Signal Processing Techniques for GNSS Reflectometry

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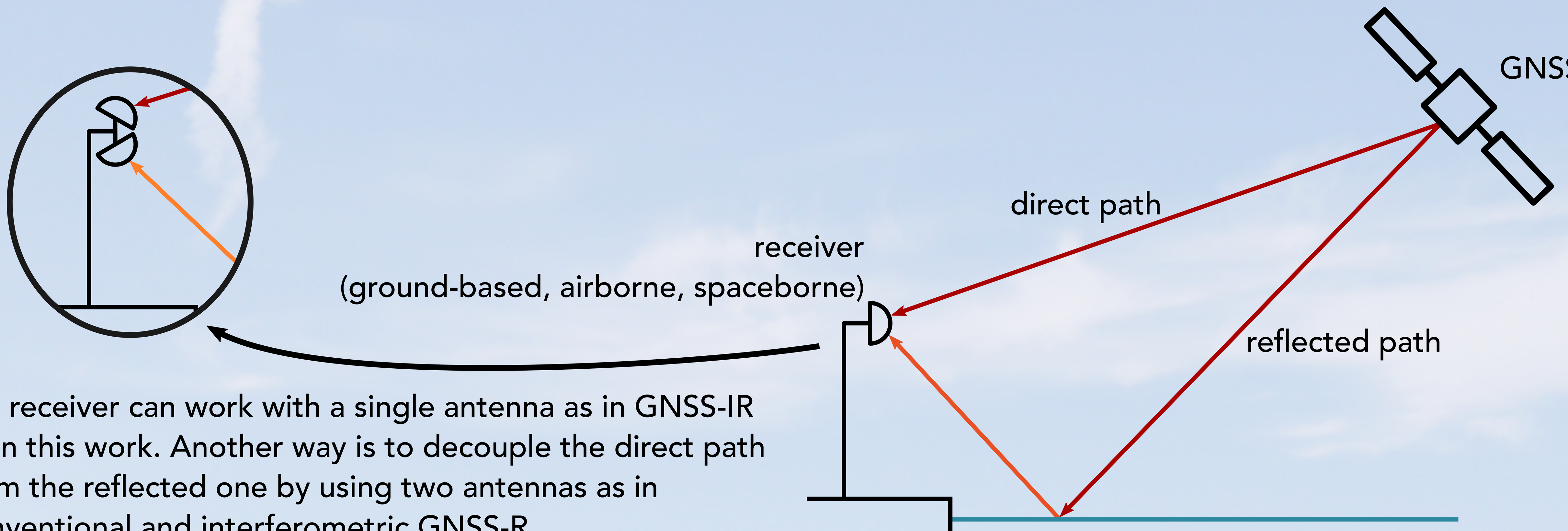
What is GNSS-R?

- **GNSS**: Global Navigation Satellite System (GPS, GALILEO, GLONASS, BEIDOU, etc.)
- **REFLECTOMETRY**: study of a signal that reflects from a surface.

GNSS-R is the exploitation of GNSS signals that reflect from the Earth surface as signals of opportunity.



the receiver can work with a single antenna as in GNSS-IR or in this work. Another way is to decouple the direct path from the reflected one by using two antennas as in conventional and interferometric GNSS-R.

Why do we study GNSS-R?

- **ALTIMETRY:** the relative delay combined with the satellite elevation can lead to information on the altitude of the receiver. This can be used for tide or water level monitoring.
- **SURFACE CHARACTERISATION:** the way the reflected path is attenuated and distorted provides information on the reflecting surface features (rugosity, salinity, moisture, etc.): for land applications, the reflection contains information on soil moisture; for sea applications, from the retrieval of the waves shape, the sea surface wind can be deduced.

How do we do it?

The single antenna signal model with τ the delay, F_d the Doppler frequency, ρ the amplitude and ϕ the phase:

$$x(t) = \underbrace{\rho_0 e^{j\phi_0} s(t-\tau_0) e^{-j2\pi F_{d0}(t-\tau_0)}}_{\text{direct path}} + \underbrace{\rho_1 e^{j\phi_1} s(t-\tau_1) e^{-j2\pi F_{d1}(t-\tau_1)}}_{\text{reflected path}} + \underbrace{w(t)}_{\text{Gaussian noise}}$$

For such a signal model, the unknown parameters to be estimated are: $\boldsymbol{\epsilon}^T = [\tau_0, F_{d0}, \rho_0, \phi_0, \tau_1, F_{d1}, \rho_1, \phi_1, \sigma_n^2]$ where σ_n^2 is the noise variance.

