Evaluation of downlink IEEE802.16e communication at airports

Jan Erik Håkegård, Tor Andre Myrvoll

{jan.e.hakegard, tor.andre.myrvoll}@sintef.no

Outline

- Background
  - Why airport communication at 5 GHz
  - Mobile WiMAX (OFDMA)
  - SECOMAS project
- Impact of channel parameters on system performance
  - Path loss
  - Fading amplitude statistics
  - Multipath delay spread
  - Doppler spread
  - Spatial correlations
- Conclusions

C-band
Airport communications

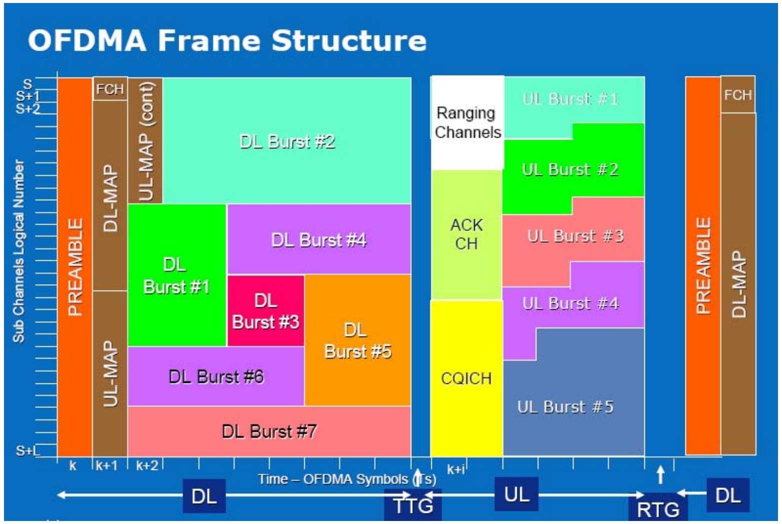
Recommendation from SESAR and NextGen:
Develop an aeronautical Mobile WiMAX profile

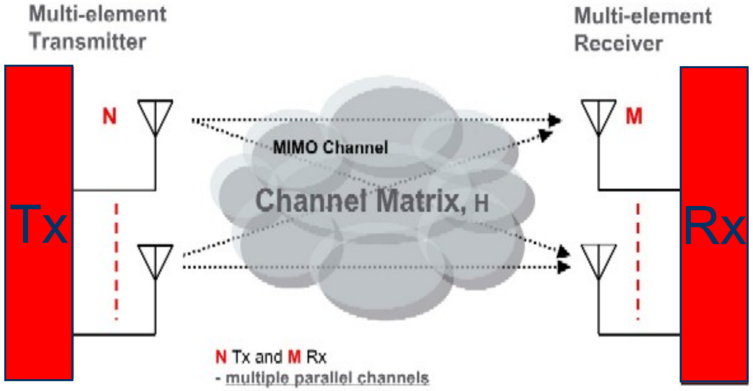
Procedure:

1. Identify how aeronautical utilization of the technology differentiates from other utilizations
   - Frequencies/bandwidths/channelization
   - Propagation conditions (environment)
   - Services (ATS, AOC, APS, others)
2. Identify the portions of the IEEE 802.16e (and future IEEE 802.16m?) standard and parameter settings that are best suited
3. Identify and develop missing required functionalities if any
4. Evaluate and validate the performance through trials and test bed development
5. Propose an aviation specific standard

IEEE802.16e (Mobile WiMAX)

- Technically advanced standard
  - Includes state-of-the-art communication techniques and signal processing
- Key properties:
  - OFDMA
    - Scalability (1.25 – 20 MHz bandwidth)
  - Adaptive coding and modulation
    - Flexibility in range and throughput
  - MIMO
    - Space time coding
      - Diversity gain
    - Spatial multiplexing
      - Increased capacity





SECOMAS project

- Nationally funded R&D project running from 2007 to 2010
- Cooperation between:
  - SINTEF
  - NTNU (University of Trondheim)
- Two paths:
  - Industrial
    - Airport communications
    - Aeronautical satellite communications in northern latitudes
  - Theoretical
    - OFDM + (distributed) MIMO with limited feedback/inaccurate channel estimations in an aeronautical setting

SECOMAS project
Airport communications

- Developed a simulator of mobile WiMAX for airport communications including
  - OFDMA physical layer
  - DL-PUSC communications
  - Flexible FFT size
  - All mandatory coding and modulation schemes
  - Adaptive antenna systems
    - 2x1 and 2x2 Space Time Coding (STC)
    - 2x2 Spatial Multiplexing (SM)
  - Airport environment channel models (Weibull, Rayleigh)

- Goals
  - Assess performance (range, capacity) based on BER simulations
  - Gain more insight into mechanisms determining system performance
  - Identify suitable portions of the standard for airport communications

Propagation channel modeling

- *Channel models capture typical channel characteristics for specific communication technologies in specific types of environments*

- Depend on
  - Transmit signal (carrier frequency, bandwidth, antenna systems,..)
  - Propagation environment (urban, sub-urban, rural, airport,…)
  - Mobility of transmitter and receiver

- *Design of new communication systems requires assessment and possibly development of new channel models*

Channel models for airport environment

- 5 GHz band: ”Ohio University report[1]”
- Three types of airports
  - Large
  - Medium
  - Small (General aviation)
- Three propagation regions within airports
  - Near gate (NLOS)
  - Near terminal buildings (NLOS-S)
  - Runways (LOS)

