2025:
  - 22 million flights per year
  - Number of flights on peak days:
    - 72,000 by commercial airlines
    - 480,000 by general aviation aircraft
    - Numerous military aircraft

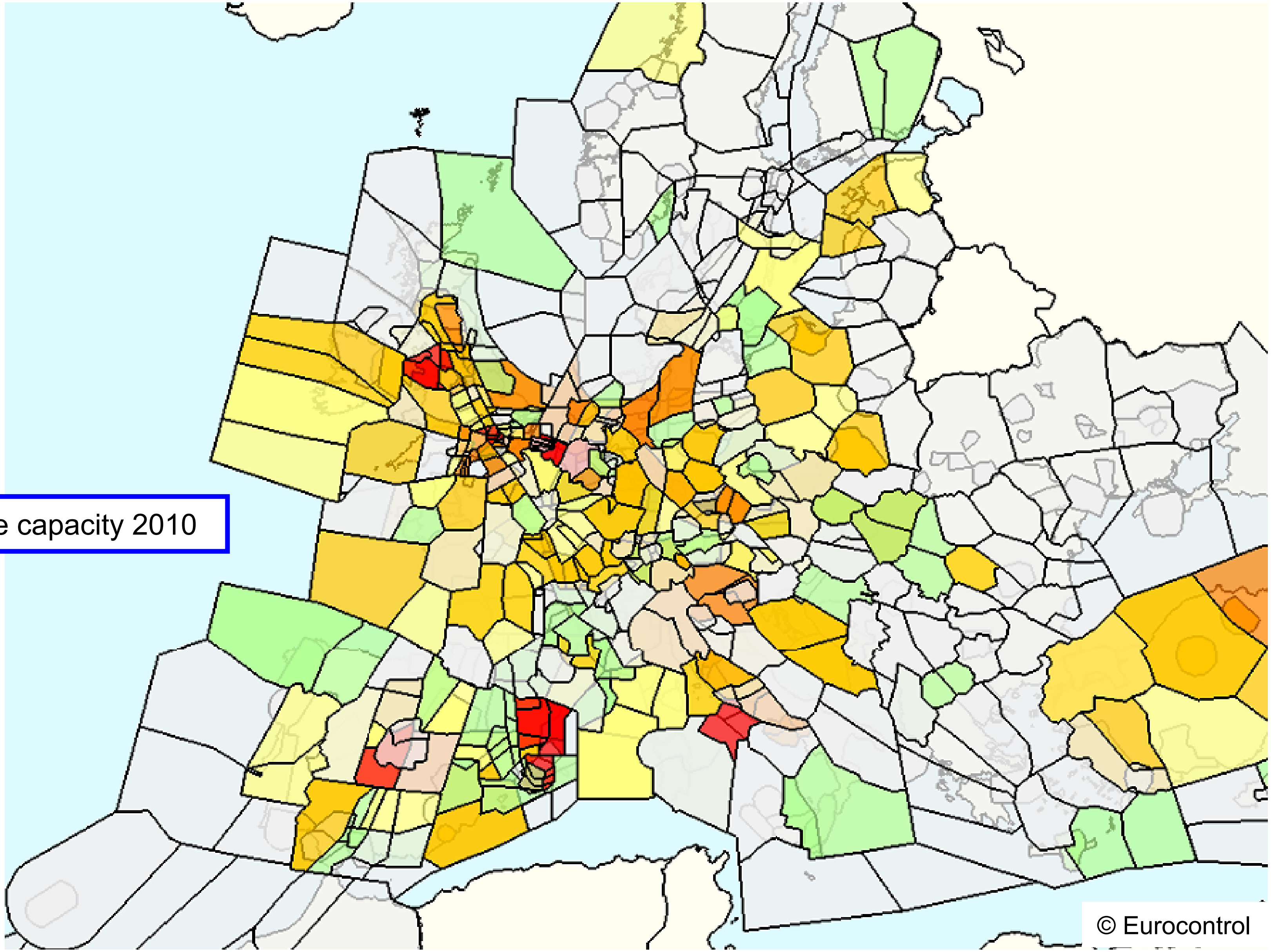


© Eurocontrol

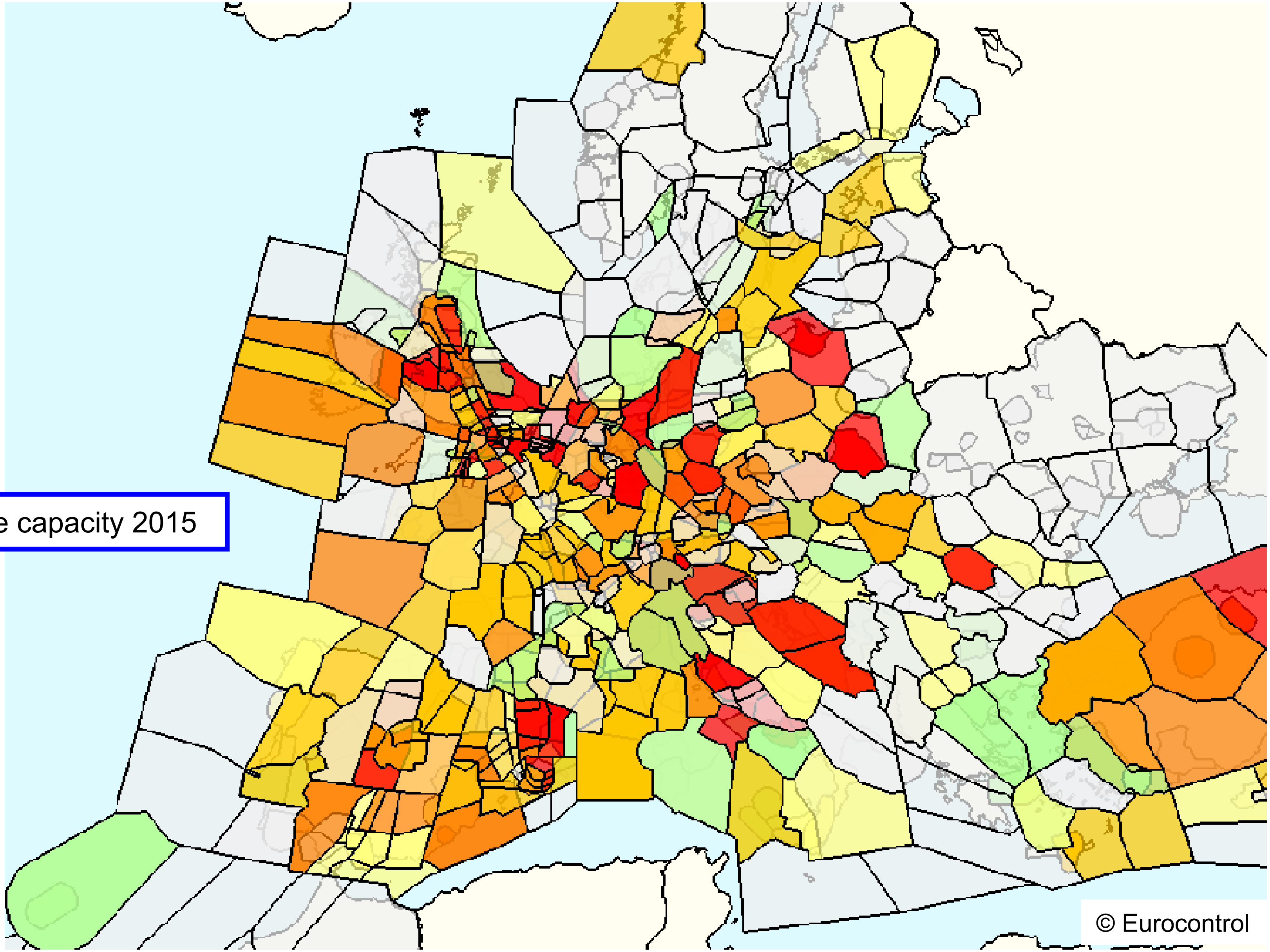
Airspace capacity 2005



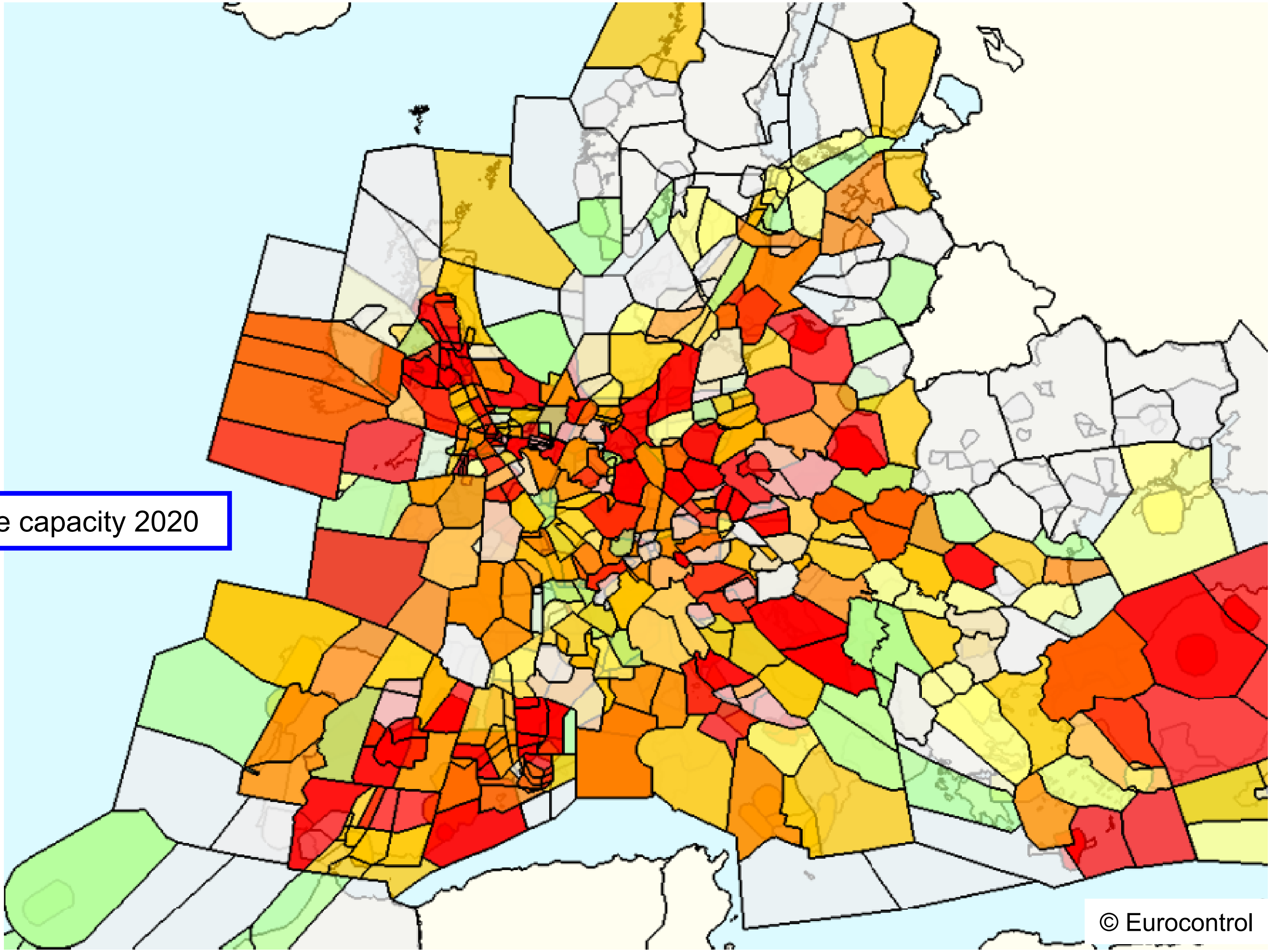
Airspace capacity 2010



Airspace capacity 2015



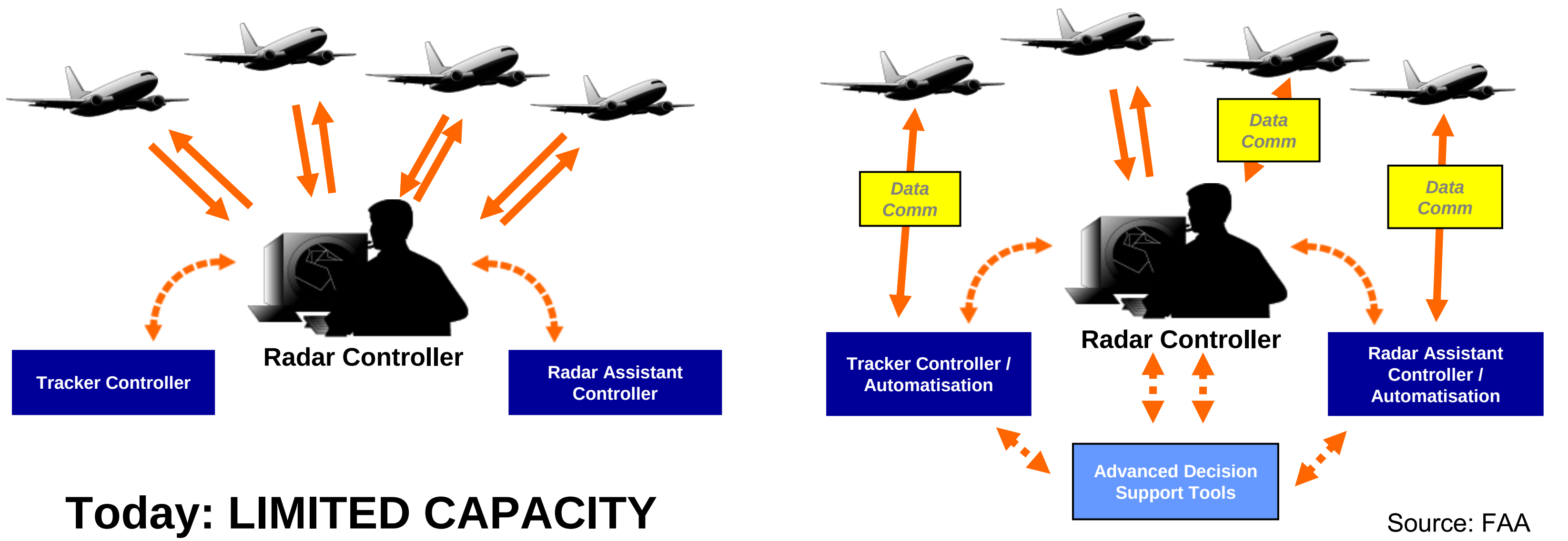
Airspace capacity 2020



Today's ATM Communication Systems are at Capacity Limits

8.33 kHz spacing will not solve problems of 2020 ++

- Apart from air traffic increase there is a huge demand for new data services



Source: FAA

Towards Tomorrow's ATM Communication Systems

The ATM Communications System after 2020

- No further increase of spectral efficiency in the VHF band (8.33 kHz channels) possible
- Today's data communication standards support only low bit-rate services

Standard	Modulation	Data rate	Access	Comments
VDL Mode 1	FSK	2.4 kbit/s	CSMA	Identical with ACARS
VDL Mode 2	D8PSK	31.5 kbit/s	CSMA	Currently introduced in EU, not yet mandatory
VDL Mode 3	D8PSK	31.5 kbit/s	TDMA	Candidate for US; not yet applied, uncertain
VDL Mode 4	GFSK	19.2 kbit/s	TDMA	Newest standard; application uncertain

- Open new frequency bands for aeronautical communication (WRC-07)
  - VHF band: 108 -118 MHz (no system proposed – not enough B/W)
  - L-band: Portions within the 960-1164 MHz for L-DACS
    - Challenge: Coexistence with DME (Distance Measurement Equipment)
  - C-band: Portions within the 5000-5150 MHz for IEEE802.16aero
