– B-AMC –
Broadband Aeronautical Multi-carrier Communications

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Introduction

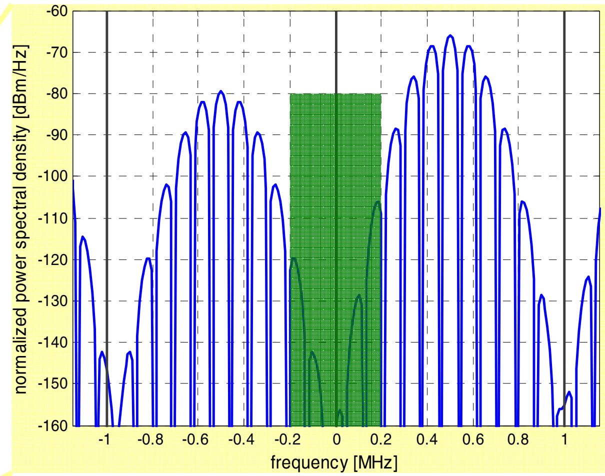
- History
  - Starting point: EC co-funded project B-VHF
    - OFDM based overlay system in VHF-band
    - Conclusion: Feasible, but high effort required
  - ECTL funded study: B-VHF like System in L-band
    - Broadband Aeronautical Multi-carrier Communication (**B-AMC**)
    - Reason: Future data link shall be applied in L-band
- Assessment results during FCS
  - ECTL ranking: B-AMC first
  - FAA ranking: B-AMC among best
  - Recommendation
    - L-DACS 1 (FDD/OFDM): Combine B-AMC and P34
    - L-DACS 2 (TDD/TDMA): Combine LDL and AMACS

