



Performance Assessment of Navigation Signals in Realistic Multipath Environments

Bernhard Krach (DLR), Geraldine Artaud (CNES)



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





Outline

➤ Motivation

- DLR Land Mobile Satellite Channel Model
- Channel model reduction

➤ Simulation Setup

- User scenario
- Navigation signals
- Receiver types

➤ Simulation Results

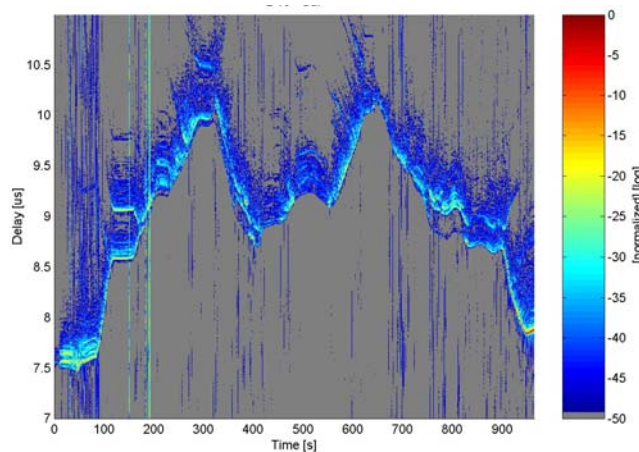
- Signal performance
- Reduction performance
- Mitigation performance



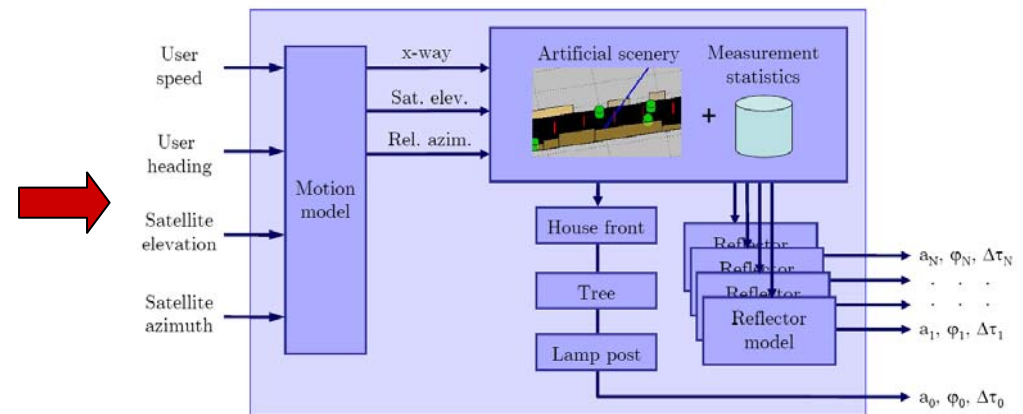


Motivation

- **Multipath** is still one of the most challenging problems in GNSS
- Hardware simulation with **realistic** models is of high interest (test & verification of novel signals and novel receiver processing algorithms)
- Latest multipath channel models have a high number of echoes (e.g. up to **60** in the DLR land mobile channel model)
- Usually hardware simulators are capable of simulating a **limited** number of simultaneous echoes only (e.g. $N=8$)



DLR measurement of the propagation channel in an urban environment



DLR channel model: Simulating realistic propagation conditions using a mixed deterministic & statistical approach



Approach

➤ Questions addressed

- Is it possible to reduce the channel model's of taps with acceptable errors? Do actually all echoes have an impact on the receiver behaviour?
- Is there still a benefit of novel navigation signals and novel mitigation algorithms under realistic propagation conditions?