- Development of a satellite component for ATM

L-DACS: L-Band Digital Aeronautical Communications System

About the history

- We started in 2004 with the EU project B-VHF initiated by Frequentis and DLR
- In 2007 we redesigned B-VHF to became B-AMC
- Our response to ECTL/FAA's "Future Communications Study" in 2008 is L-DACS1

	United States	Common shortlist / Screening Results		Europe
Continental		•P34/TIA-902 •LDL •W-CDMA	•P34/TIA-902 •LDL •W-CDMA	•B-AMC •AMACS •Custom Satellite
Oceanic/Remote		•Inmarsat SBB •Custom Satellite	•Inmarsat SBB •Custom Satellite	
Airport		•IEEE 802-16e	•IEEE 802-16e	

FAA ranking:
B-AMC best performance

ECTL ranking:
B-AMC first

B-AMC chosen as baseline for L-DACS1

Source: Eurocontrol/FAA

Development of L-DACS

Thus, since 2009 there are two proposals:

- L-DACS1 and L-DACS2

Today, L-DACS1 is the strongest candidate

DLR, Frequentis, Uni Salzburg, Selex Communications (L-DACS-1)

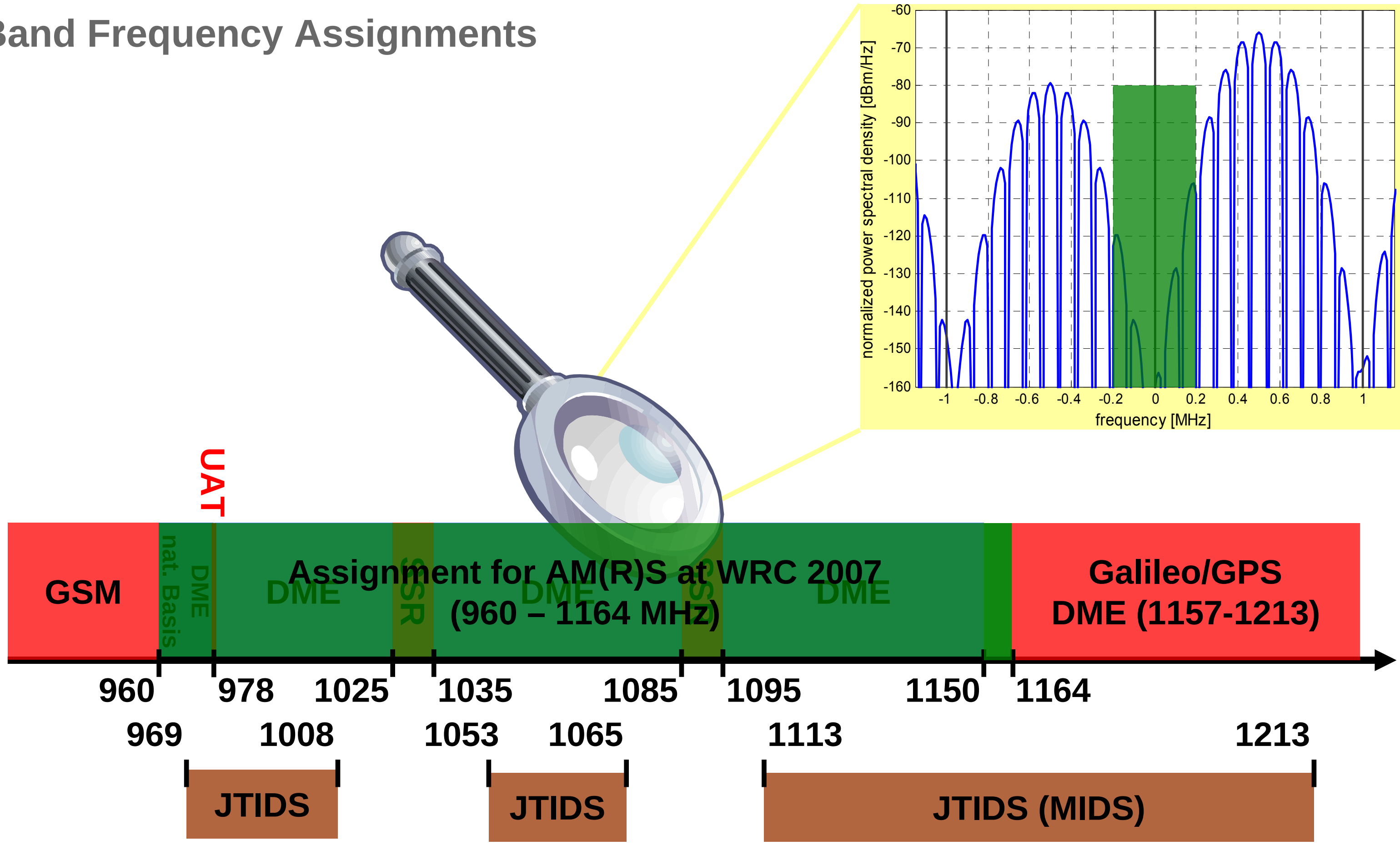
Options	Access Scheme	Modulation	Origins
L-DACS-1	FDD	OFDM	B-AMC (B-VHF) by DLR (2004++) TIA 902 (P34) (US)
L-DACS-2	TDD	CPFSK / GMSK type	LDL (US), AMACS (DSNA, LFV)

Flight Guidance France (DSNA) and Sweden (LFV) (L-DACS-2)

AMACS: All-purpose Multi-channel Aviation Communication System (new development); **B-AMC**: Broadband Aeronautical Multi-Carrier Communications (B-VHF for L-band); **B-VHF**: Broadband VHF Communications System (new development); **LDL**: L-Band Digital Link (VDL Mode 3 for L-band); **P34**: Public Safety Standard (US standard, e.g. for fire brigades etc.)