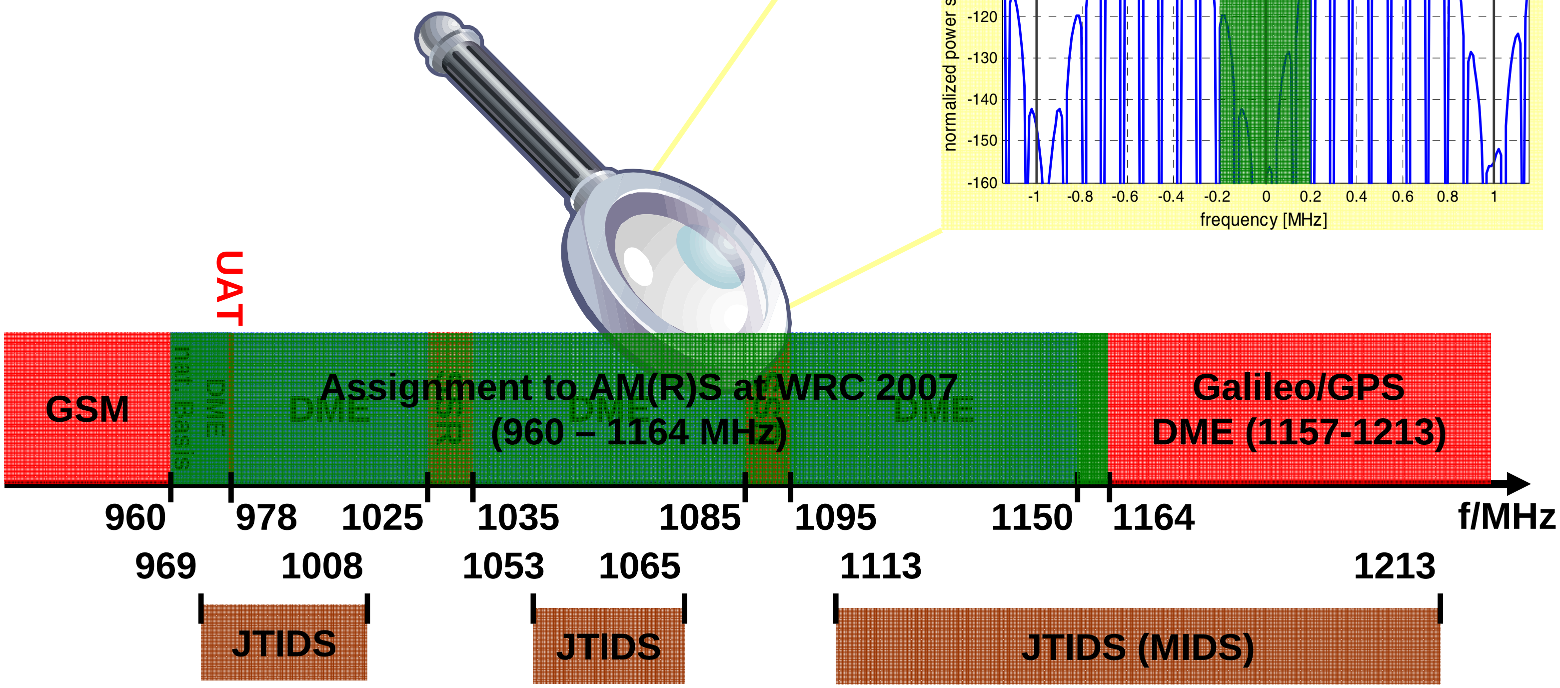
Introduction

- General B-AMC capabilities
  - B-AMC supports A/G and A/A communications
    - A/G communications centralized via ground station
    - A/A communications decentralized (not addressed here)
  - B-AMC supports data and voice communications
    - Focus is on data communications
    - Voice communications is a configurable option
  - B-AMC covers all ATS and safety-related AOC services
    - Extendable to non safety-related AOC, AAC (and APC?) services
  - B-AMC is designed to meet the requirements for future radio systems as defined in COCR document