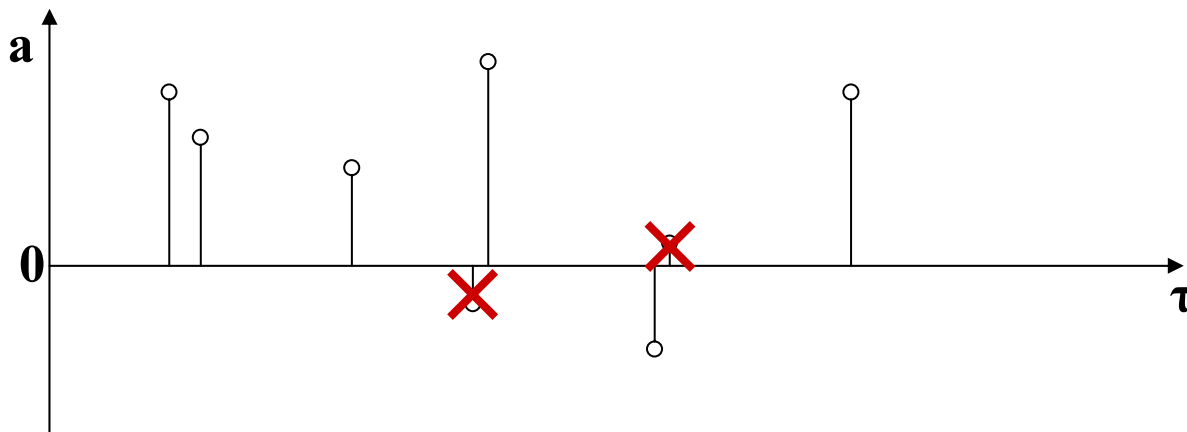
➤ Selected approach

- Carry out software simulation to study the impact of signals, algorithms & reduction methods
- Use of CNES J-GNSS software receiver as simulator (configured for multi-correlator output)
- Assessment of reduction methods, which depend on the channel realization only, i.e. which are applied on each generated channel impulse response **independently**



Reduction Method 1: Power-based Selection

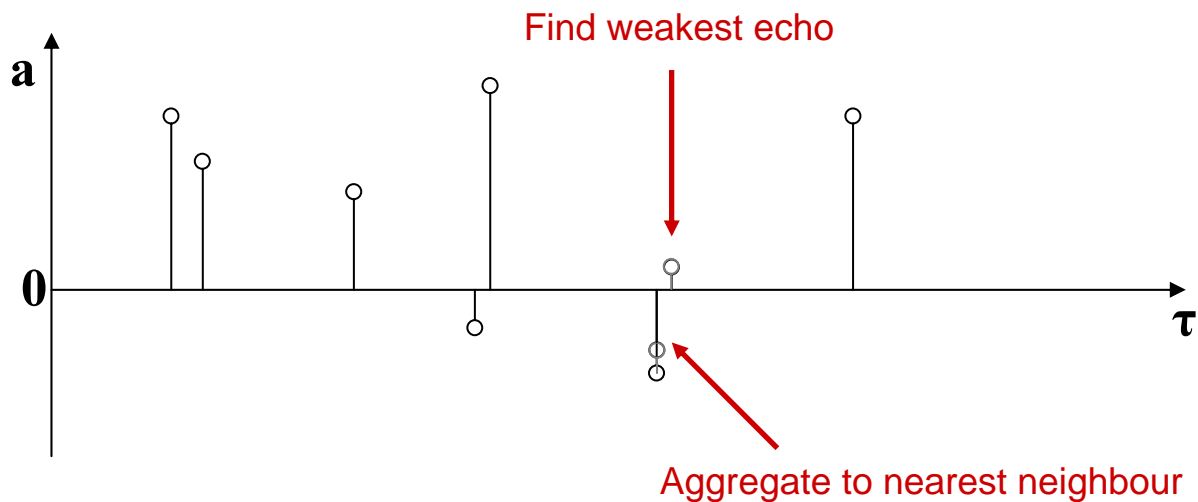
- **Selection of N most powerful taps**
 - Discard weak echoes





Reduction Method 2: Nearest Neighbour Aggregation

- **Aggregate weak echoes with nearest neighbours**
 - Iterative reduction method (Mehlführer, Rupp, *ICASSP 2008*)



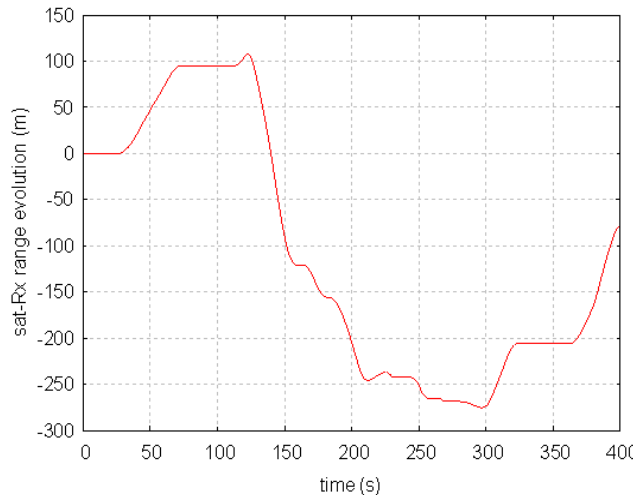
Repeat until desired number of echoes is reached