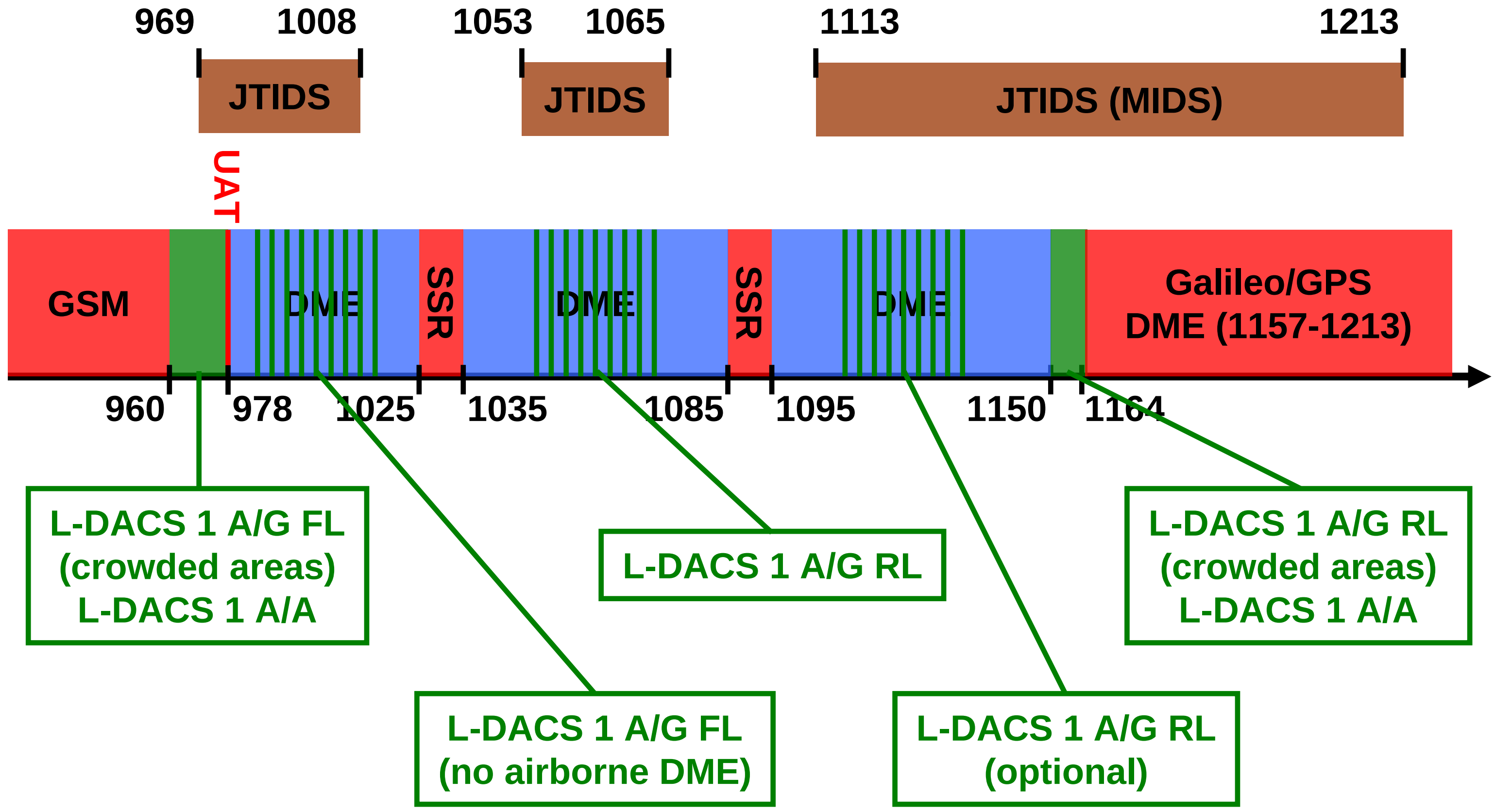
Development of L-DACS1

L-Band Frequency Assignments



Development of L-DACS1

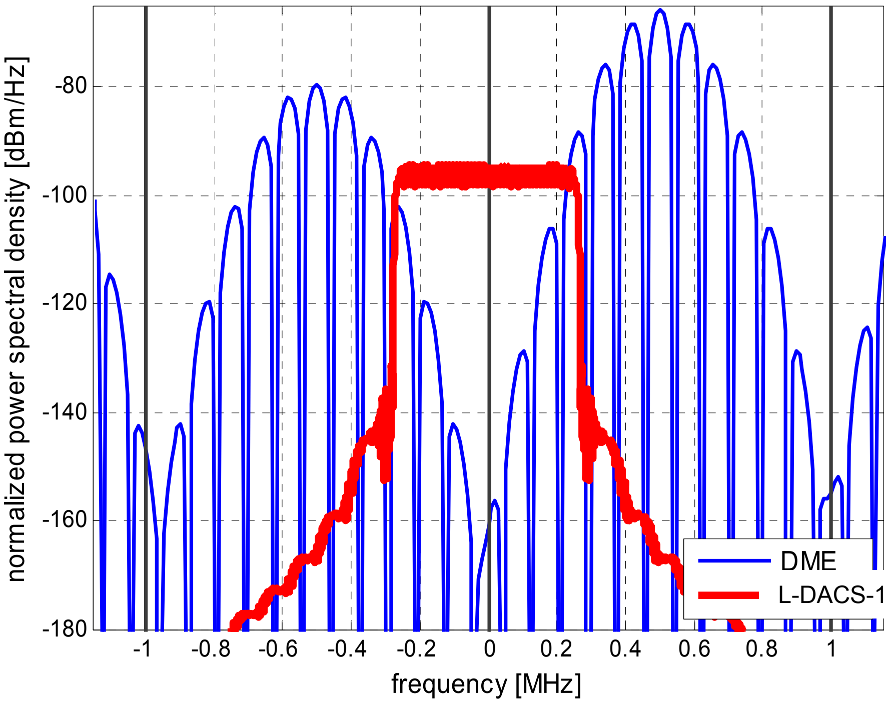
L-Band: Assignment of L-DACS frequencies



Development of L-DACS1

Fitting L-DACS1 into the DME frequency grid

- A/G Data Link
  - Available bandwidth:
    500 kHz per channel
  - Challenges:
    - Minimize interference to other systems (out-of-band radiation)
    - Minimize interference from other systems (robustness)
    - Take into account mainly DME system



Development of L-DACS1

Key Features of L-DACS-1

- Based on OFDM
- Centralized communication via ground station
- Cellular deployment concept
- Inlay system between DME channels
- Duplex scheme is FDD (Frequency-Division Duplex)
  - More efficient than TDD (Time-Division Duplex)
  - Separate FL/RL channels advantageous for inlay design
- Multiple-access schemes
  - Forward link: OFDM(A), incl. pure OFDM as special case
  - Reverse link: OFDM(A) combined with TDMA
- A/G mode supports data and voice communication

Development of L-DACS1

A/G Data Link System Parameters

- Main system parameters

Bandwidth (overall / occupied)	625 / 488,28 kHz
Number of subcarriers	64 (50 used)
Sub-carrier spacing	625/64 = 9.765625 kHz
OFDM symbol duration	120 µs
Overall guard time duration = RC-window + guard	17.6 µs = 12.8 µs + 4.8 µs
OFDM symbols per data frame	54 (forward link)

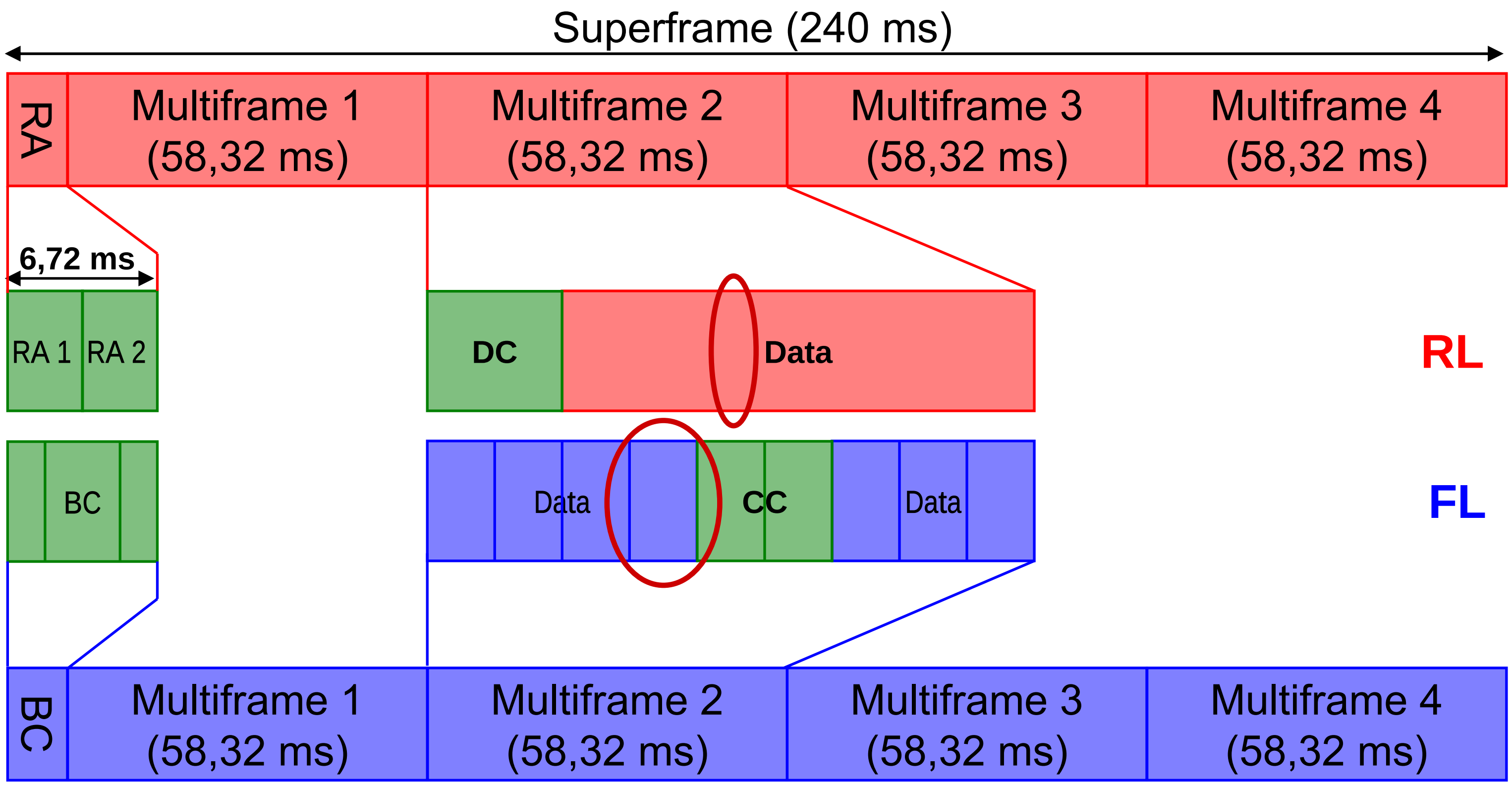
- Data rates & adaptive coding and modulation

Modulation rate (overall FL + RL)	833.33 ksymbols/s
Min. net data rate (QPSK)	291/270 kbit/s
Max. net data rate (64-QAM)	1318/1267 kbit/s

Development of L-DACS1

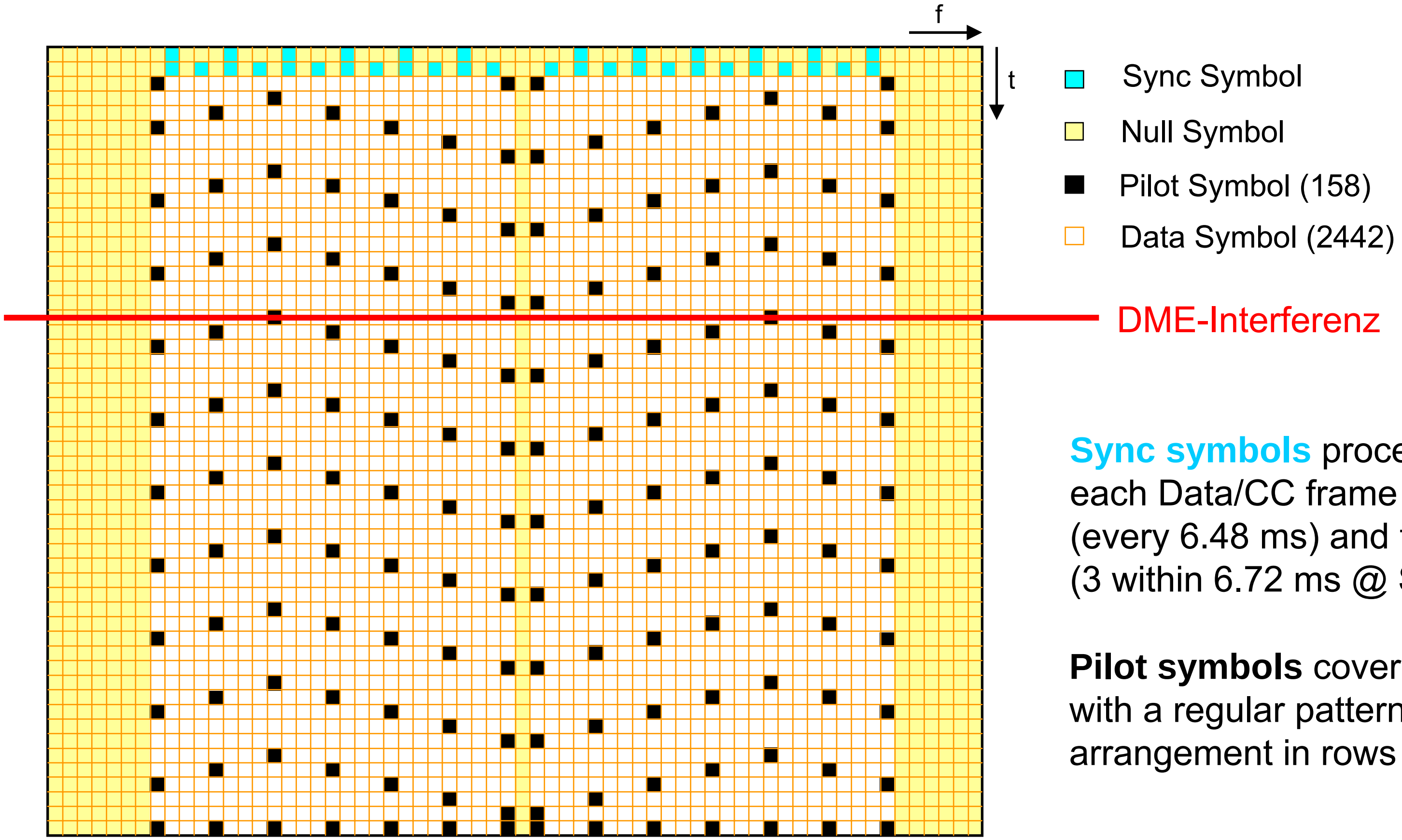
A/G Data Link – Frame Structure

RA: Random Access frame net entry)
BC: Broadcast Channel (cell information broadcast)
DC: Dedicated Control channel (resource requests)
CC: Common Control channel (resource assignment)