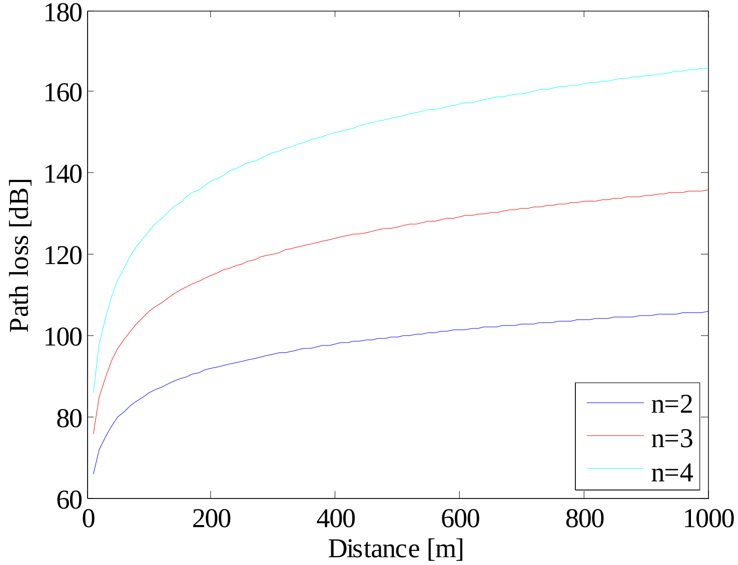
[1] Matolak, David W., May 2006, Wireless Channel Characterization in the 5 GHz Microwave Landing System Extension Band for Airport Surface Areas, Ohio University.

Propagation channel characteristics

- Path loss

  Important for network planning

- Fading amplitude statistics
- Multipath delay spread
- Doppler spread
- Spatial correlations



n: exponential loss factor

- n = 2: free space loss
- n ~ 3-4: urban areas

Propagation channel characteristics

- Path loss
- Fading amplitude statistics
  Important for ACM
- Multipath delay spread
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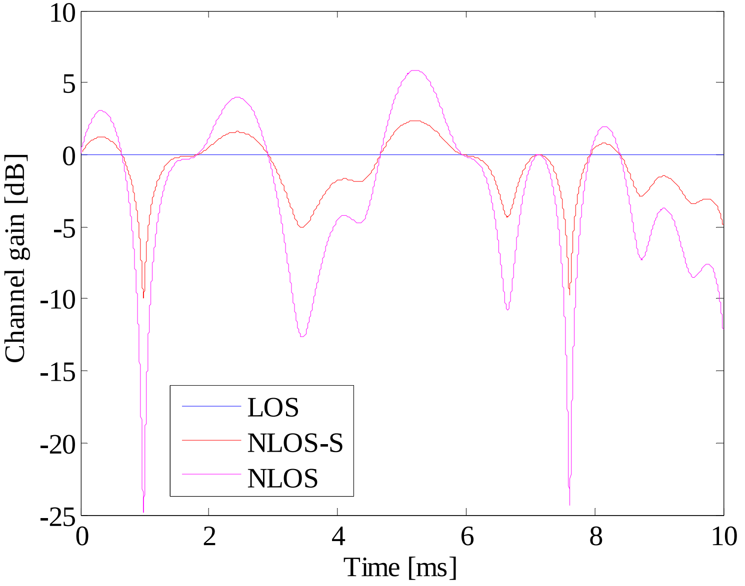
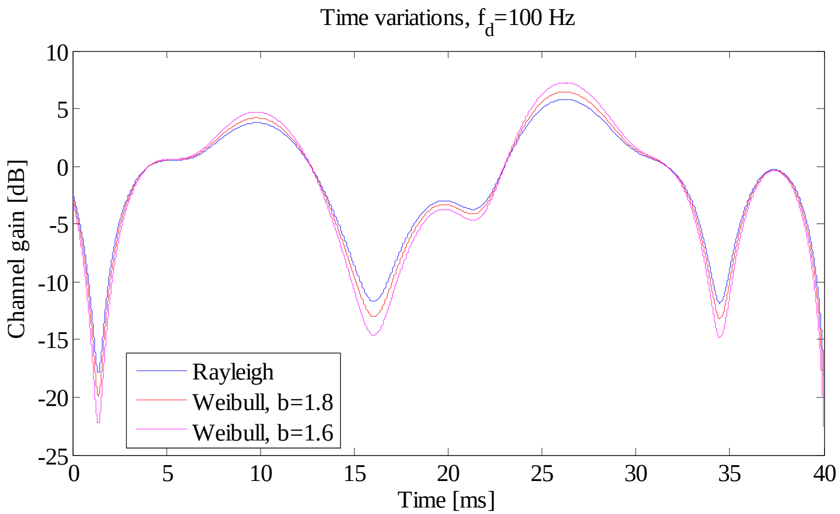
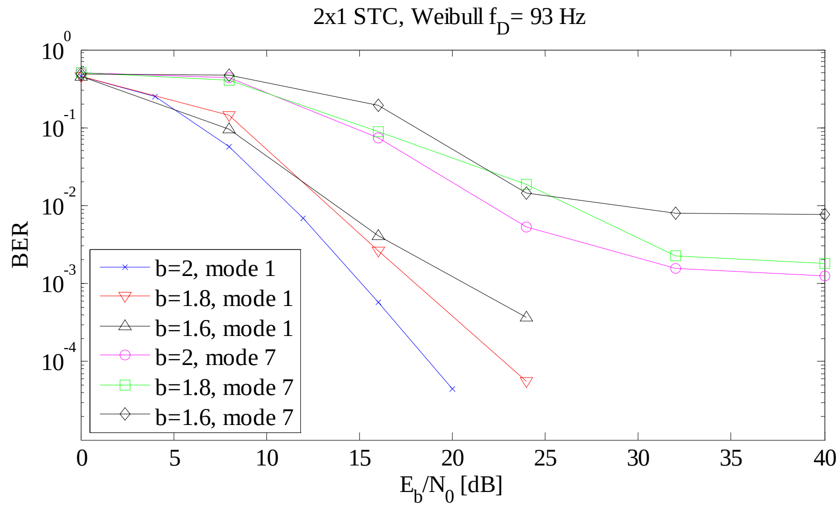