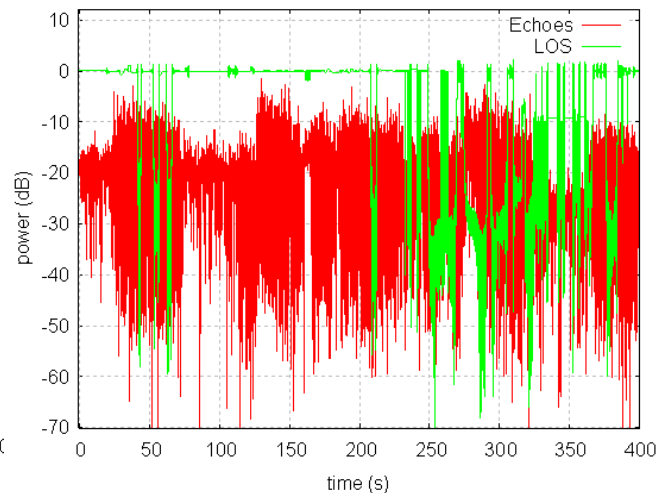
Channel Setup

➤ Scenario

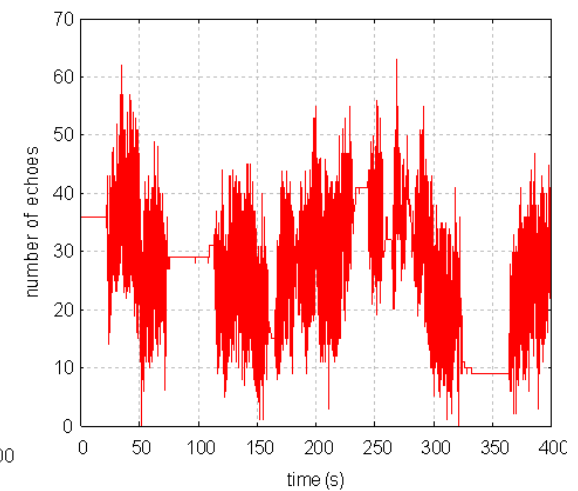
- Dynamic vehicular user (speed & azimuth profiles obtained from measurement data)
- Urban environment, 50 degrees elevation, nominal $C/N_0 = 50$ dB-Hz
- LOS and non-LOS conditions
- Channel reduction down to 8 taps



SV-Rx range evolution



LOS & Echo Power

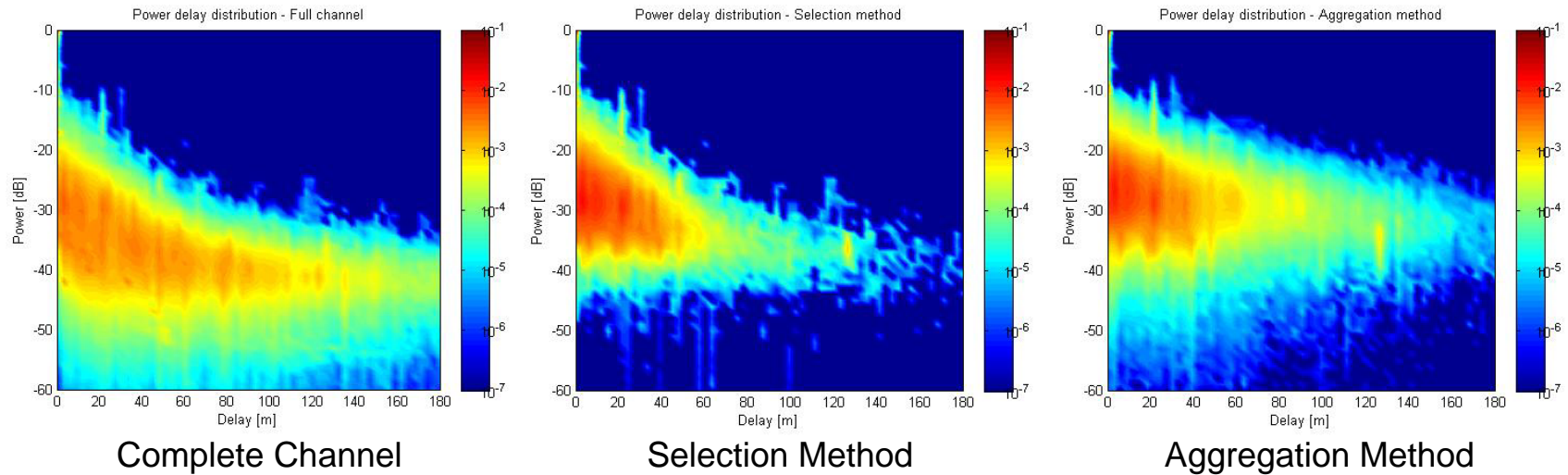


Number of echoes



Reduction & Channel Characteristics

➤ Power Delay Profiles



➤ Mean Values

	Mean Delay [m]	Mean Power [dB]
Complete Channel	43,7	-35,8
Selection Method	15,8	-26,8
Aggregation Method	20,4	-25,8