Development of L-DACS1

A/G Forward Link – Frame Structure (Data and CC Frame)

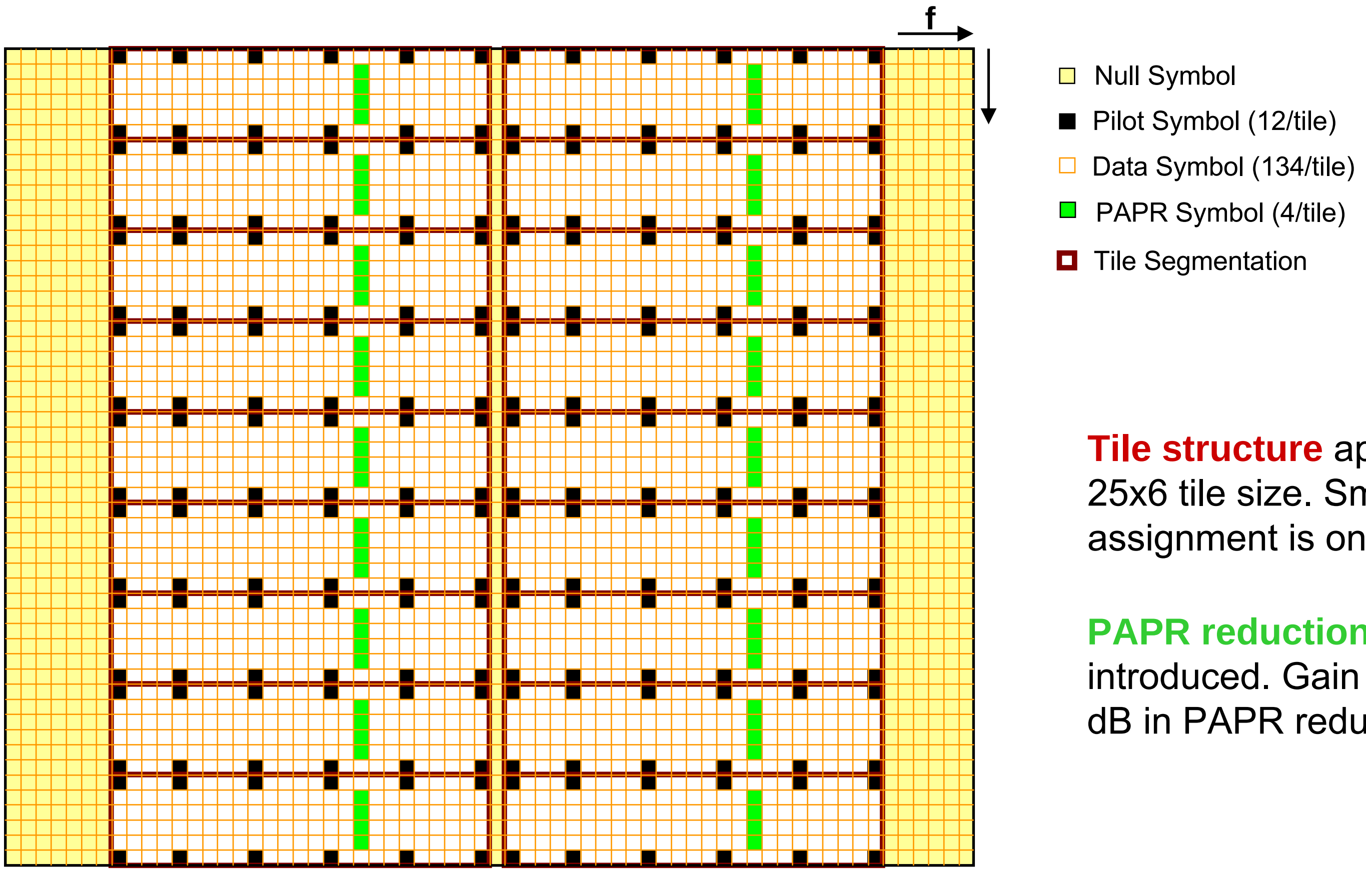


Sync symbols proceed each Data/CC frame (every 6.48 ms) and the BC frames (3 within 6.72 ms @ SF start).

Pilot symbols cover Data/CC frame with a regular pattern; pilot arrangement in rows avoided.

Development of L-DACS1

A/G Reverse Link – Frame Structure (Data Frame)

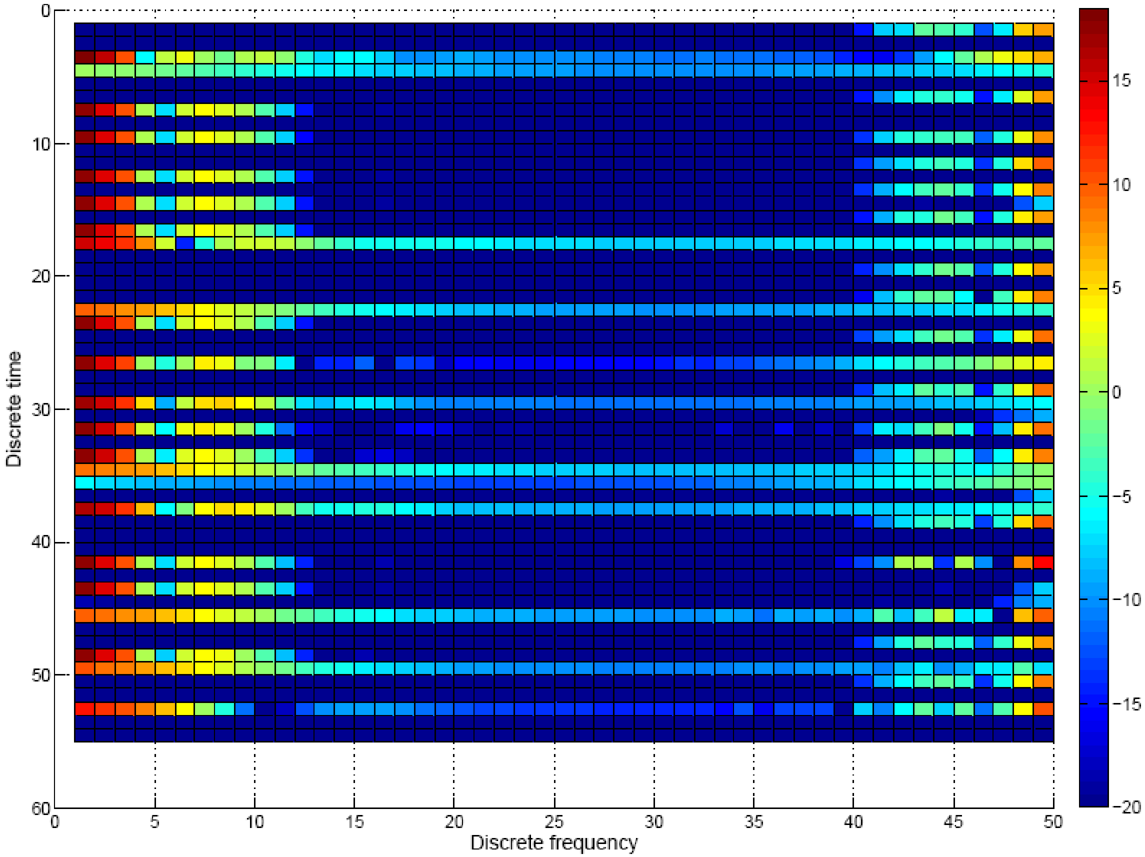


Tile structure applied using a 25x6 tile size. Smallest assignment is one tile.

PAPR reduction symbols introduced. Gain around 1-2 dB in PAPR reduction.

Development of L-DACS1

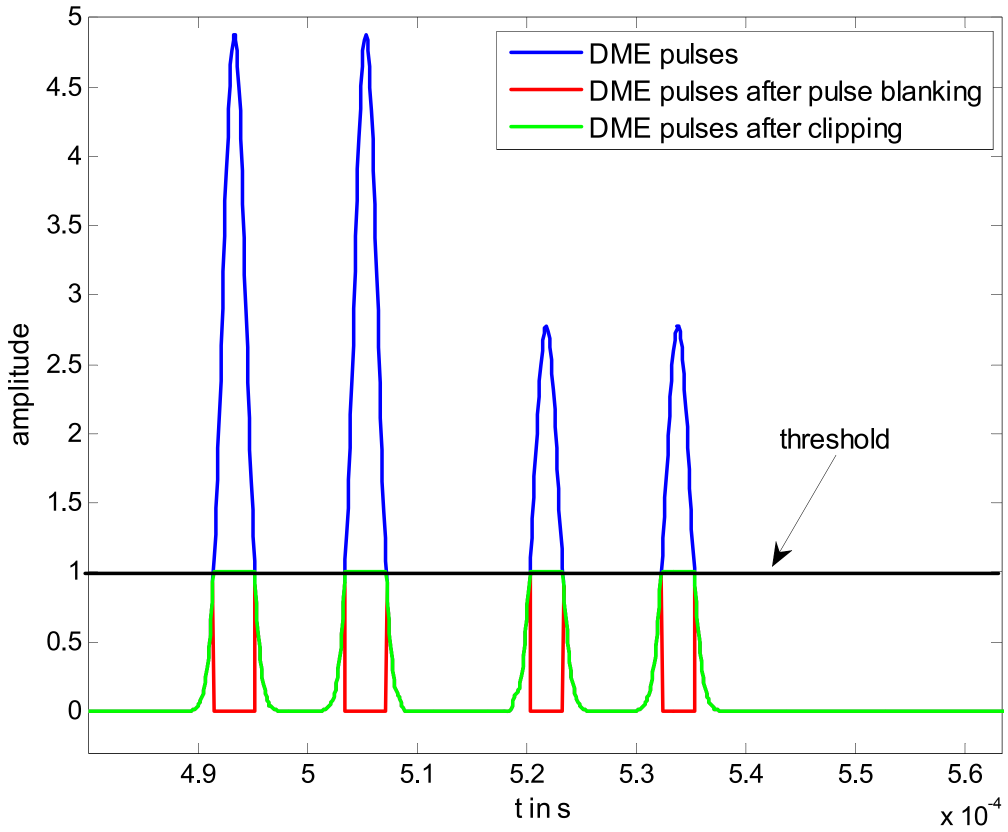
Example of worst case DME interference



Normalized DME power in the frequency domain

Development of L-DACS1

DME Double Pulse

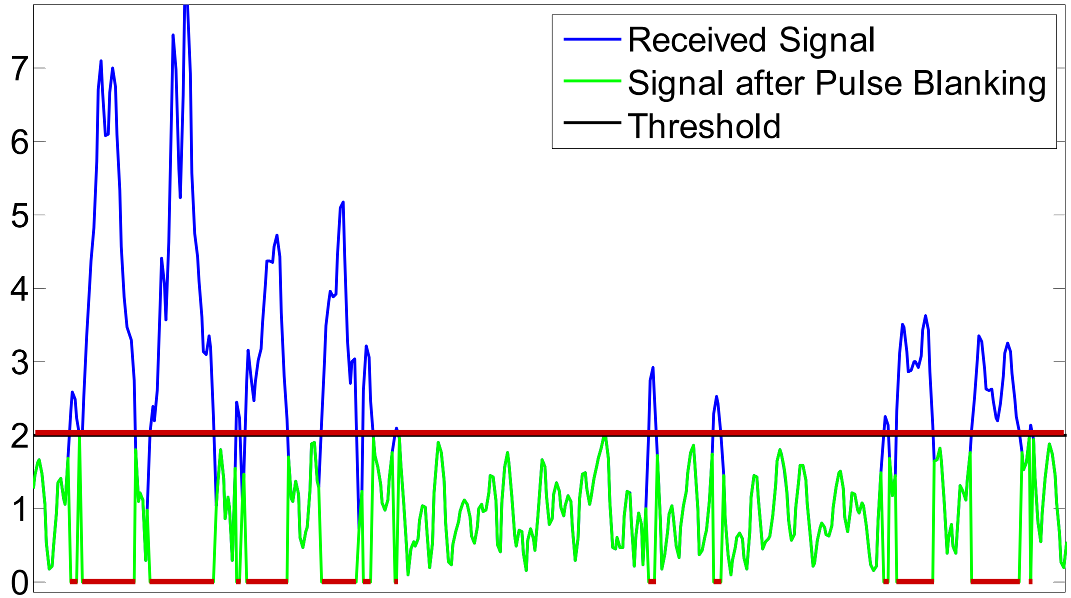


- DME pulses occur always as pairs
- DME pulse duration (above threshold) is 3.5 µs