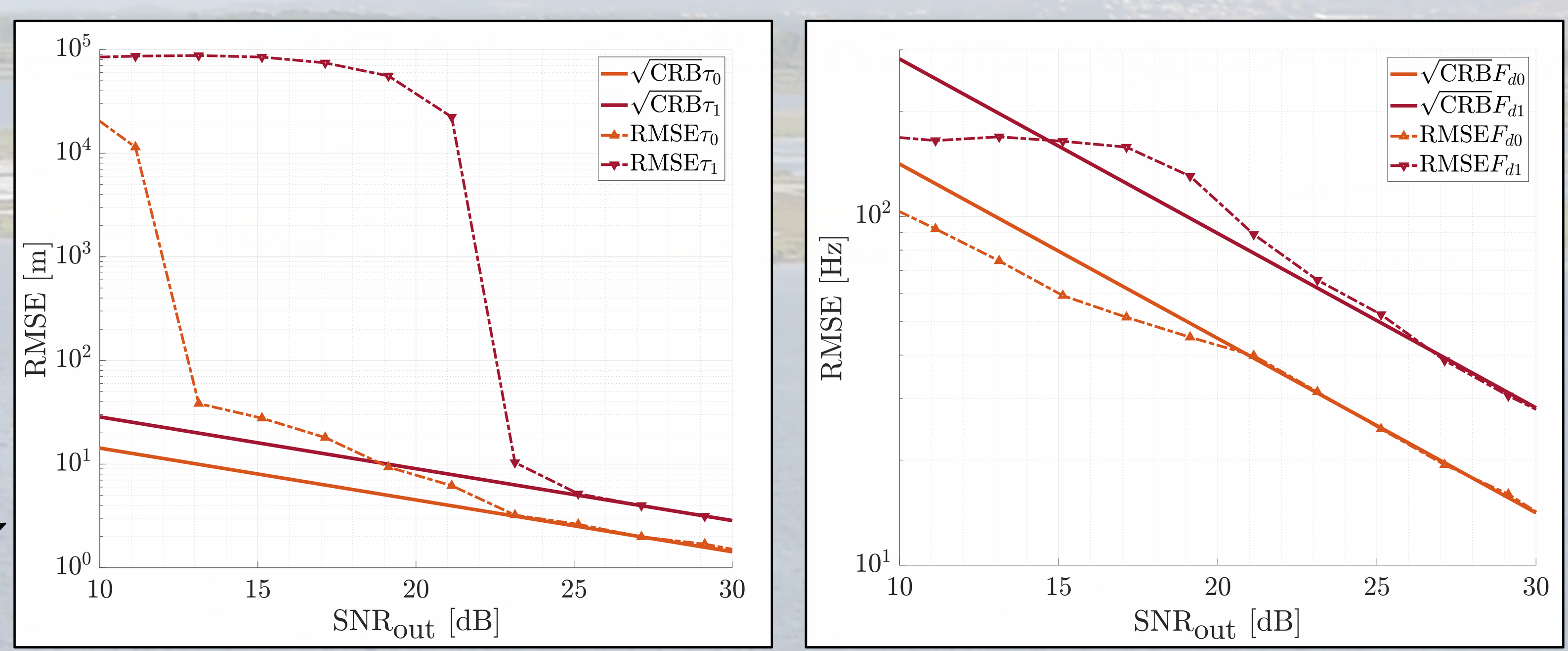
Estimation theory: development of nearly efficient estimators that are unbiased and with the best accuracy possible. This best accuracy, or minimum variance, is defined by the Cramér-Rao Bounds (CRB):

$$\text{CRB}(\boldsymbol{\epsilon}) = -E\left\{\frac{\partial p(x;\boldsymbol{\epsilon})}{\partial \boldsymbol{\epsilon} \partial \boldsymbol{\epsilon}^T}\right\}^{-1}$$

with $p(x;\boldsymbol{\epsilon})$ the probability density function.