Navigation Signals

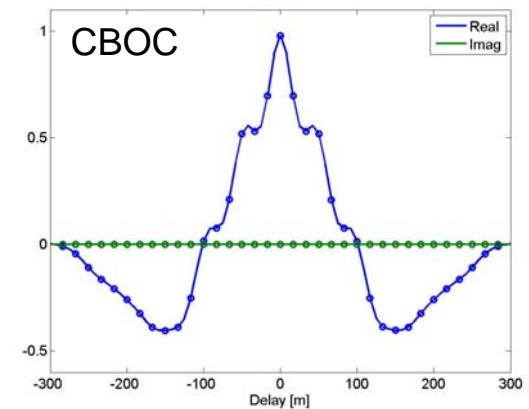
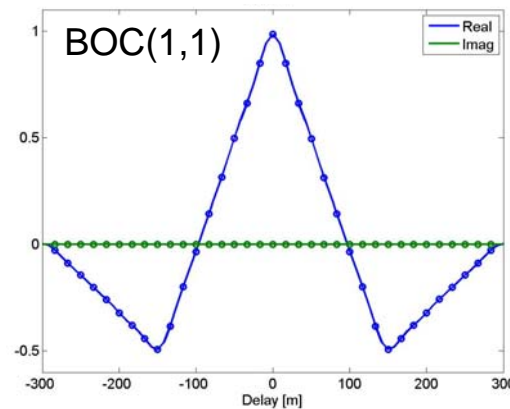
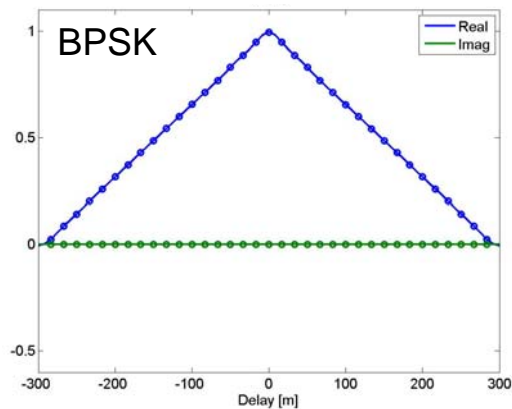
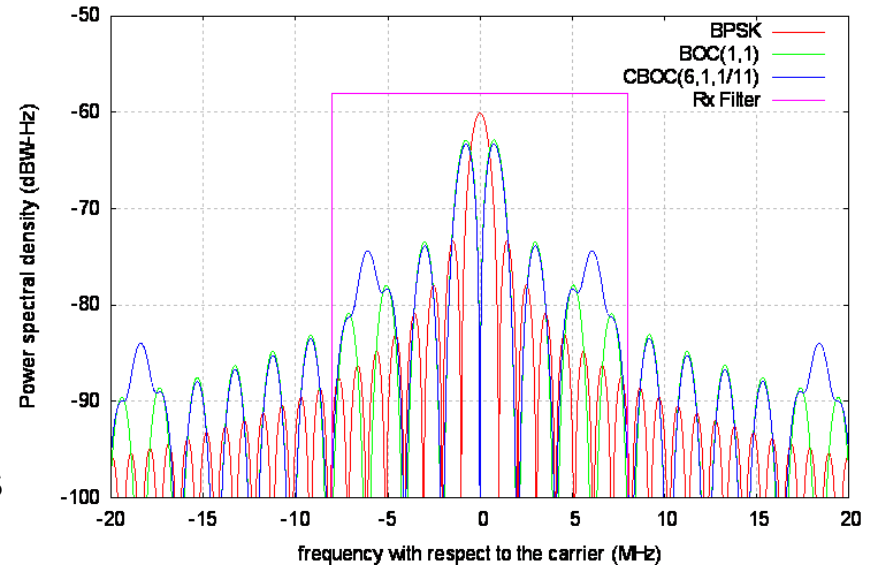
➤ Modulations

- BPSK
- BOC(1,1)
- CBOC(6,1,1/11), Pilot

➤ Parameters

- Gold code of length 1023
- Chipping Rate 1.023 MChips/s
- Rx-Filter Bandwidth 8 MHz