Development of L-DACS1

Interference Mitigation: Pulse Blanking

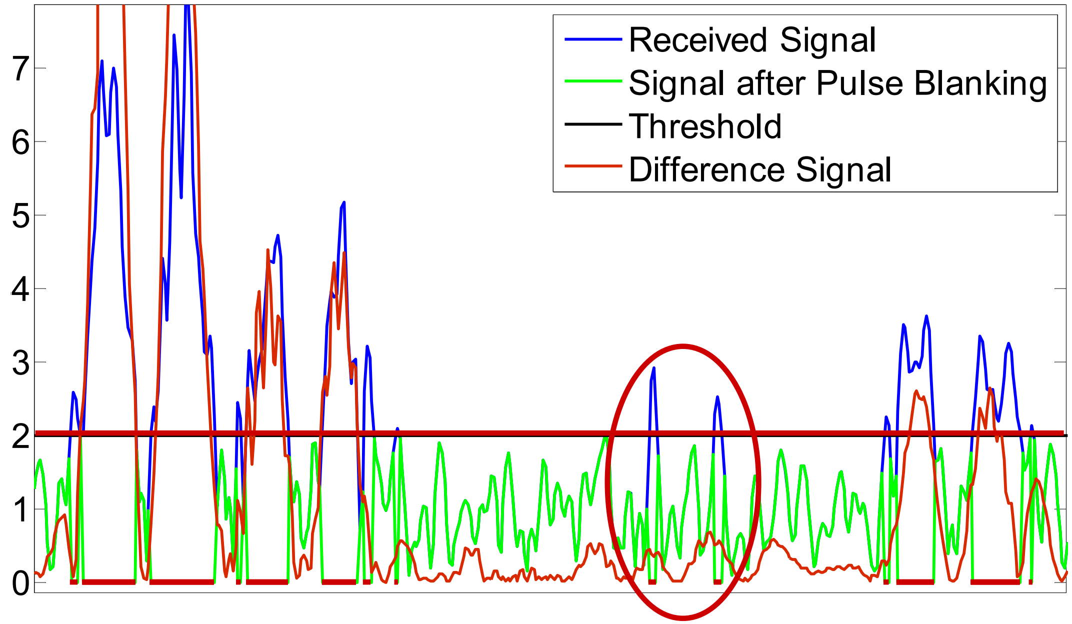
- Principle of pulse blanking (PB)
  - Define a threshold for the time domain samples
  - Set received samples to zero, if its amplitude exceeds threshold



Development of L-DACS1

Interference Mitigation: Pulse Blanking

- Advantage: No knowledge about the interference has to be known in advance
- Problem: OFDM signal peaks (due to PAPR) may be interpreted as interference



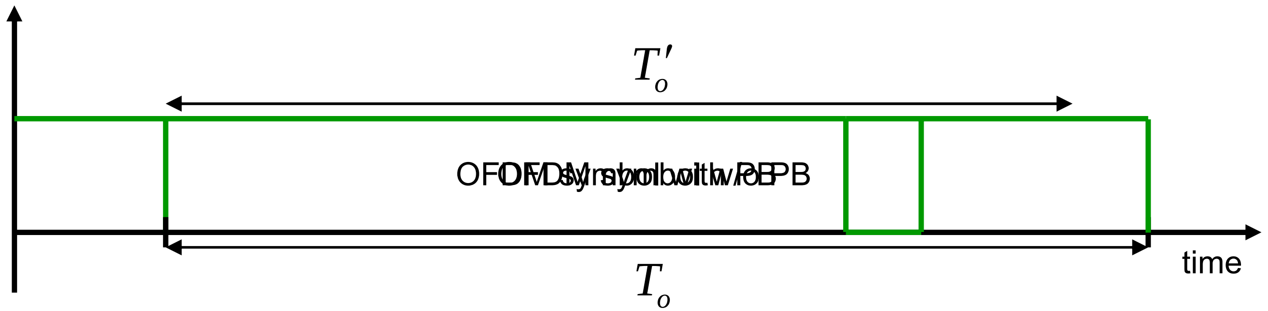
Use difference signal between outer and inner subcarriers

Clear distinction between LDACS1 and interference signal

Development of L-DACS1

Interference Mitigation: Pulse Blanking

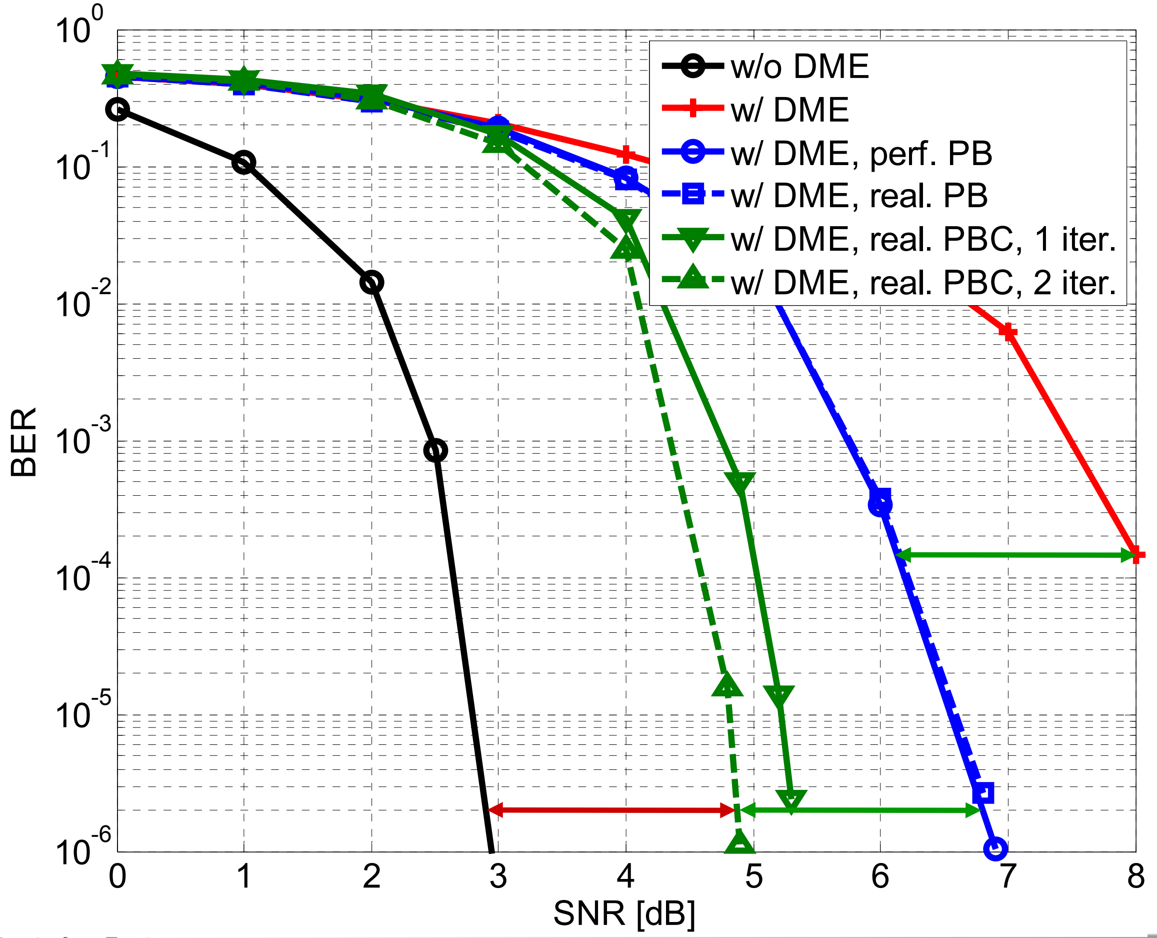
- Drawback of pulse blanking
  - Cutting out interference pulses affects useful signal
  - Impact on OFDM signal – loss of orthogonality → ICI



- Countermeasure – pulse blanking compensation (PBC)
  - Manipulation (pulse blanking) of received signal exactly known
  - Impact on OFDM signal can be compensated/mitigated
  - Iterative scheme using estimated channel and estimated data

Development of L-DACS1

Interference Mitigation: Simulation Results



PB with PBC further improves performance (**another 2 dB**)

Remaining **gap** due to imperfect estimation (data, channel), SNR degradation, and remaining pulse interference

L-DACS1 Prototype

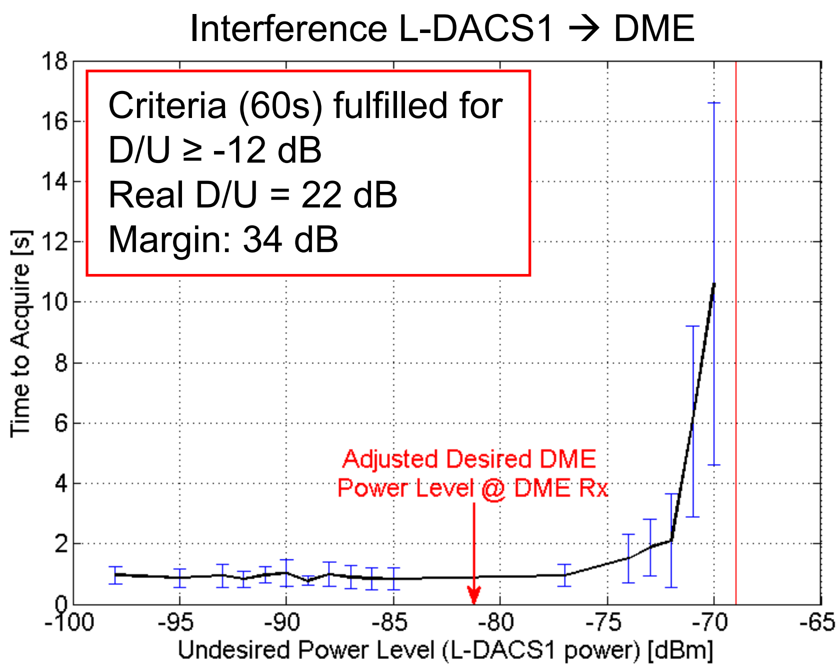
Implementation of own physical layer lab demonstrator

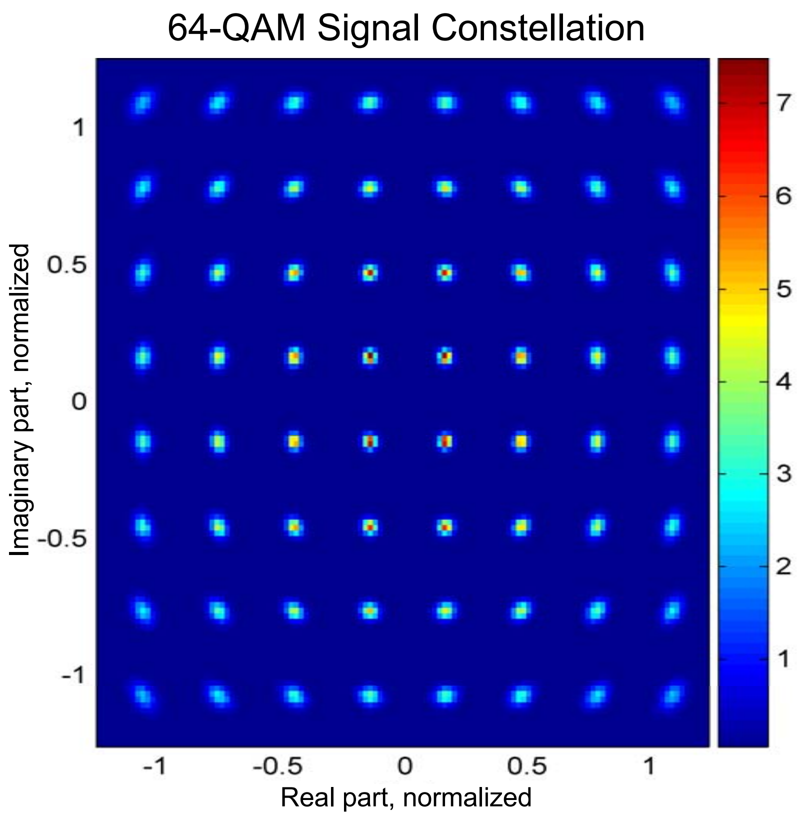
- Complete transmitter implementation
- Software receiver (data grabber and offline evaluation)
- Main purpose: L-band compatibility measurements
  - Prove of L-DACS1 concept
  - Assist decision for L-DACS1
- First lab measurements in March 2011
- Planned activities
  - Compatibility measurements in summer 2011 @ DFS labs
  - Proof L-band compatibility according to SJU P15.2.4 testing scenarios