Fading amplitude statistics

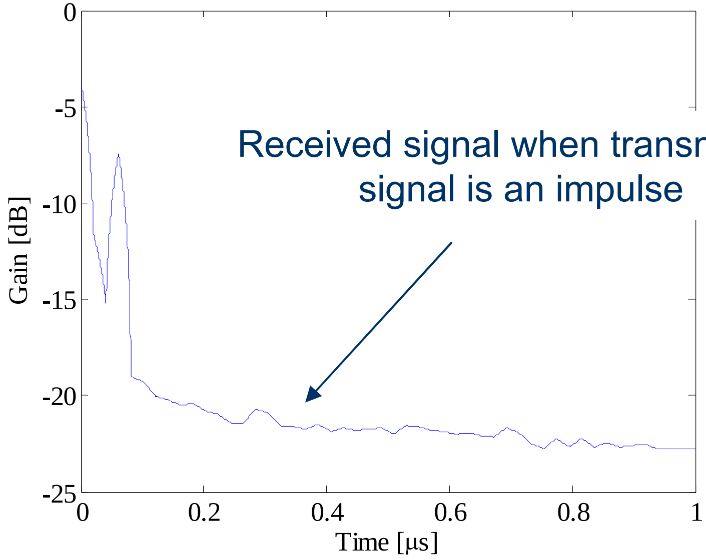
- NLOS
  - ”Worse than Rayleigh”
    - Weibull b={1.6, 1.8}
  - Lower b-value leads to deteriorated BER performance
  - Different optimal thresholds for ACM compared to Rayleigh channel
- NLOS-S/LOS
  - Better BER performance than Rayleigh channel





Propagation channel characteristics

- Path loss
- Fading amplitude statistics
- Multipath delay spread
  - *Important for size of FFT and cyclic prefix*
  - *Important for channel estimation*
- Doppler spread
- Spatial correlations

