“Enabling Joint Localization and Synchronization in mmWave Multiple-Input Single-Output (MISO) Systems via Reconfigurable Intelligent Surfaces”

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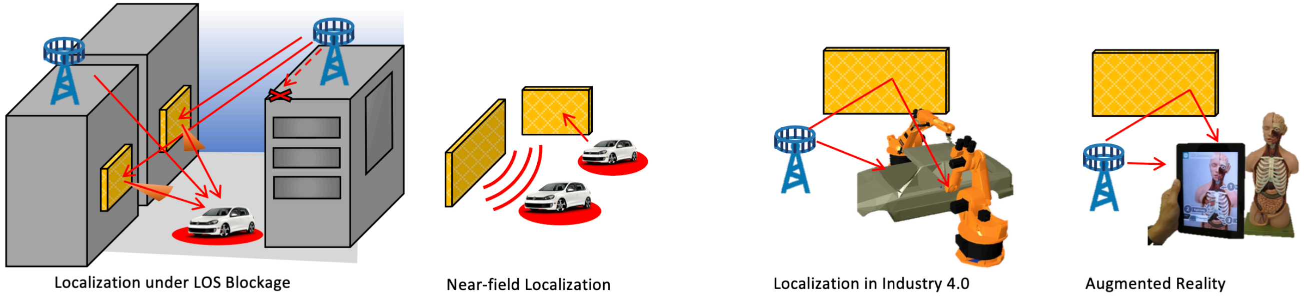
Localization and Sensing in 5G and Beyond 5G Networks

- mmWave MIMO enable very accurate localization and more favorable multipath propagation

...*beyond 5G*

- **Reconfigurable Intelligent Surfaces**: shaping the radio environment for improved positioning



H. Wymeersch et al"Radio Localization and Mapping With Reconfigurable Intelligent Surfaces: Challenges, Opportunities, and Research Directions," IEEE Vehicular Technology Magazine, Dec. 2020

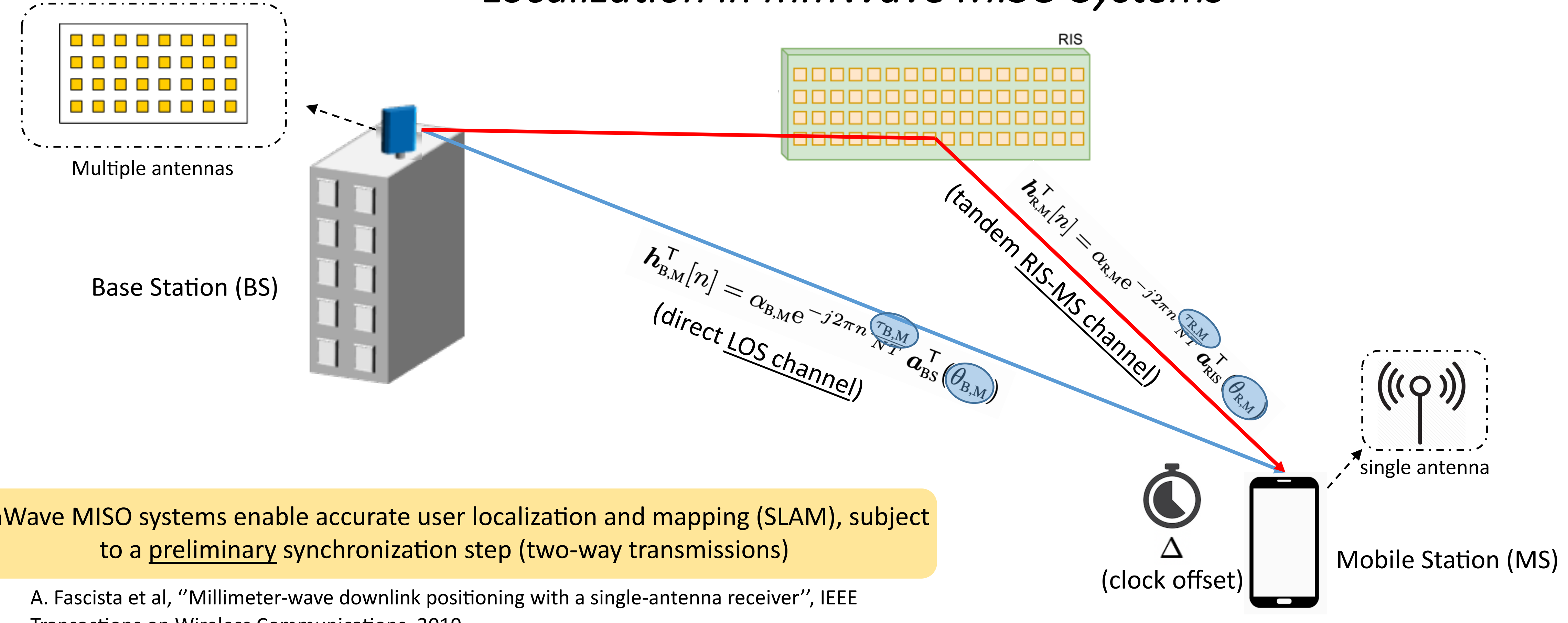
More challenging case: single-antenna receivers (mmWave MISO)