➤ Correlation Functions





Receivers

- **Standard receiver**
 - DLL, 1 Hz loop bandwidth
 - Dot-product discriminator
 - Narrow early/late correlator spacing
- **Maximum Likelihood (ML) receiver**
 - Comparable to MEDLL, ...
 - 100 ms observation period
 - Newton-type optimization
 - Likelihood-Ratio test for path detection
- **Bayesian Minimum Mean Square Error (MMSE) receiver**
 - Particle filter implementation
 - Update rate 10 Hz (100 ms observation)

Multipath Signal Model:

Received Signal = Superposition of LOS and replica + Noise

$$z(t) = \sum_{i=0}^N e_i(t) a_i(t) s(t - \tau_i(t)) + n(t)$$

τ_i : time delays
 a_i : complex amplitudes
 e_i : path activities (0 or 1)

Likelihood

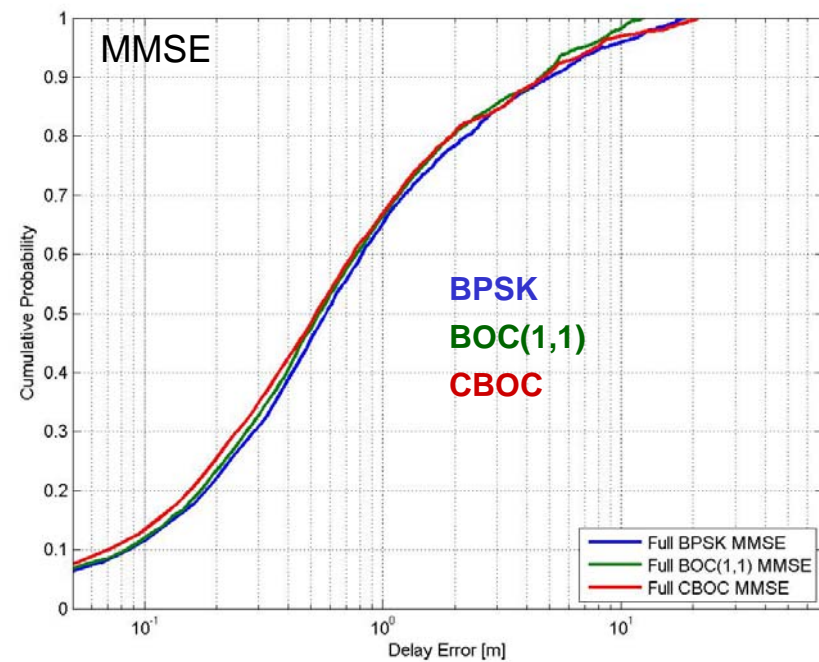
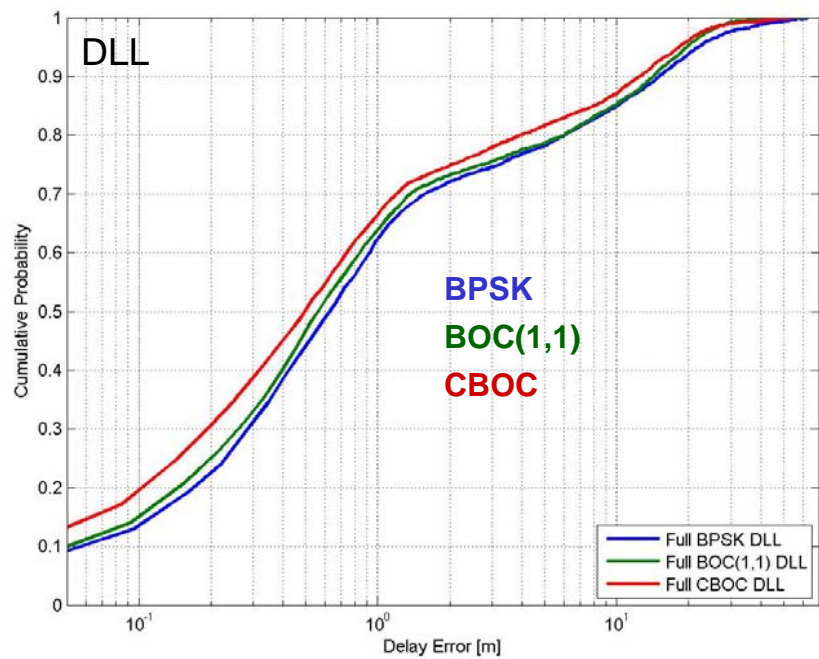
$$\{\hat{\boldsymbol{\tau}}_k^{ML}(\mathbf{e}_k), \hat{\mathbf{a}}_k^{ML}(\mathbf{e}_k)\} = \arg \max_{\mathbf{a}_k, \boldsymbol{\tau}_k} p(\mathbf{z}_k | \boldsymbol{\tau}_k, \mathbf{e}_k, \mathbf{a}_k)$$