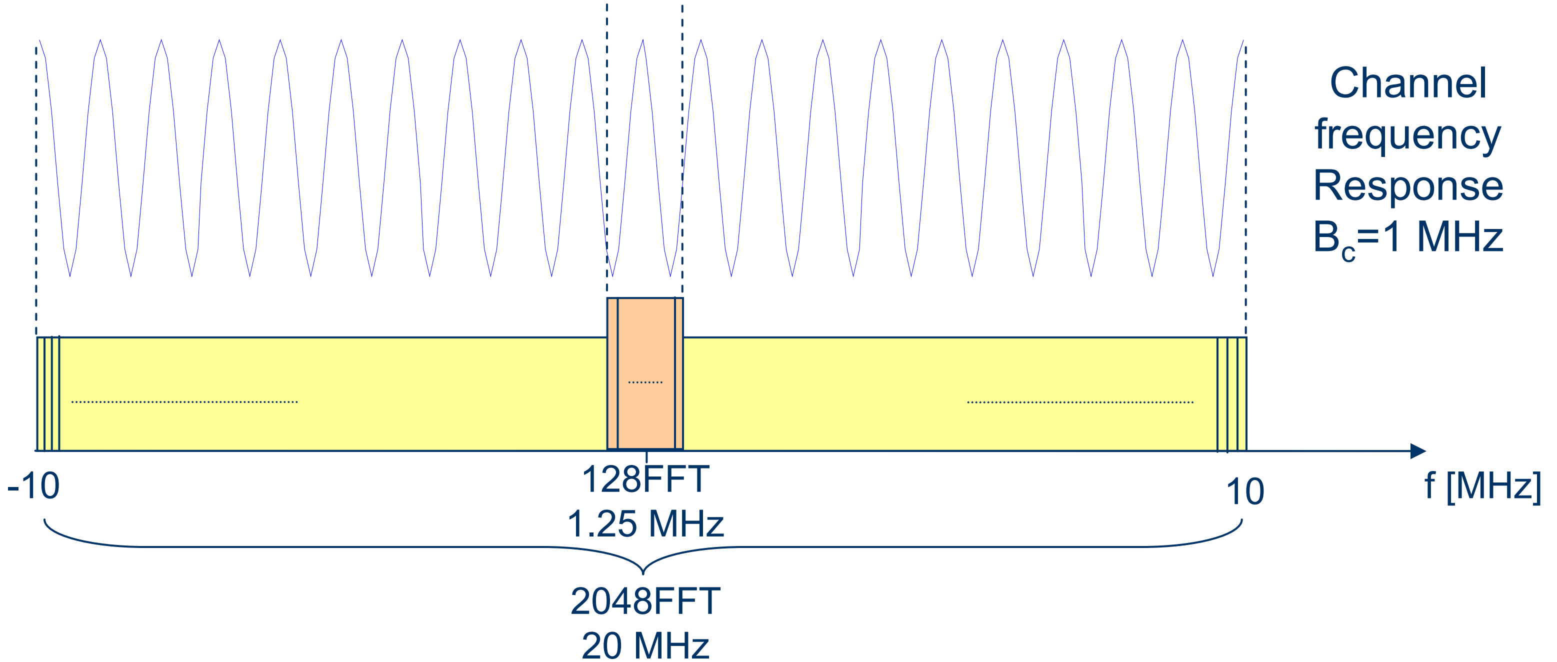


Multipath delay spread
Airport

- Delay spread large airport
  - Typically $\tau \approx 1\ \mu s$
  - Worst case significantly longer
- Coherence bandwidth
  - Related to delay spread
    - $B_c \sim 1/\tau \sim 1$ MHz
  - Narrowband communication
    - $B \ll B_c$
  - Frequency selective communications
    - $B \gg B_c$

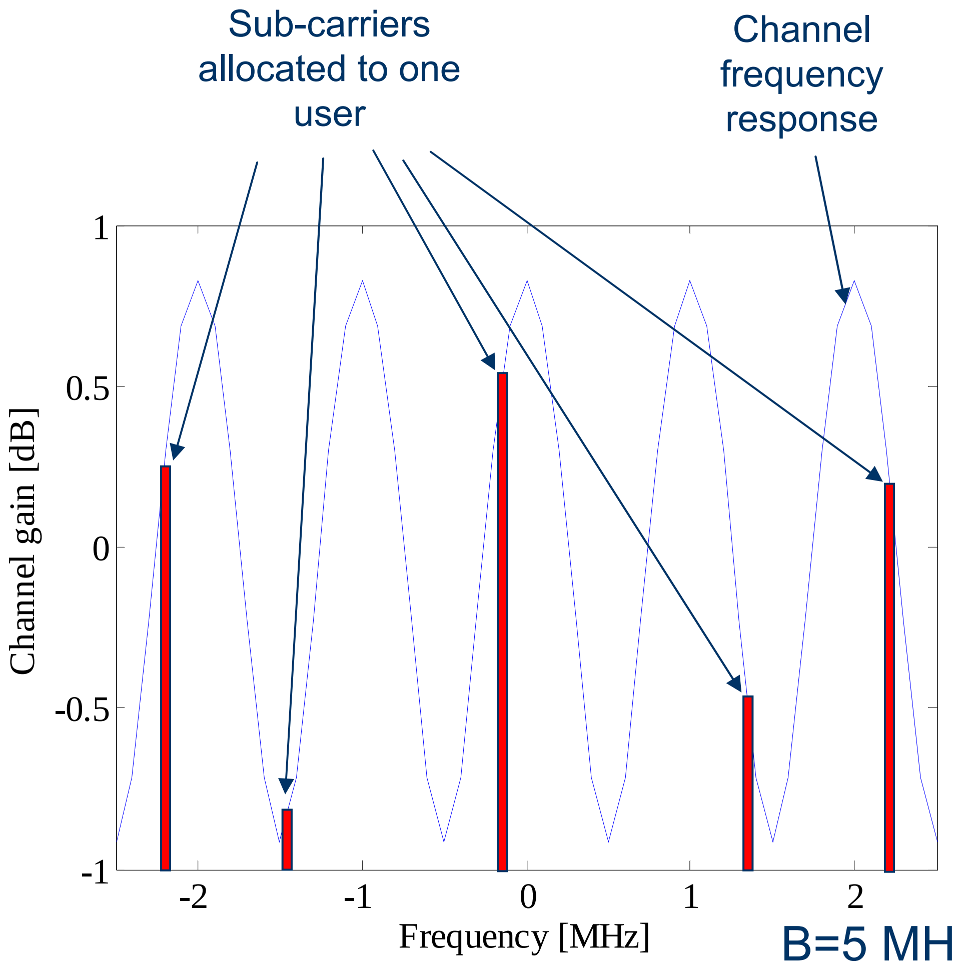
Size of FFT vs. multipath delay spread

- OFDMA PHY of IEEE802.16e standard:
  - 1.25 MHz ≤ B ≤ 20 MHz
- 1.25 MHz WiMAX channel: frequency dispersive fading
- 20 MHz WiMAX channel: very frequency dispersive fading
- Larger bandwidths potentially increase frequency diversity gain in NLOS environments



Sub-carrier allocation providing frequency diversity gain

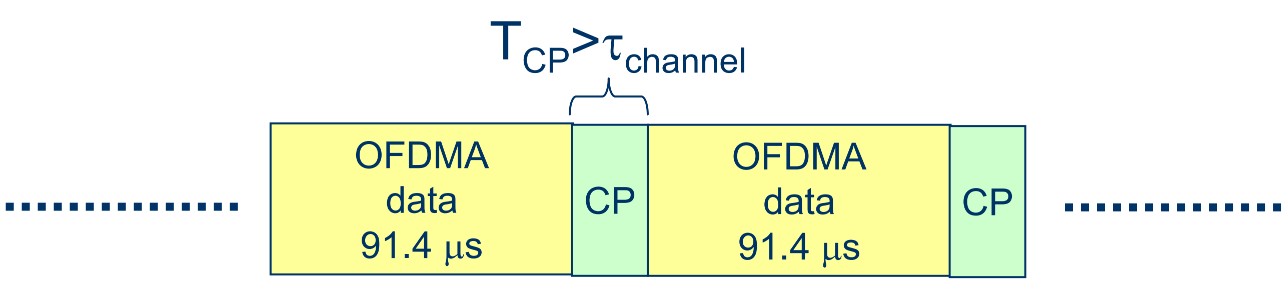
- Distributed sub-carriers
  - PUSC
  - FUSC
- FEC
  - Recovers errors due to sub-carriers experiencing bad channel conditions
- Frequency diversity gain