Estimators implemented: dual source maximum likelihood estimator (MMT), CLEAN-RELAX (MEDLL), Alternating Projection, ...

validation by evaluating the Root Mean Square Error (RMSE)

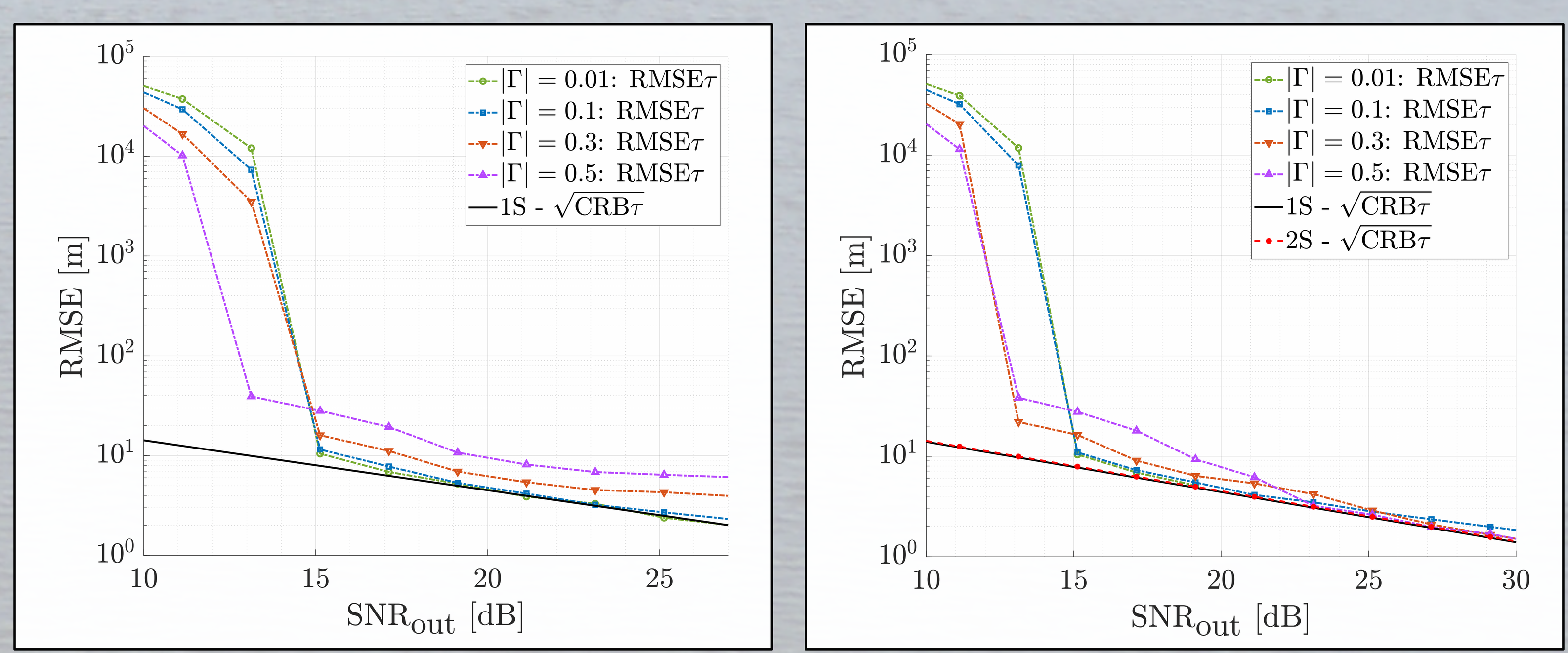


Time delay (left) and Doppler frequency (right) CLEAN-RELAX RMSE with regard to the signal-to-noise ratio (SNR)

Now what about it?

DIRECT APPLICATIONS:

- altimetry accuracy knowledge,
- GNSS multipath mitigation techniques and performance loss prevision,
- signal crosstalk impact analysis (leakage of the direct signal into the downlooking antenna) in the following figures, an analysis between a single source maximum likelihood estimator (left) and the CLEAN-RELAX estimator (right) in a dual source context.



PERSPECTIVES:

- new signal model to study the reflecting surface: so far the reflection was assumed specular which corresponds to scenarios with ground-based receiver and a flat mirror-like reflecting surface (calm sea, lake, ...), another approach is to consider a diffuse reflection and characterise the way the reflected signal is distorted.
- validation with real data (airborne and ground-based).