$$p(\boldsymbol{\tau}_k, \mathbf{e}_k, \mathbf{a}_k | \mathbf{Z}_k) = \frac{\overset{\text{Likelihood}}{p(\mathbf{z}_k | \boldsymbol{\tau}_k, \mathbf{e}_k, \mathbf{a}_k)} \overset{\text{Prior}}{p(\boldsymbol{\tau}_k, \mathbf{e}_k, \mathbf{a}_k | \mathbf{Z}_{k-1})}}{\overset{\text{Posterior}}{p(\mathbf{z}_k | \mathbf{Z}_{k-1})}}$$



Results: Signal Performance

➤ **Signal performance:** Complete channel, different receivers

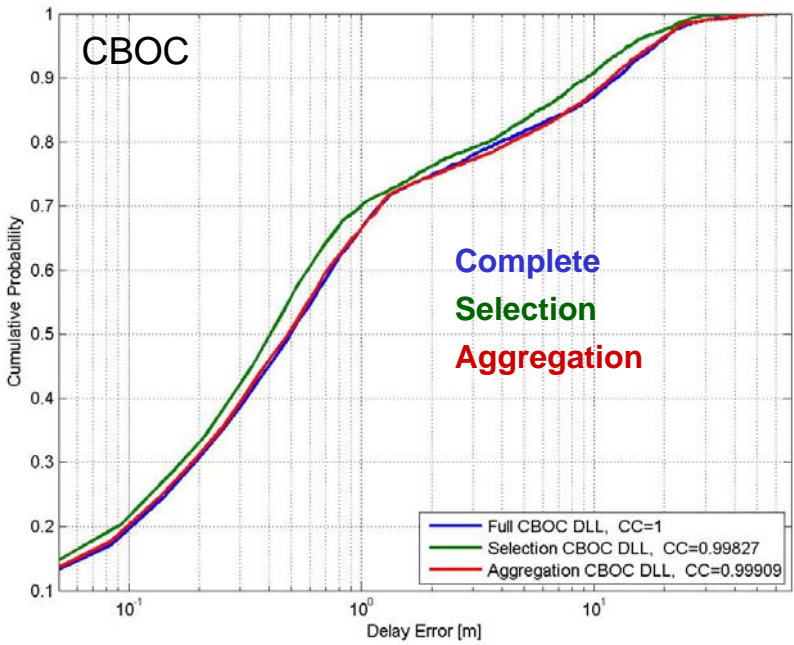
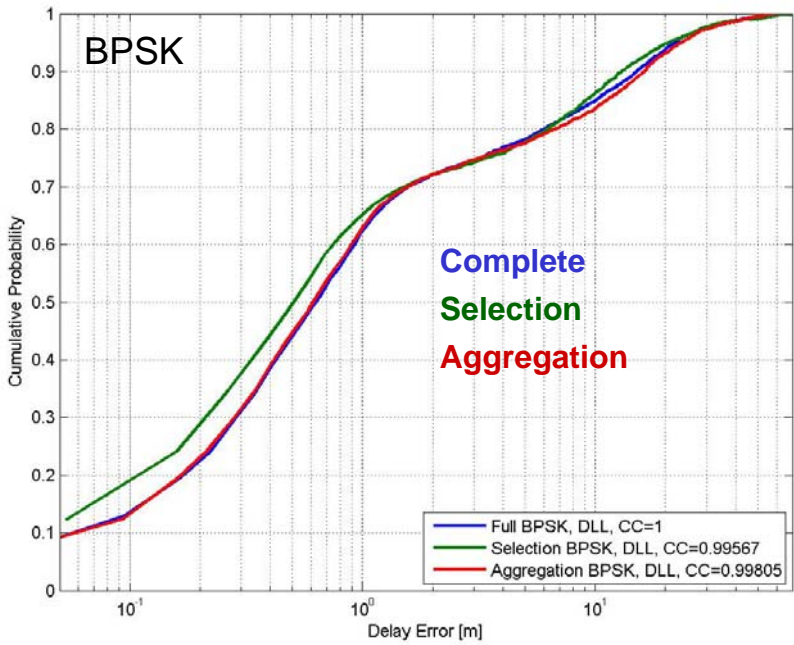