B=5 MHz

Size of cyclic prefix (CP) vs. multipath delay spread

- $T_{OFDM\text{-}symb}$ =91.4 μs (without CP)
- No ISI: $T_{CP} > \tau_{channel}$
- CP lengths as function of OFDMA symbol length:
  - 1/4: 22.8 μs
  - 1/8: 11.4 μs
  - 1/16: 5.7 μs
  - 1/32: 2.8 μs



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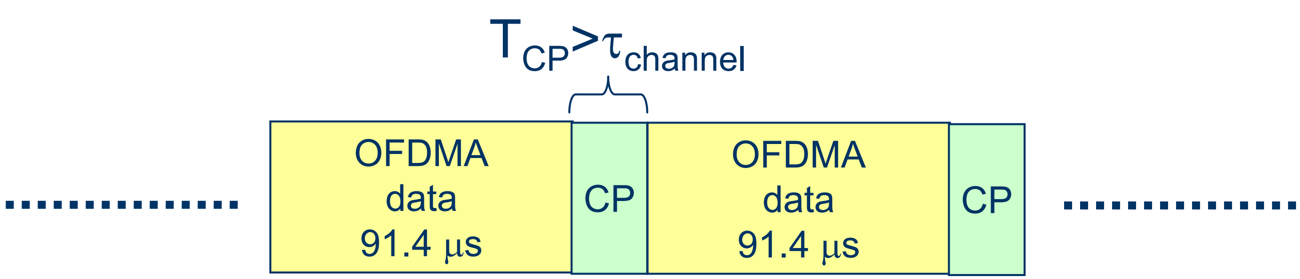
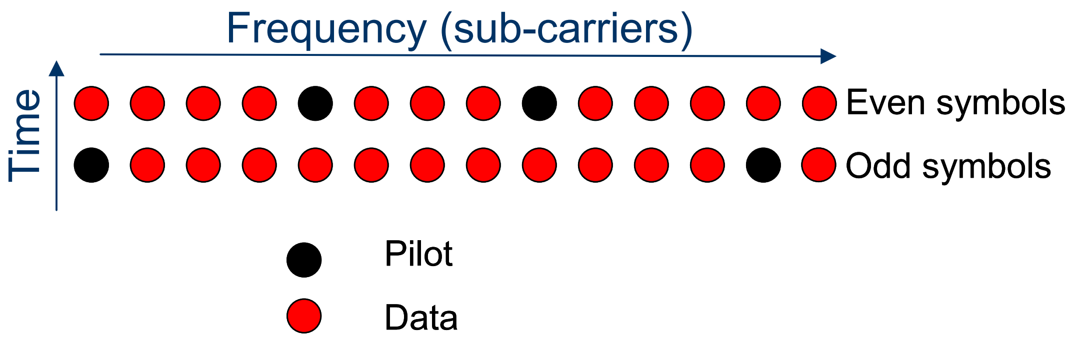


Channel estimation

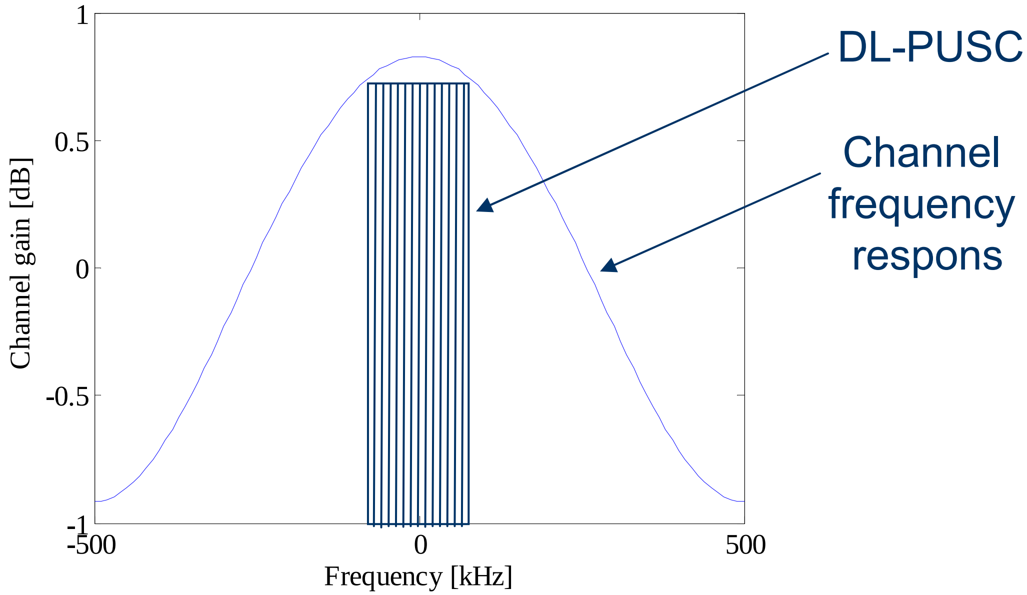
- Using pilot symbols
- Interpolating between pilots
- Estimation error depends on:
  - Frequency selectivity (multipath delay spread)
  - Time variation (Doppler spread)