PHY – Inlay Approach

- B-AMC is designed as inlay system



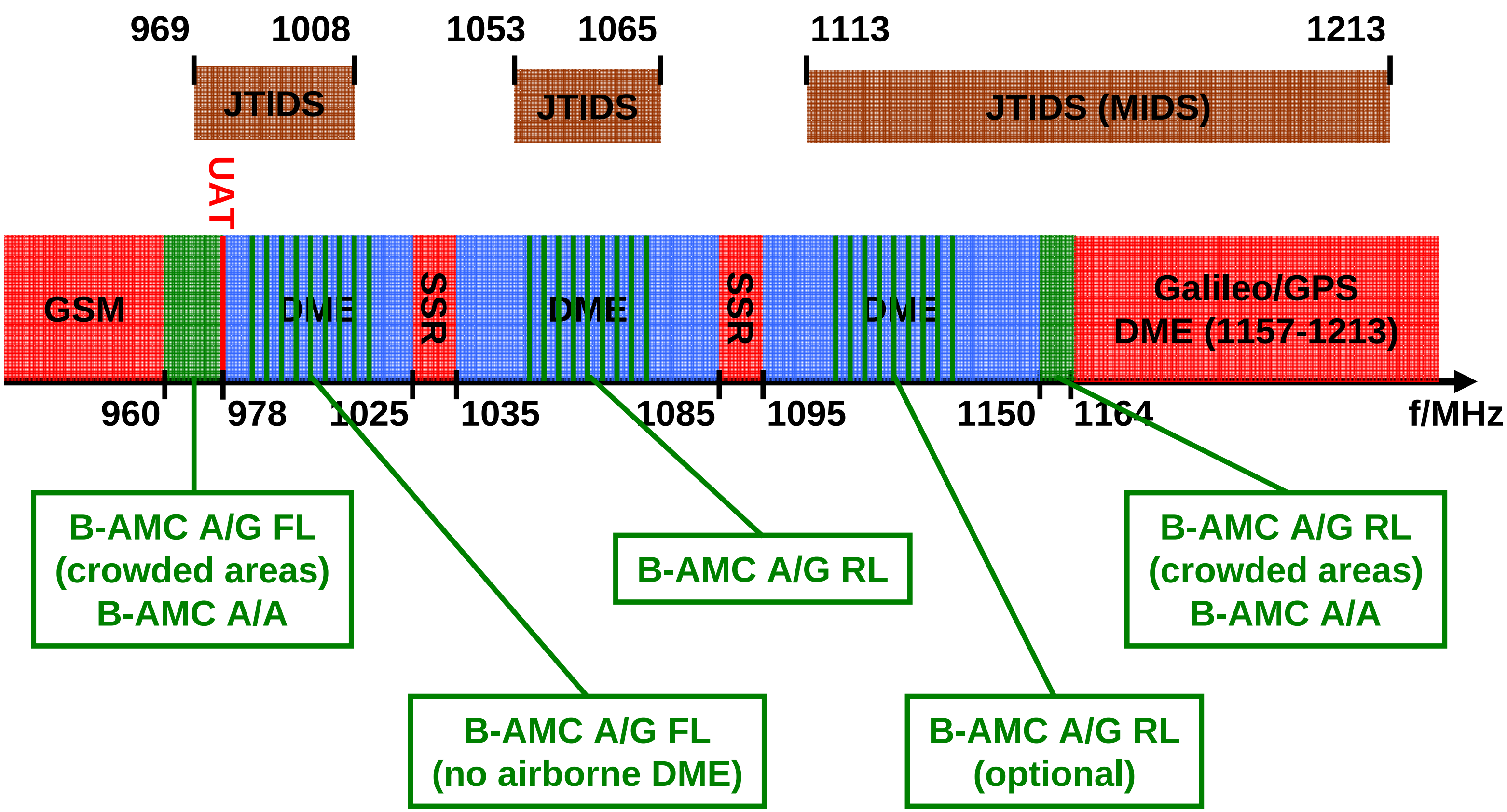


PHY – Inlay Approach

- Reasons for inlay approach
  - L-band is crowded (navigation and military communications)
  - Inlay approach requires no “green” spectrum
  - Make available as much bandwidth as possible in L-band
    - Future system shall cover data demand well beyond 2030
- Inlay approach is a challenging concept
  - B-AMC must not disturb existing L-band systems
  - Concept can be realized with standard techniques
- B-AMC is also applicable to “green” spectrum
  - Also “green” parts of assigned L-band spectrum might be used
  - No change of design required
  - Foreseen for very crowded areas and air/air mode

PHY – Inlay Approach

- B-AMC spectrum usage



PHY – System Design

- B-AMC is an FDD broadband system
  - Duplexing scheme is FDD (Frequency-Division Duplex)
    - Maximizes capacity per cell, since FL and RL are separated
    - Maximizes L-band spectrum utilization
  - System bandwidth per cell: 1 MHz
    - Bandwidth for FL and RL is 500 kHz each
    - B-AMC is a broadband system and bandwidth is a main feature
- B-AMC is based on OFDM
  - Standard OFDM like P34 (SAM) or WiMAX
  - Adaptive subcarrier modulation: QPSK, 8-, 16-, 64-QAM
  - Standard PAPR reduction, e.g. via "pilot phasing" like P34

PHY – System Design

- B-AMC main system parameter
  - Channel bandwidth: $B = 500$ kHz
  - Length of FFT: $N_c = 64$
  - Used sub-carriers: $N_{c,used} = 48$
  - Number of cancellation carriers: $N_{cc} = 2x2$
    - Side-lobe suppression
  - Sub-carrier spacing (500/48 kHz): $\Delta f = 10.416$ kHz
  - OFDM symbol duration with guard: $T_{og} = 120$ µs
  - OFDM symbol duration w/o guard: $T_o = 96$ µs
  - Overall guard time duration: $T_g = 24$ µs
    - RC-window (roll-off 0.1) for side-lobe suppression (12 µs)
    - Large remaining guard interval (12 µs)
  - OFDM symbols per data frame: $N_s = 54$