L-DACS1 Prototype

Measurement results with DLR L-DACS1 laboratory demonstrator

- First measurement campaign at DFS labs, March 2011





Towards APNT: Alternative Positioning, Navigation, Timing

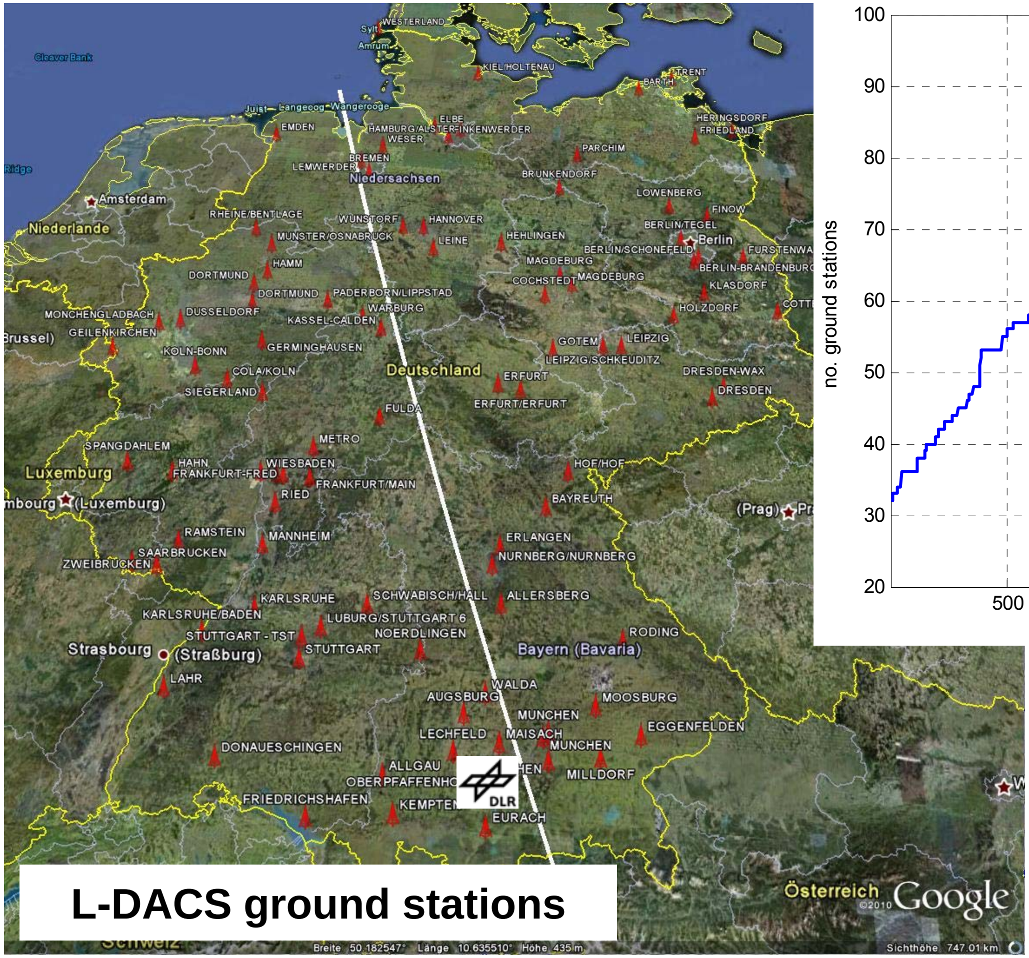
APNT approach:

- Increase DME density and use DME for multilateration
  - DME system already available
  - Costly extension of infrastructure
  - Endangers sustainable use of L-band for communications
    - L-band foreseen for future A/G communication
    - Future A/G system shall be long-term solution

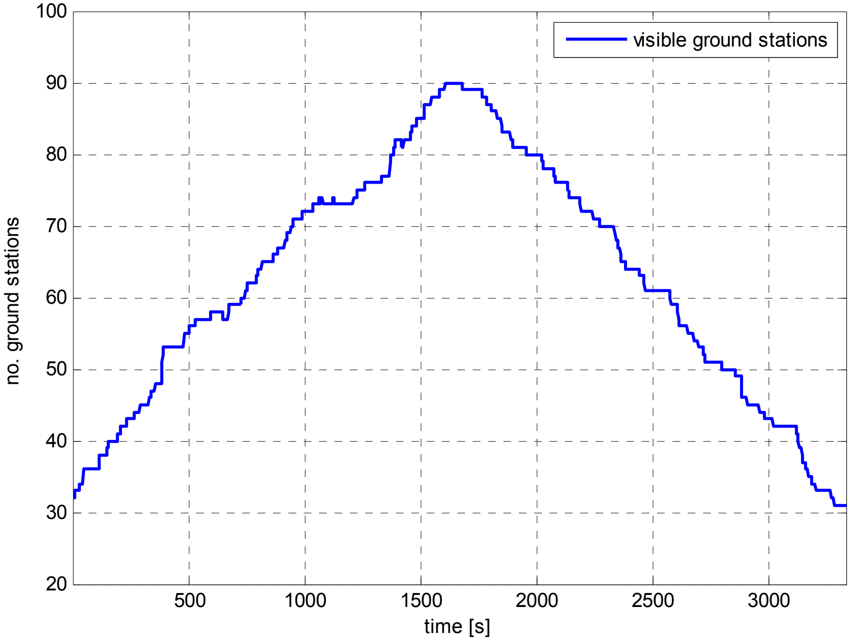
Our alternative approach:

- Integrate a navigation functionality into the L-DACS communications system
  - No additional DME ground stations required
  - Even partial removal of DME infrastructure possible
  - Assures sustainable use of L-band for both communications and navigation

L-DACS1 for APNT – Performance Assessment

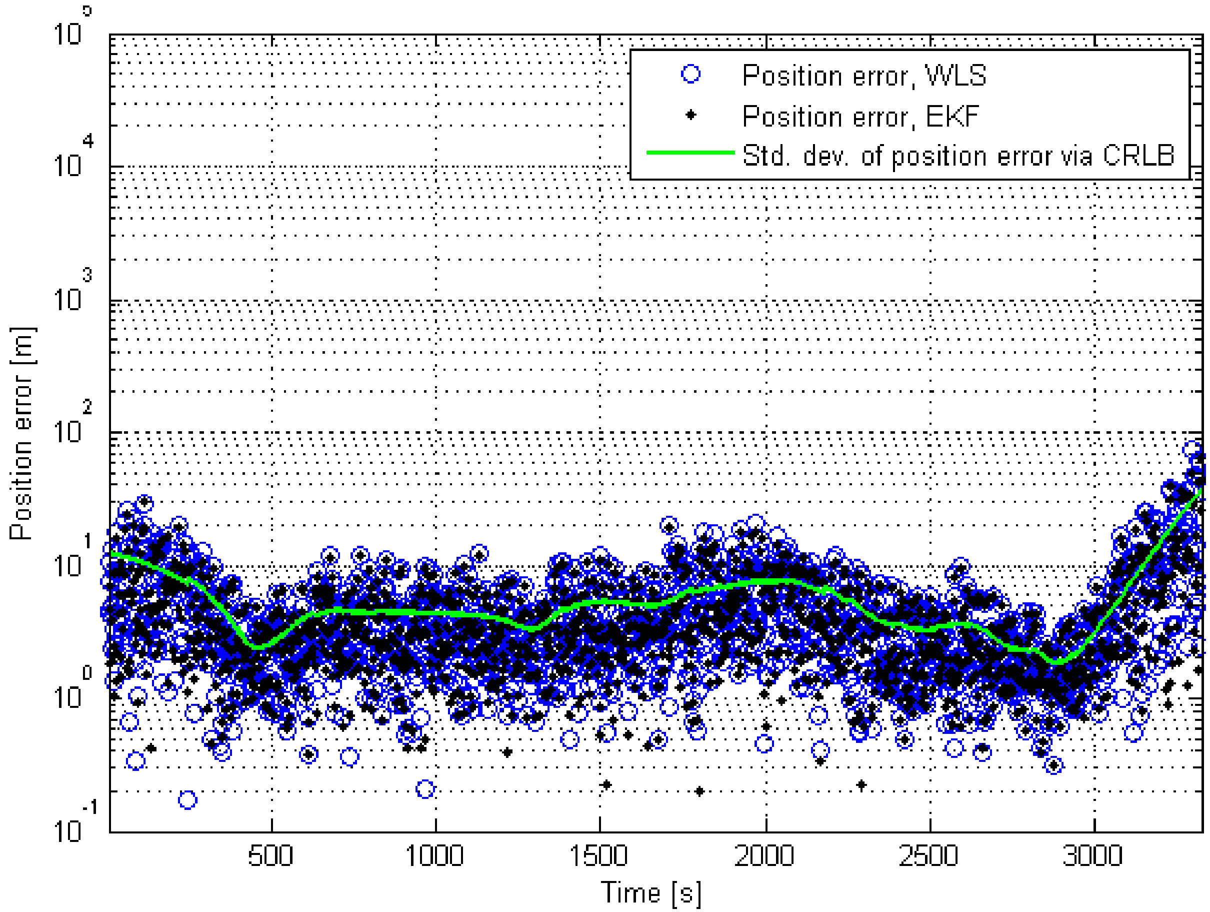


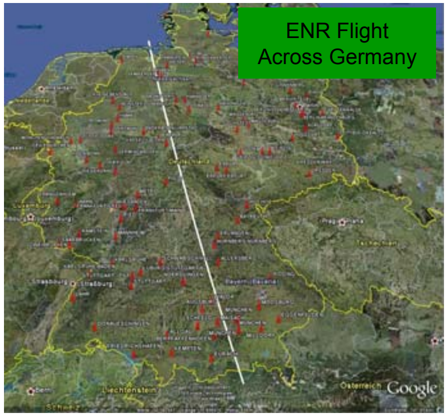
L-DACS ground stations



Enroute flight across Germany

L-DACS1 for APNT – Performance Assessment





10 Stations SNR only

P1 → circle Snapshot WLS

P2 → dot EKF, correlations

P3 → solid curve CRLB on position error, real sync

Development of L-DACS

Our conclusions

- L-DACS1 is a feasible inlay concept which allows the efficient use of L-band
- Mutual interference can be kept at acceptable levels
  - Considerably decreased out-of-band radiation
  - L-DACS1 performs well even under strong L-band interference
- No fix resource assignments
  - No waste of resources
  - “Breathing reservation cycle” adapted to number of A/C
- Protocol simulations shows that L-DACS1 can support all Communications Operating Concept & Requirements (COCR) scenarios
  - Enough capacity available for future applications (FL 1/3 and RL 2/3 still unused)
  - Flight test with new DLR aircraft
- Navigation Option very attractive for APNT