DL-PUSC cluster
• 14 sub-carriers
• 2 OFDMA symbols



Channel estimation vs. frequency selectivity

- DL-PUSC
  - Sub-carriers spacing: 10.94 kHz
  - Clusters formed by 14 sub-carriers
  - Bandwidth of cluster:153 kHz
  - Coherence bandwidth (NLOS): 1 MHz



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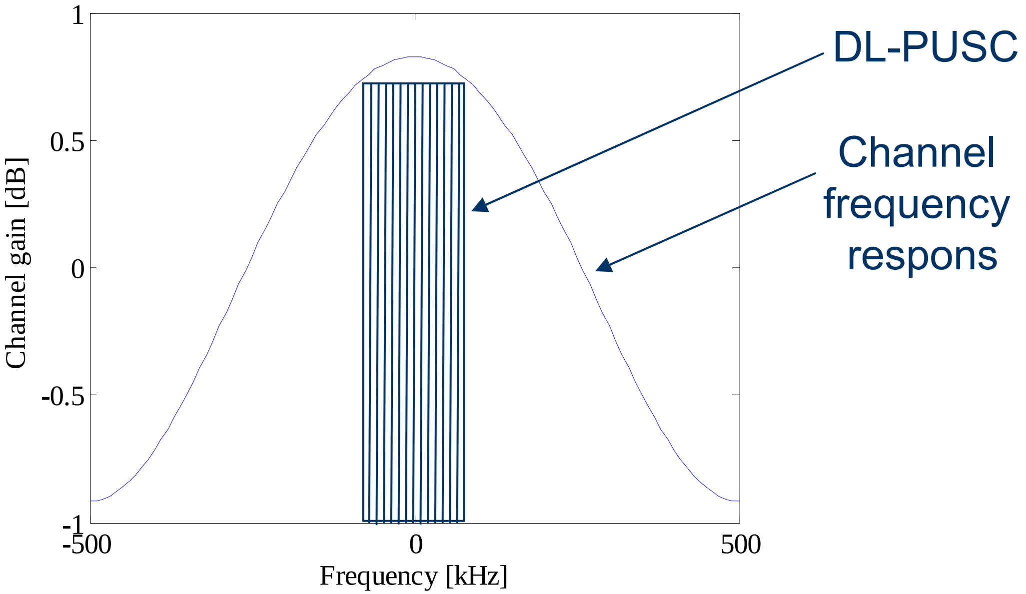
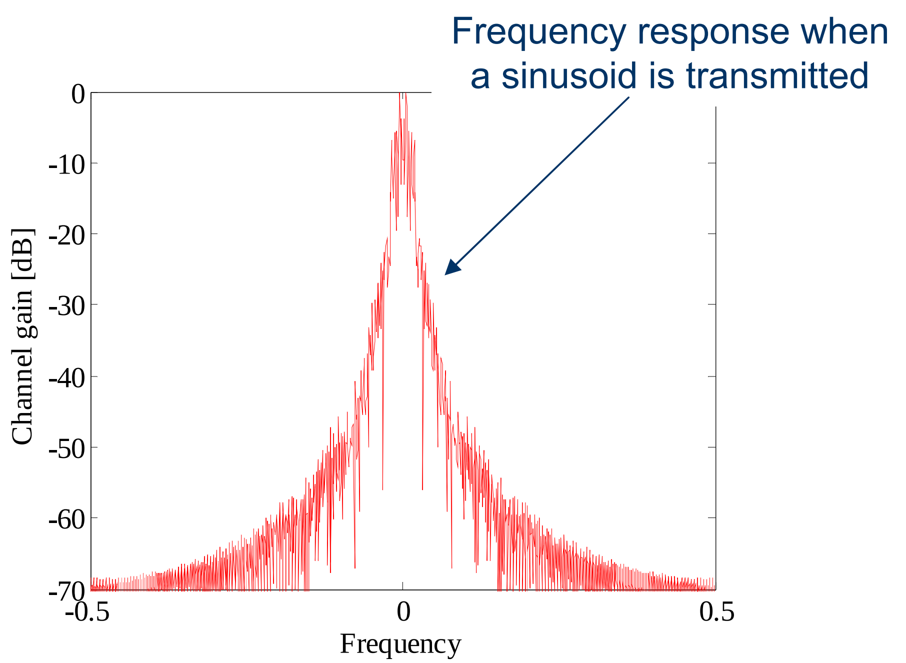


Mildly frequency selective channel

Propagation channel characteristics

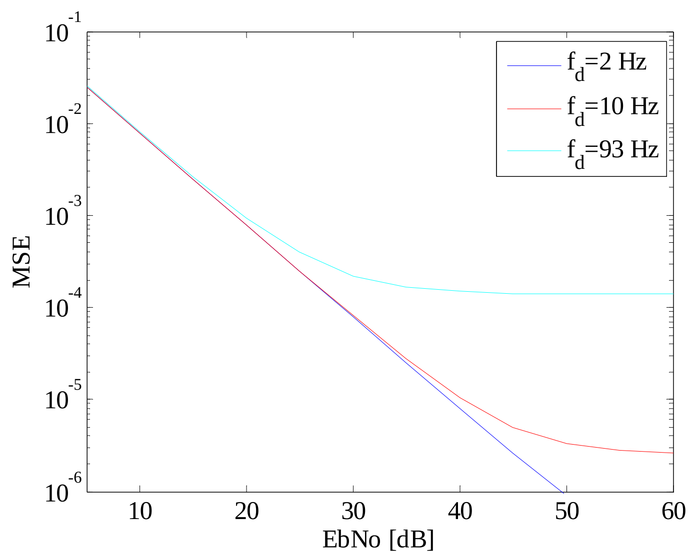
- Path loss
- Fading amplitude statistics
- Multipath delay spread
- Doppler spread
  - *Important for channel estimation*
- Spatial correlations