PHY – System Design

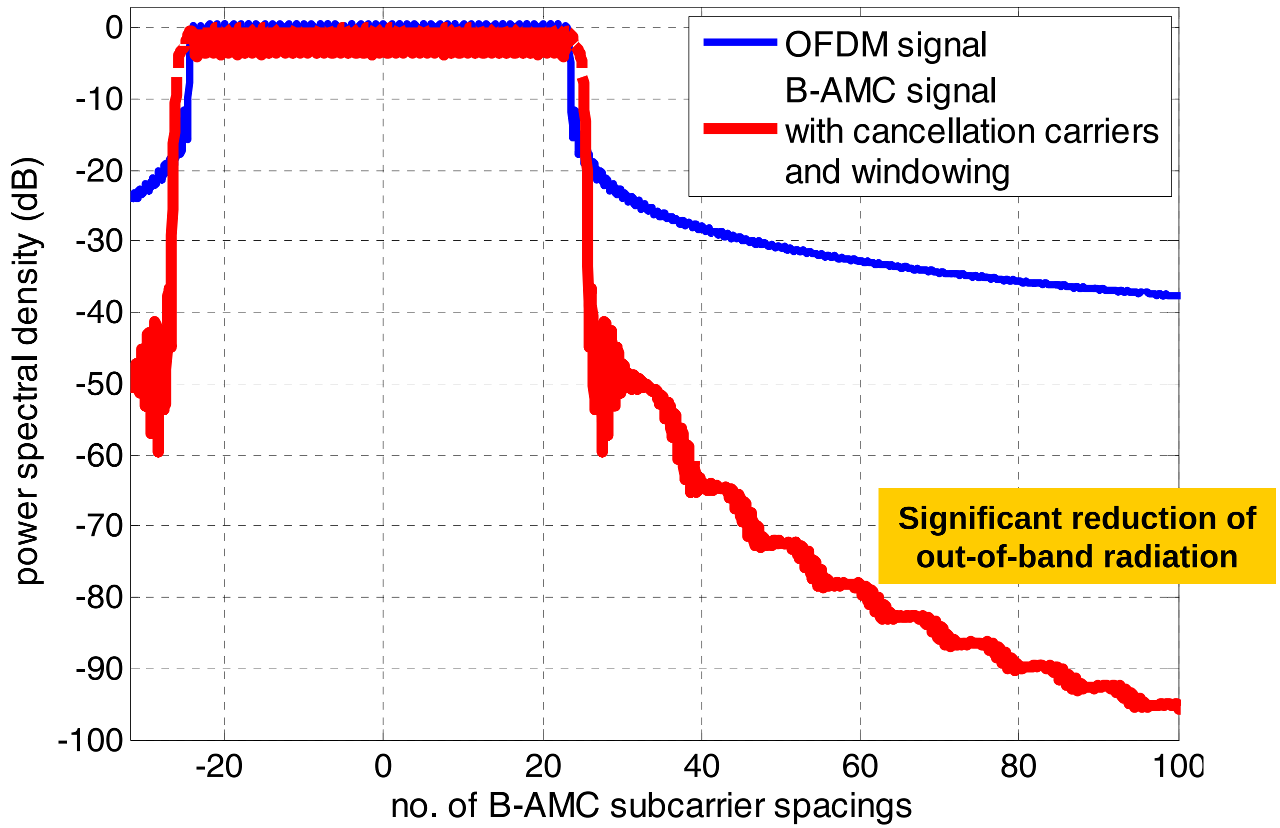
- B-AMC multiple-access scheme
  - Forward link: OFDM
    - Immediate access to resources in FL on packet-switched basis
    - FL data frame is shared by several messages to different AC
  - Reverse link: OFDMA/TDMA, similar to WiMAX
    - TDMA component in RL ensures low duty cycle
    - TDMA component reduces co-site interference impact
    - No fix resource assignments in RL, except for SA
    - RL data frame is shared by several users (OFDMA component)
- B-AMC adaptive modulation and coding
  - Allows adaptation to channel conditions
  - Net data rates from 270 kbit/s (most robust mode) to 1.4 Mbit/s

PHY – Coexistence as Inlay System

- B-AMC coexistence as inlay system in L-band
  - Frequency planning for B-AMC cells to minimize mutual interference between B-AMC and existing L-band systems
  - Interference reduction towards existing L-band systems
    - Transmit windowing
    - Sidelobe suppression using cancellation carrier
    - Transmit power control
  - Interference mitigation at B-AMC receiver
    - Receiver windowing
    - Code design and interleaving with respect to interference environment in L-band
    - Interference adjusted decoding with erasure setting
    - Pulse blanking