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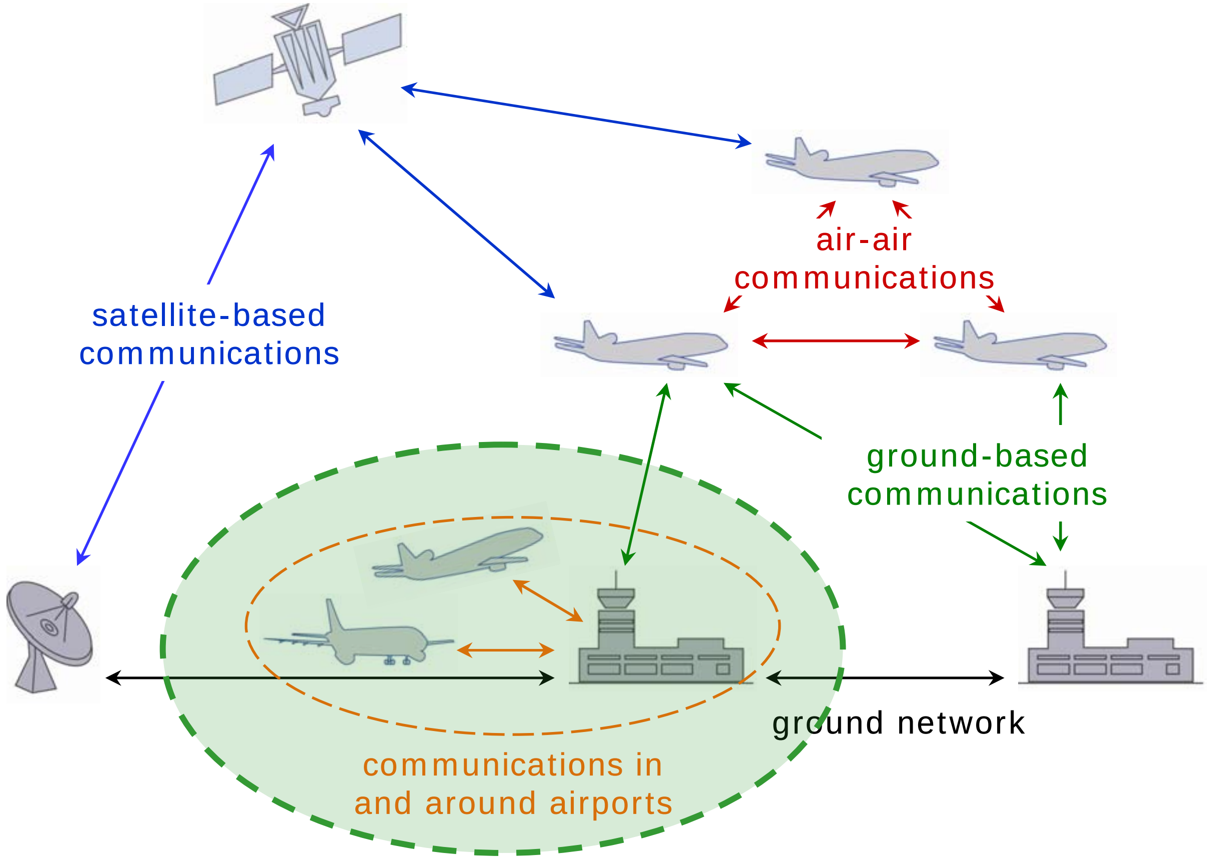
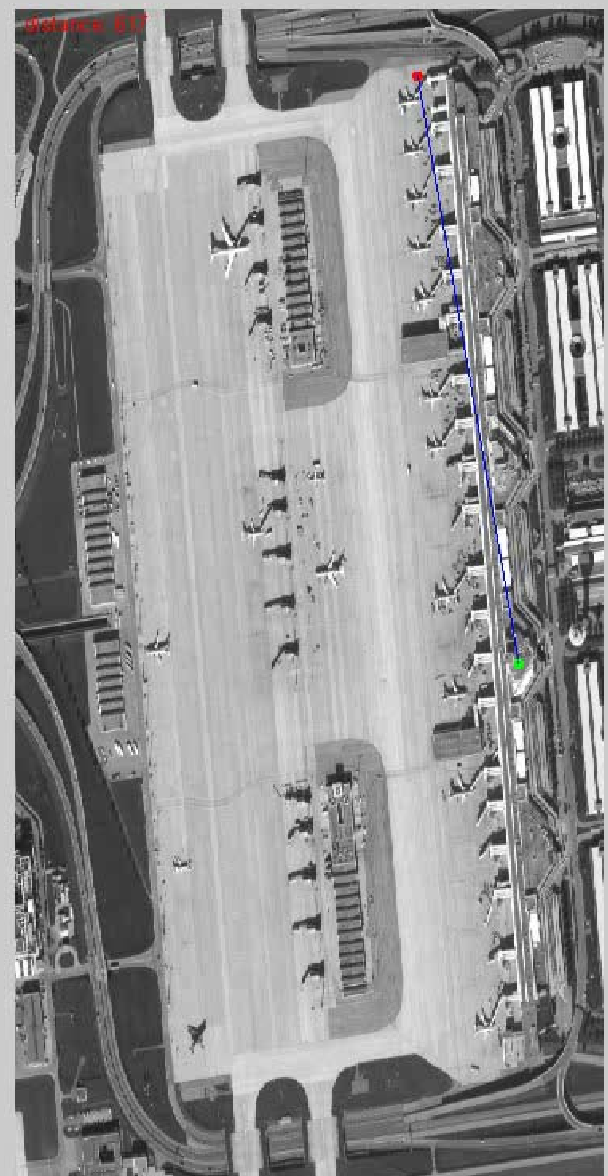
Aeronautical Communications for Air Traffic Management

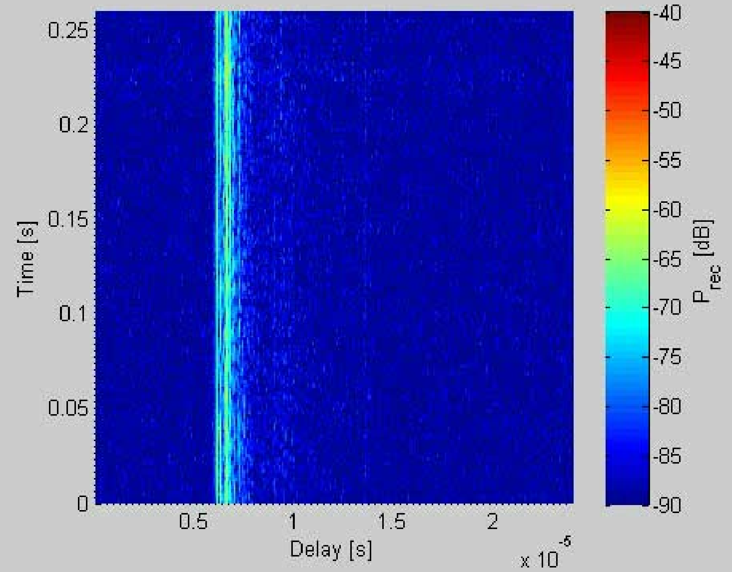


Airport Data Link

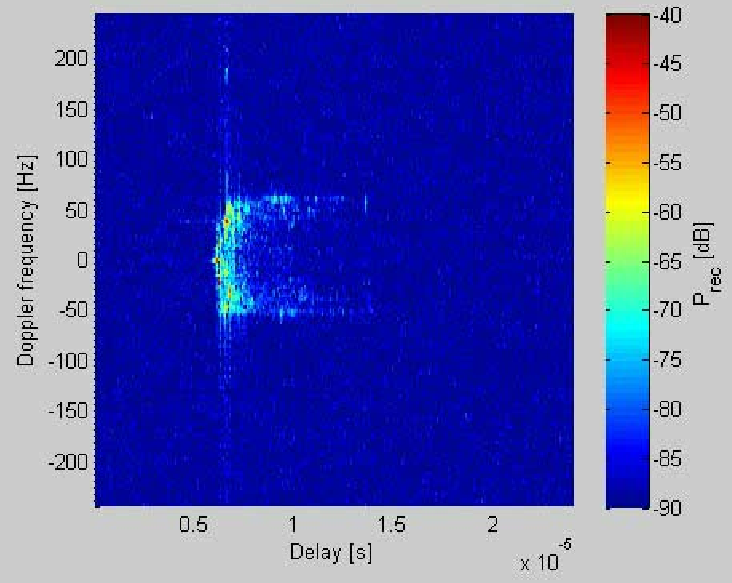
Towards a data link for ATM airport services, mainly A-SMGCS

- Airport Data Link
  - EU project EMMA
  - Channel measurement campaign (C-band) at Munich airport
  - Channel modeling of airport channel (taxiing, parking, take-off/landing)
  - Development of a new data link for A-SMGCS
    - Exact guiding of aircraft on airports (space and time)
    - Optimization of aircraft throughput
  - Baseline: IEEE 802.16a (WiMAX)
  - Goal: IEEE 802.16aero





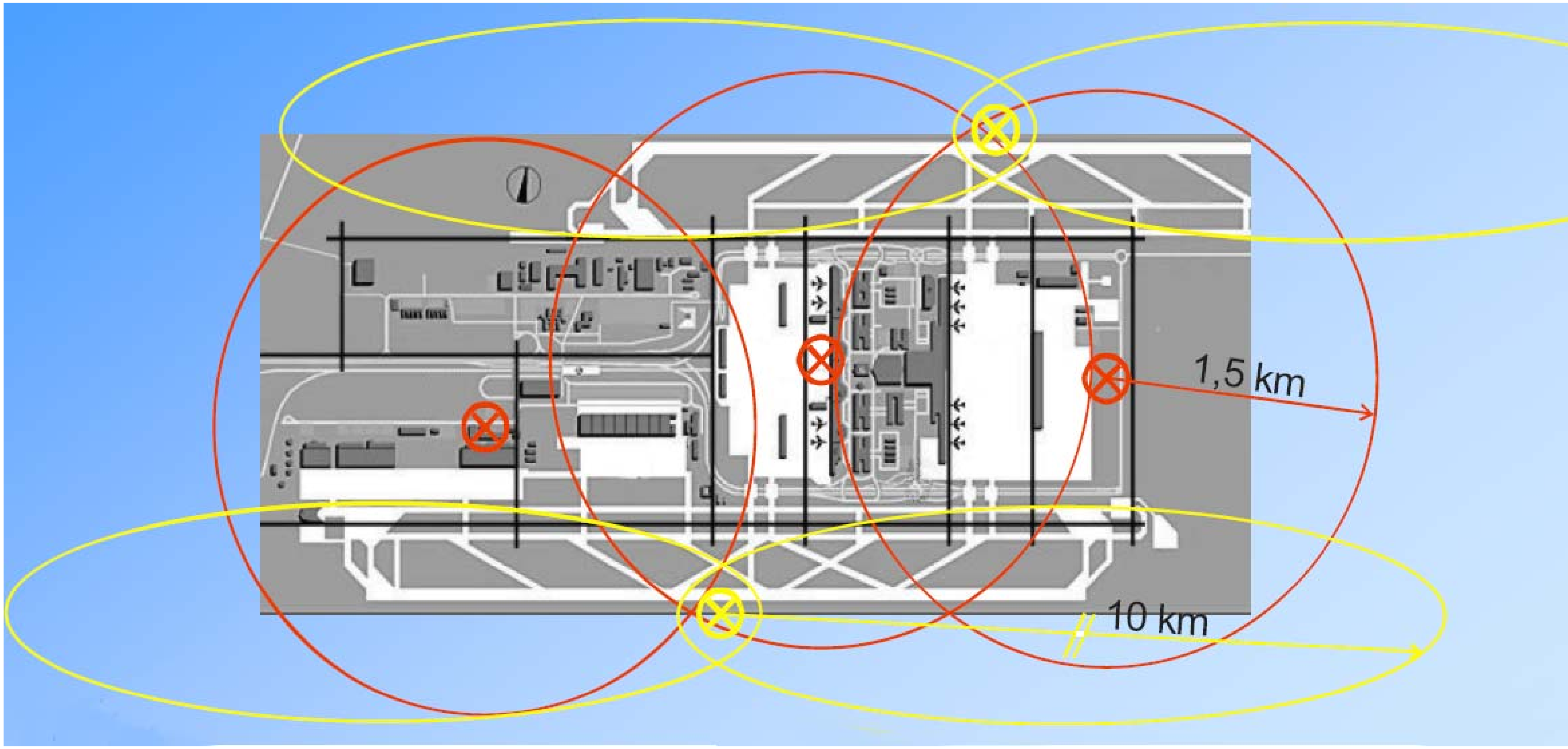
0.25
0.2
0.15
0.1
0.05
0
Time [s]
0.5
1
1.5
2
Delay [s]
x 10^-5
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
P_rec [dB]