Channel estimation vs. time variations

- DL-PUSC
  - Length of OFDMA symbol: ~100 μs
  - Near gate: v ≤ 5.5 m/s → f_d ≤ 93 Hz
    - Normalized Doppler spread: 93·100 μs=0.93 % → slow fading
  - Every second OFDMA symbol contain pilot symbols

Piecewise linear interpolators



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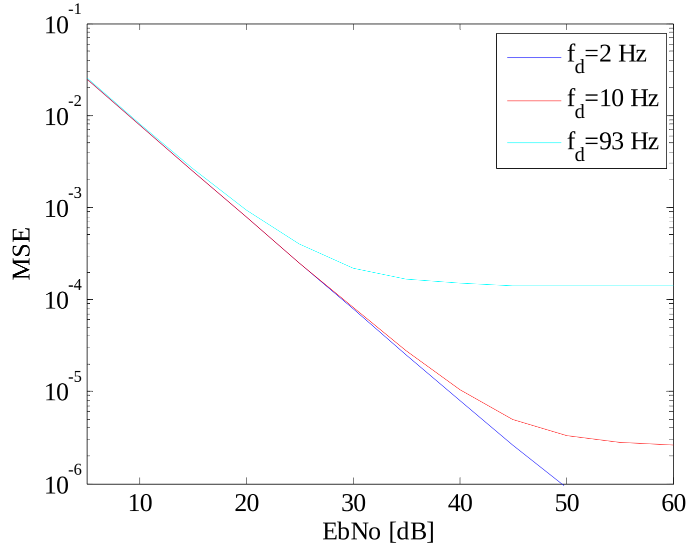
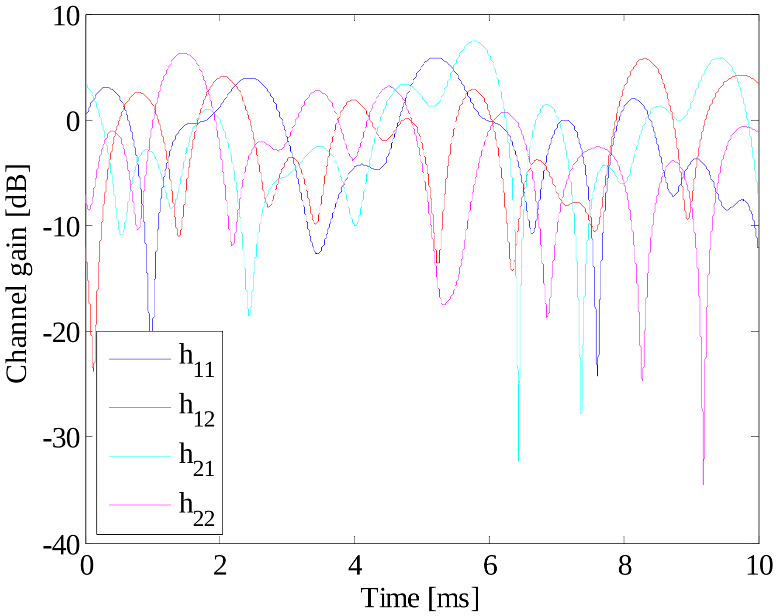


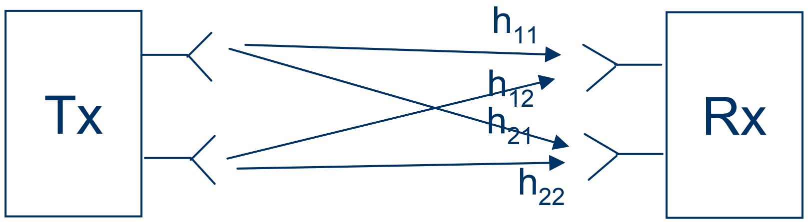
Gives rise to error floor in particular for high Doppler spreads

Propagation channel characteristics

- Path loss
- Fading amplitude statistics
- Multipath delay spread
- Doppler spread
- Spatial correlations