PHY – Coexistence as Inlay System

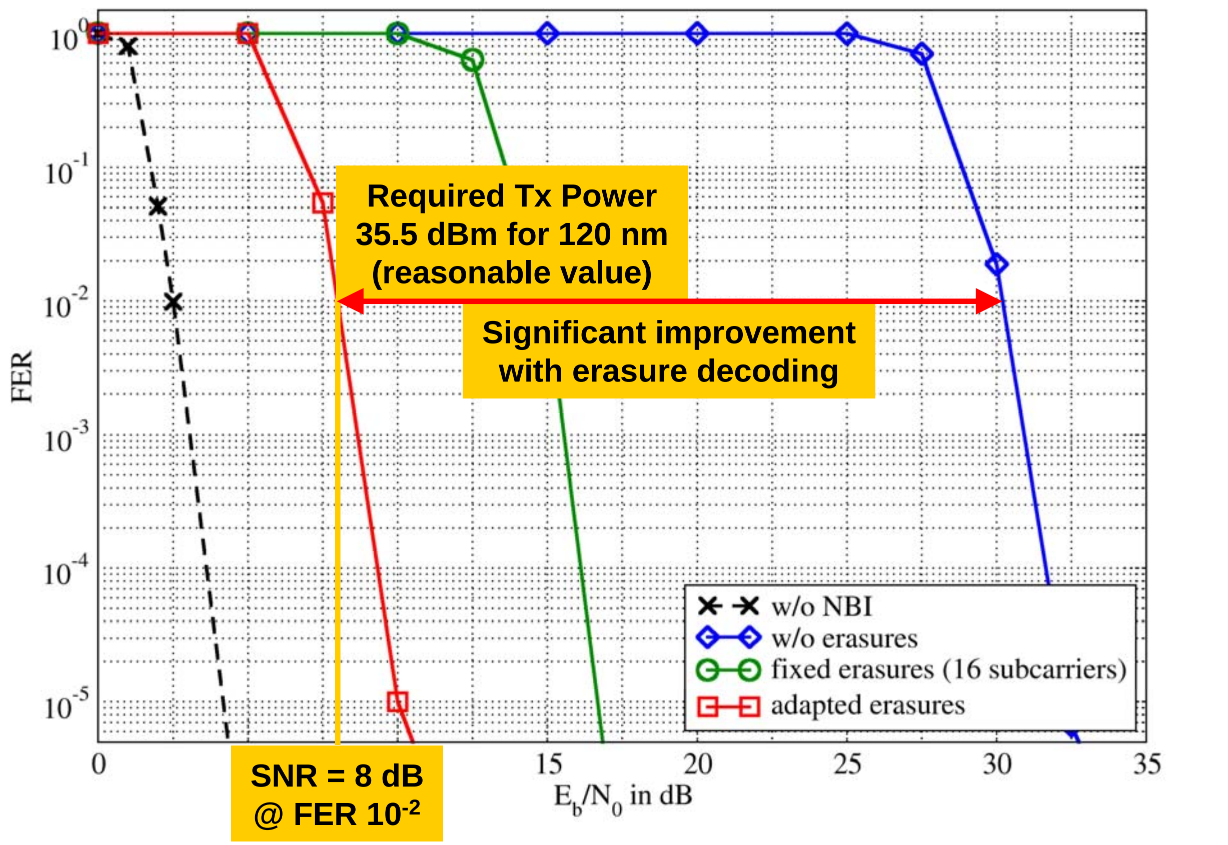
- B-AMC out-of-band radiation



PHY – Coexistence as Inlay System

- B-AMC performance in DME/TACAN interference

FL simulation, ENR scenario, CC+RS coding with erasures, no pulse blanking



PHY – Coexistence as Inlay System

- Simulated DME/TACAN interference towards B-AMC

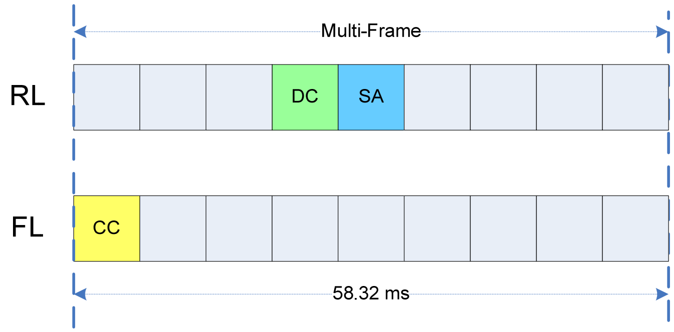
Station	Frequency [MHz]	Interference power at victim RX input	Pulse rate (ppps)
TACAN TACAN TACAN	994 994 994	-72.4 dBm -74.0 dBm -88.2 dBm	3600 3600 3600