200
150
100
50
0
-50
-100
-150
-200
Doppler frequency [Hz]
0.5
1
1.5
2
Delay [s]
x 10^-5
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
P_rec [dB]

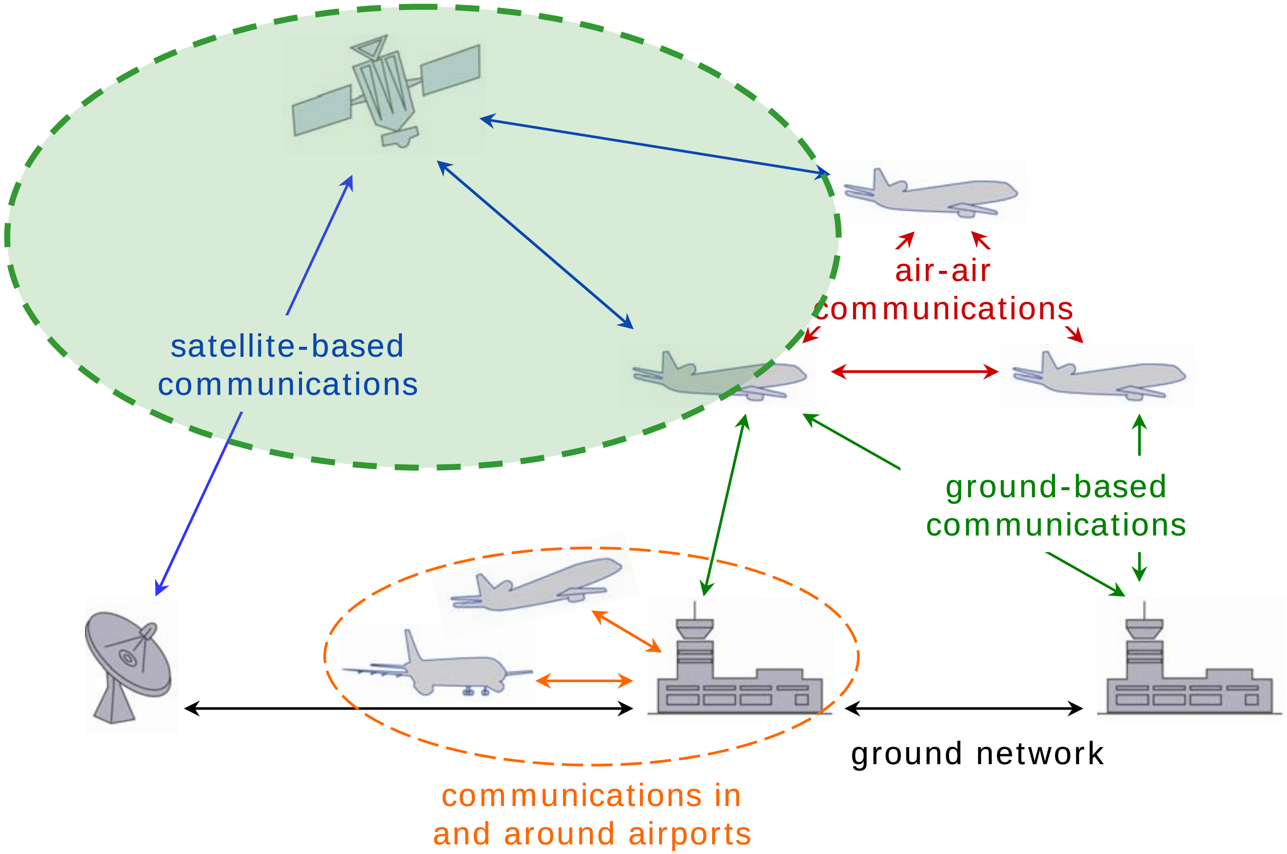
Airport Data Link

802.11aero cell layout for A-SMGCS at Munich airport



DLR – Institute of Communications and Navigation

Aeronautical Communications for Air Traffic Management



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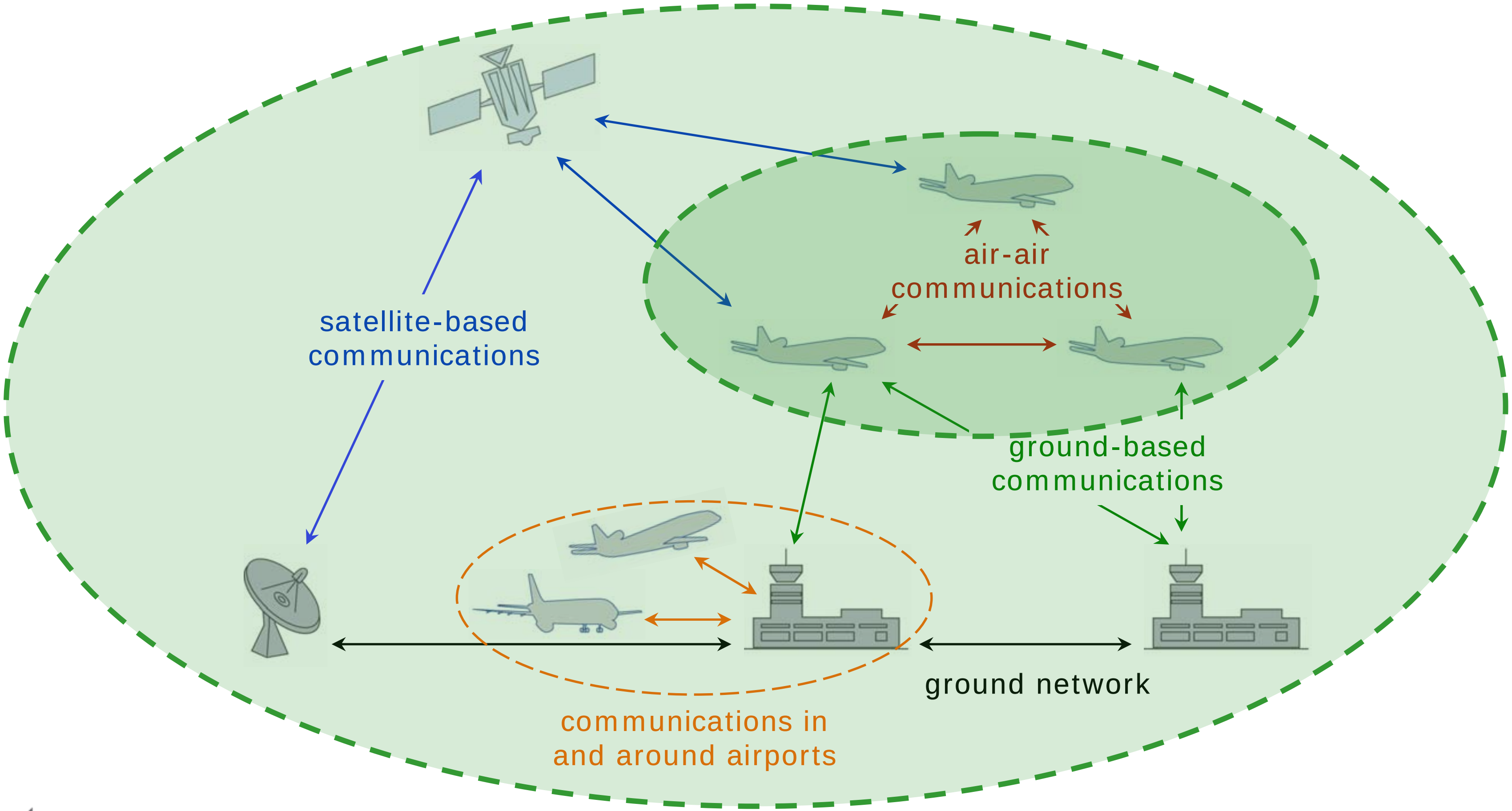
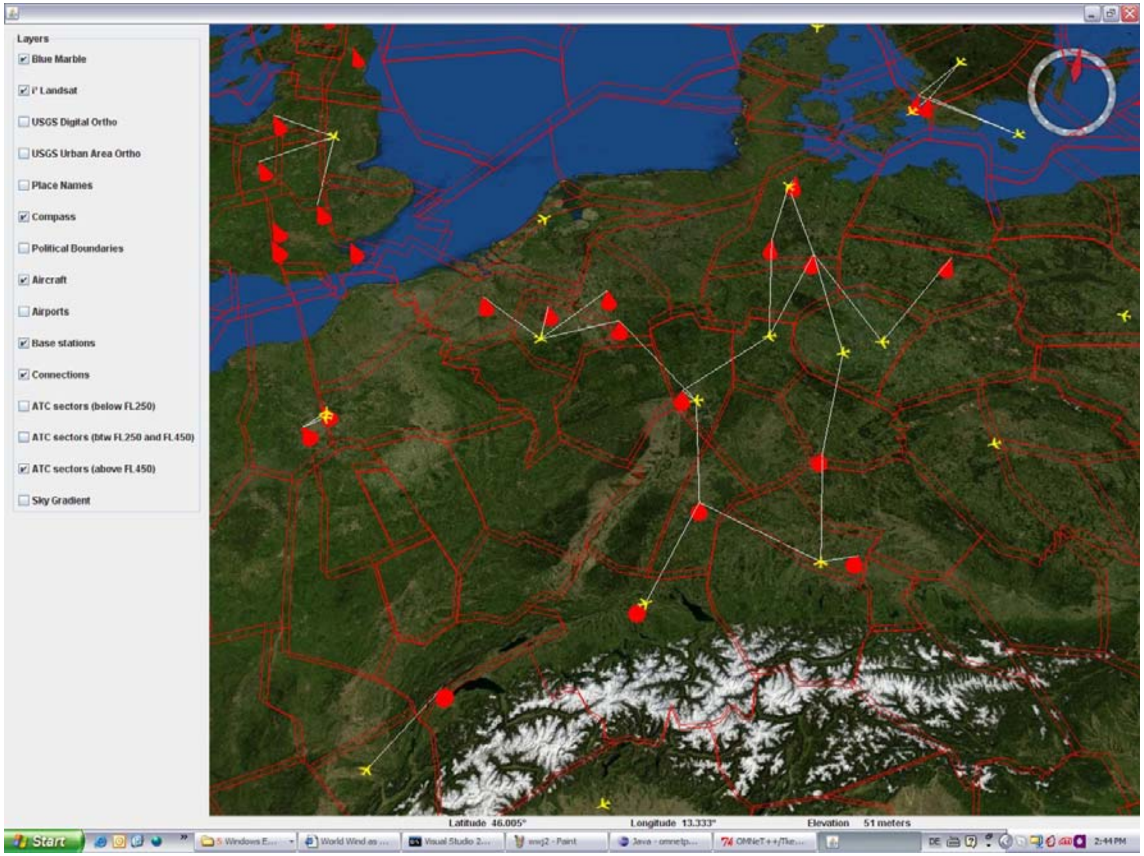
Aeronautical Communications for Air Traffic Management



Air Traffic Simulators

Realistic air traffic simulation

- DLR project FACTS (Future Aeronautical Communications Traffic Simulator)
  - Ground stations
  - ATC sectors
  - Air traffic
  - Data traffic
- Simulator applications
  - Data links
  - Networking aspects
  - Frequency planning



Contributions to International Panels

- DFS (Deutsche Flugsicherung) and BMVBS (Bundesministerium für Verkehr, Bau und Stadtentwicklung)
  - Advisor of DFS and BMVBW in the ACP (Aeronautical Communications Panel) of ICAO
  - Support of DFS for standardisation issues and in course of the preparation of decisions

DFS Deutsche Flugsicherung

- ICAO (International Civil Aviation Organisation)
  - Member of WG-T „Technology“ of ACP
  - Member of WG-I “Internet Protocol Suite” of ACP

ICAO · OACI · ИКАО

- Eurocontrol
  - Member in NexSAT (Next Generation Satellite System) Steering Group
  - Member in AGC-FG (Air-Ground Communications Focus Group)

EUROCONTROL

Modernisierung des Flugfunks