➡ **CBOC signal outperforms BPSK and BOC(1,1) signal (similar results for ML receiver)**



Results: Reduction Performance

➤ **Impact of reduction:** Different signals, standard DLL receiver

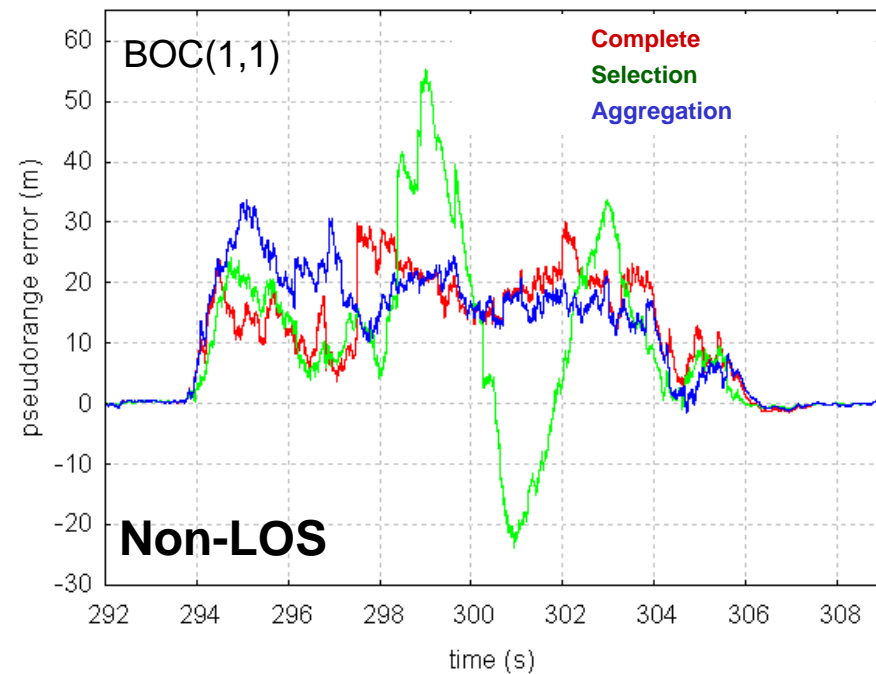
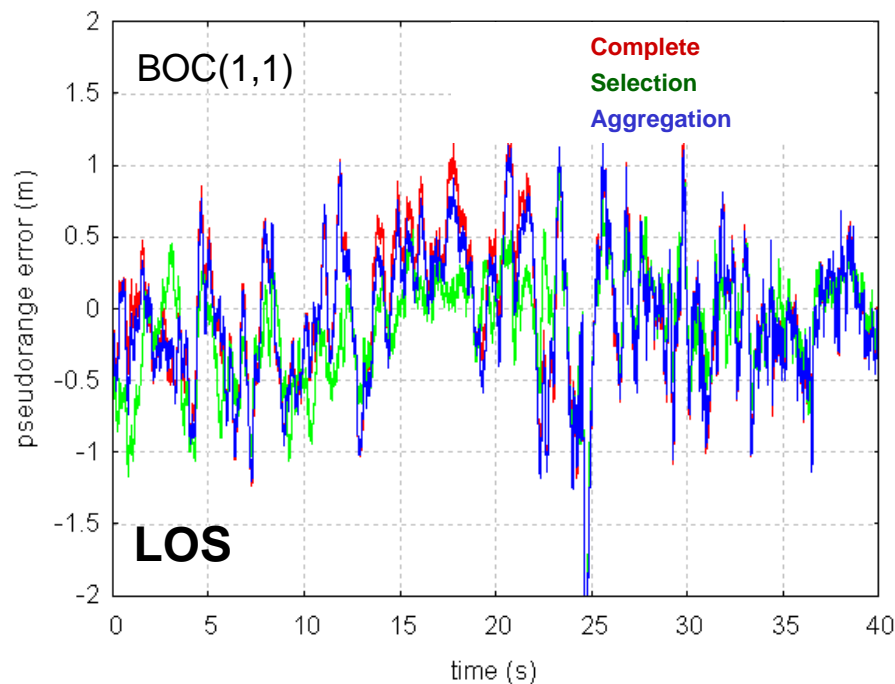


➔ **Aggregation method outperforms selection method (similar results for BOC(1,1) signal)**