TACAN	995	-67.9 dBm	3600
B-AMC	995.5		
TACAN TACAN	996 996	-74.0 dBm -90.3 dBm	3600 3600
DME DME DME DME DME TACAN	997 997 997 997 997 997	-81.6 dBm -86.5 dBm -85.7 dBm -88.1 dBm -82.5 dBm -68.9 dBm	2700 2700 2700 2700 2700 3600

Every third OFDM symbol affected

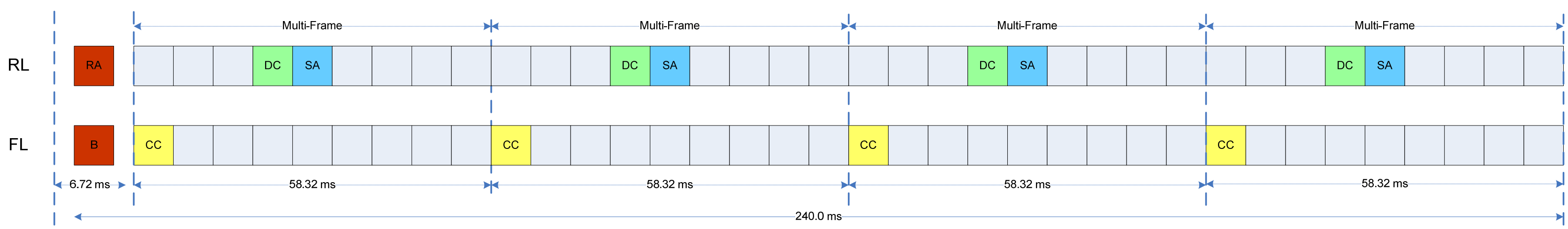
Nearly every OFDM symbol affected

DLL – Frame Structure

- The multi-frame has four types of slots
  - Data, common control (CC), dedicated control (DC), synchronized access (SA)