  Important for MIMO techniques



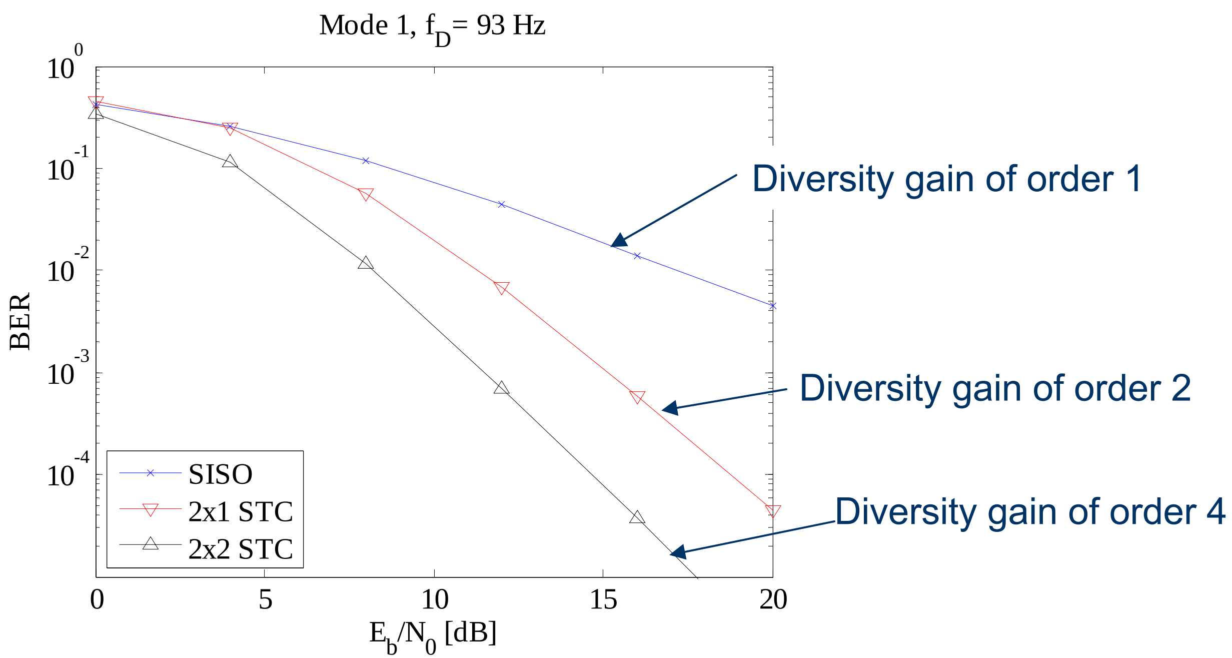


MIMO techniques

- 2x2 Space time coding (STC)
  - ”Matrix A”
  - Diversity gain: factor 4
  - Coding rate 1
- 2x2 Spatial Multiplexing (SM)
  - ”Matrix B”
  - Diversity gain: factor 2 (ML decoding)
  - Coding rate 2
- Diversity/multiplexing gain depends on correlation between channel matrix elements
  - Complete correlation: no gain
  - Complete decorrelation: maximum gain

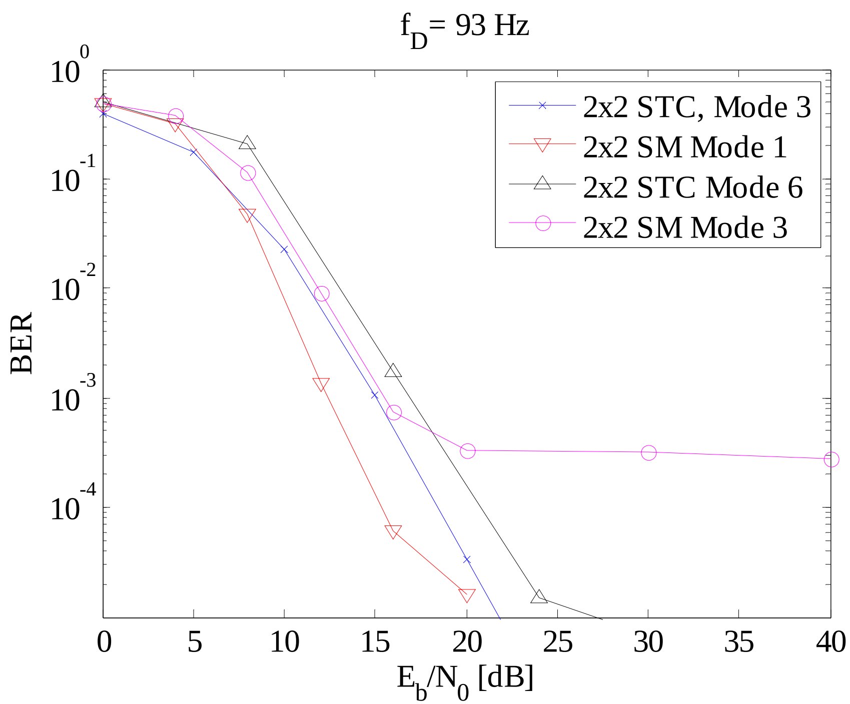
MIMO techniques
Diversity gain

- Assuming complete decorrelation
  - NLOS conditions
  - Sufficiently large antenna spacing
    - d>λ/2 ~ 3 cm at 5.1 GHz



MIMO techniques
Comparison STC/SM

- Number of info bits per symbol=2
  - 2x2 STC mode 3
  - 2x2 SM mode 1
- Number of info bits per symbol=4
  - 2x2 STC mode 6
  - 2x2 SM mode 3
- For equal number of info bits per symbol:
  - SM equal/better than STC in low SNR regions
  - SM more sensitive to channel estimation errors
    - More severe error floor



Conclusions

SECOMAS

- Developing a mobile WiMAX profile for airport communications requires significant work
  - Analysis, simulations and trials
  - Mobile WiMAX simulator for airport communications in 5 GHz band developed

- General considerations
  - Worse than Rayleigh channel conditions in NLOS regions may lead to less than expected range
  - Severe fading may be combated by
    - A wide channel bandwidth through frequency diversity gain
    - MIMO through spatial diversity gain
  - Mobility in NLOS regions degrades performance due to channel estimation errors
    - Time variations more critical than frequency selectivity
    - IEEE802.16m WG considers channel estimation schemes for high mobility (v=100 m/s)