Results: Reduction Performance

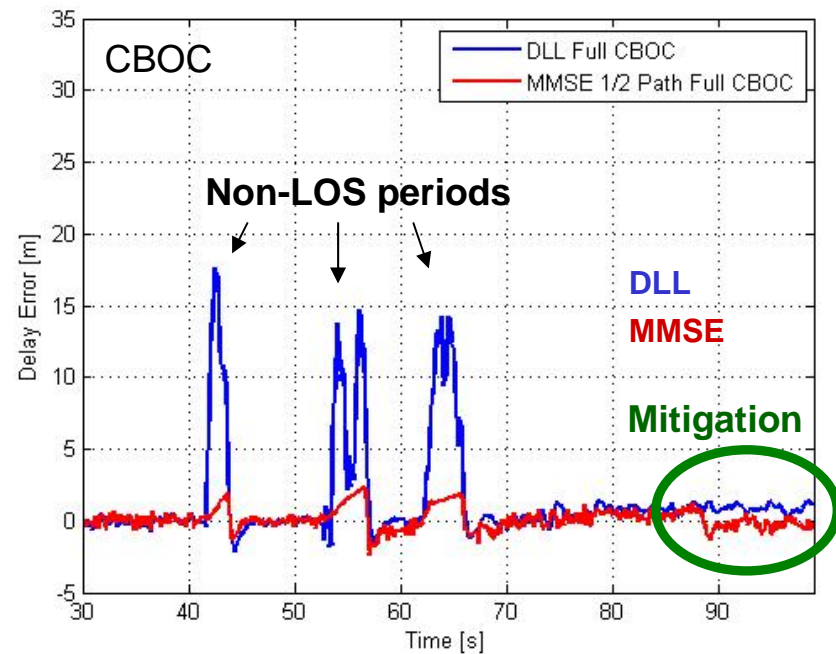
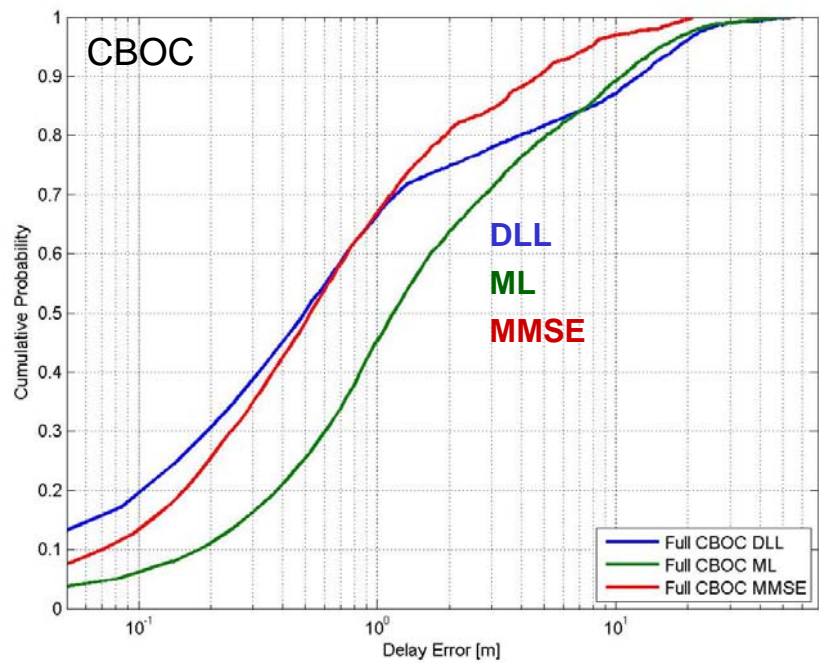
➤ **Comparison of LOS and non-LOS conditions: BOC(1,1) signal**



➔ **Reduction performance is degraded during non-LOS periods (similar results for BPSK and CBOC signal)**

Results: Mitigation Performance

➤ **Complete channel:** CBOC signal



➔ **Benefit of advanced algorithms, in particular during non-LOS (similar results for BPSK and BOC(1,1) signal)**



Conclusions

➤ Reduction

- Aggregation method outperforms selection method
- Aggregation may serve as a future baseline
- Good performance under LOS conditions, degraded for non-LOS periods

➤ Novel navigation signals & advanced receivers

- Confirmed benefit of novel signals (BPSK \Leftrightarrow BOC(1,1) \Leftrightarrow CBOC)
- Confirmed benefit of advanced receiver concepts (DLL \Leftrightarrow ML \Leftrightarrow MMSE), in particular during non-LOS conditions

➤ Future work

- Investigations on further reduction methods
- Improve reduction performance for non-LOS scenarios
- Carry out hardware simulations





This work was supported by the
Satellite Network of Excellence (SatNEX)
see www.satnex.org

Thank You



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