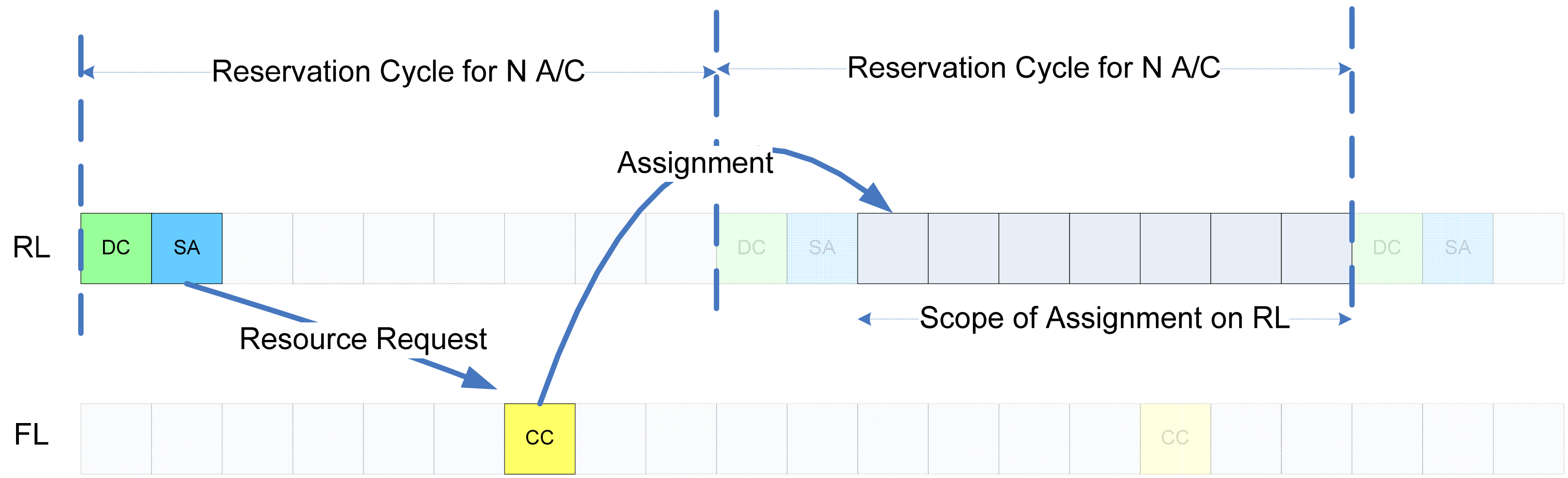


- Super-frame (240 ms duration)
  - Four multi-frames together with BC/RA slot



DLL – Resource Allocation

- Resources are requested by an A/C over the SACH in the SA slot
  - This creates a "Reservation Cycle"



  - The length of the reservation cycle is dynamically adjusted to the number of registered A/C ("breathing reservation cycle")
  - Each A/C has a dedicated SACH (using OFDMA in SA slot)

DLL – Resource Allocation

- B-AMC dynamically assigns different amounts of data capacity (“transport channels”) to different A/C

Traffic Channel Type	T48	T24	T12	T6	T3
QPSK Data Symbols	2304	1152	576	288	144
Coding Rate	0.44	0.44	0.44	0.43	0.41
Traffic Channel Capacity/slot (bits)	2027	1013	506	247	118
Available User Data Rate FL (kbit/s)	270.27				
Available User Data Rate RL (kbit/s)	236.48				

DLL – System Performance

- Performance evaluation for one representative case
  - COCR scenario "en-route large" with PIAC of 204 A/C
  - No QoS management (not yet implemented for simulations, but foreseen within B-AMC design)

	FL	RL	Required TD_{95}
Throughput	220.02 kbps	44.01 kbps	
Average latency	26 ms	531 ms	1400 ms
95%-quantile of latency (TD_{95})	39 ms	833 ms	1400 ms

- Previous evaluations have also shown that B-AMC can support almost all COCR scenarios
  - In the case of the COCR scenario "en-route super large" (400x400 nm) QoS management is required

Summary

- Inlay concept is a feasible approach which allows to use L-band efficiently for communications
- Mutual interference can be kept at acceptable levels
  - B-AMC performs well even under strong L-band interference
  - First (draft) frequency planning results indicate acceptable (mutual) interference conditions in most parts of Europe
- No fix resource assignments
  - No waste of resources
  - "Breathing reservation cycle" adapted to number of A/C
- Protocol simulations shows that B-AMC can support almost all COCR scenarios (even without QoS)
  - QoS management will further improve protocol performance

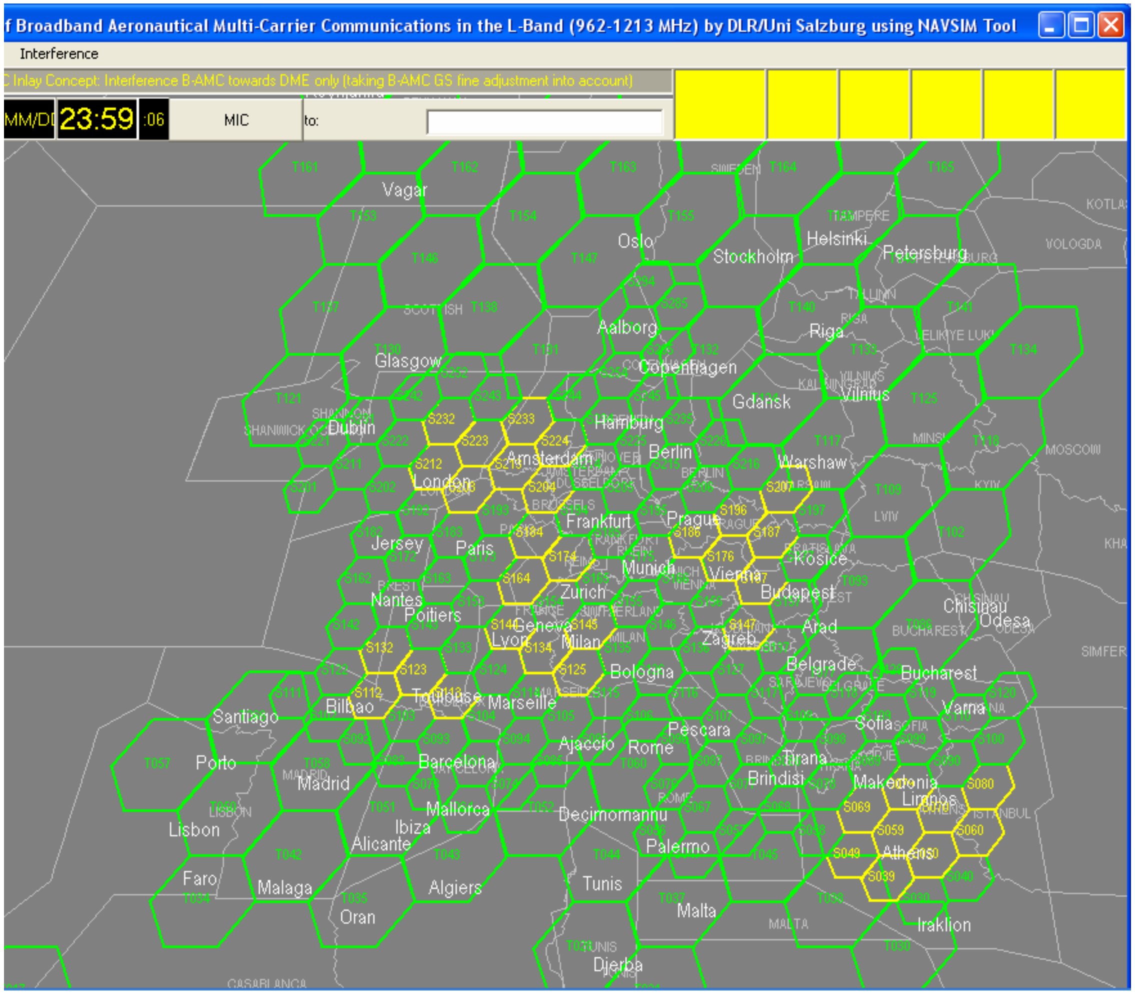
Outlook

- Further development on L-DACS 1 based on B-AMC combined with P34 standard
  - Coordinated L-DACS 1 design (B-AMC, P34) in cooperation with FAA/NASA/ITT
  - Improved interference mitigation at B-AMC receiver
  - Improved protocol implementing QoS management
- B-AMC/L-DACS 1 laboratory prototype development
  - Physical layer and protocol
  - RF front-end
- Laboratory interference testing
  - Prove co-existence with other L-band systems
  - Cooperation with DFS, measurements at DFS labs

PHY – Draft Frequency Planning

- Motivation: demonstrate feasibility of inlay concept
- Focus: B-AMC FL in sub-band 979-1019 MHz
  - Protection of airborne DME receivers
  - Protection of airborne B-AMC receivers
- Interference from ground B-AMC
  - Check level of interference power at DME receiver, i.e. is interference power at the closest possible airborne DME receiver operating at ±0.5, ±1.5, or ± 2.5 MHz offset < -106.6 dBm (very conservative assumption)
- Interference from ground DME
  - Check worst interference occurring in the considered cell, i.e. is expected FER < 10^{-2} within whole cell

PHY – Draft Frequency Planning



- First approach: 120 nm cells
  - Interference from DME acceptable
  - Interference on DME sometimes too high
- Second approach: 120/60 nm cells
  - Interference on DME acceptable in most cells (green)
  - In some cells, 12 dB margin would have to be reduced by 6 dB (yellow)