a) before full-fledged MIMO will be widespread

b) limit case of MIMO, in presence of blockages/obstructions

c) in cases of low-cost IoT single-antenna devices (e.g., WSN nodes, miniaturized sensors, …)

Localization in mmWave MISO Systems



mmWave MISO systems enable accurate user localization and mapping (SLAM), subject to a preliminary synchronization step (two-way transmissions)

- A. Fascista et al, ''Millimeter-wave downlink positioning with a single-antenna receiver'', IEEE Transactions on Wireless Communications, 2019
- A. Fascista et al, 'Downlink Single-Snapshot Localization and Mapping with a Single-Antenna Receiver'', IEEE Transactions on Wireless Communications, 2021

With the aid of a RIS, joint localization and synchronization becomes possible using one-way transmission!

Jointly estimate **user position and clock offset** from signals received from a **single BS** and a **single RIS** in **unknown MISO environment**

Maximum Likelihood Joint Localization and Synchronization

- Desired parameters: $\boldsymbol{\Theta} = [p_x \; p_y \; \Delta]^{\mathsf{T}}$ (user position and clock offset)

- Stack all the N samples collected for each transmission g

$$\boldsymbol{y}^g = \sqrt{P}\boldsymbol{B}^g(\boldsymbol{\Theta})\boldsymbol{\alpha} + \boldsymbol{\nu}^g$$

- Joint ML Estimation Problem

$$\hat{\boldsymbol{\Theta}}^{\mathrm{ML}} = \arg\min_{\boldsymbol{\Theta}} \left[\min_{\boldsymbol{\alpha}} \sum_{g=1}^{G} \|\boldsymbol{y}^g - \sqrt{P}\boldsymbol{B}^g\boldsymbol{\alpha}\|^2 \right]$$

Inner minimization possible in closed-form

$$\hat{\boldsymbol{\alpha}}^{\mathrm{ML}} = \frac{1}{\sqrt{P}}\boldsymbol{B}^{-1}\sum_{g=1}^{G}(\boldsymbol{B}^g)^{\mathsf{H}}\boldsymbol{y}^g$$

$$\hat{\boldsymbol{\Theta}}^{\mathrm{ML}} = \arg\min_{\boldsymbol{\Theta}} \sum_{g=1}^{G} \|\boldsymbol{y}^g - \sqrt{P}\boldsymbol{B}^g(\boldsymbol{\Theta})\hat{\boldsymbol{\alpha}}(\boldsymbol{\Theta})\|^2$$

➢ **Problem**: highly-non linear and requires exhaustive 3D grid search

✓ **Solution**: find a good initial estimate of $\boldsymbol{\theta}$ and solve joint ML via iterative optimization (e.g., Nelder-Mead)

Good Initialization via Relaxed ML Estimation

- More convenient rewriting to **decouple** dependencies on AODs and delays

$$\underbrace{\begin{bmatrix} \boldsymbol{y}^1 \\ \vdots \\ \boldsymbol{y}^G \end{bmatrix}}_{\boldsymbol{y}\in\mathbb{C}^{GN\times 1}} = \underbrace{\begin{bmatrix} \boldsymbol{\Phi}^1_{\mathrm{B,M}}(\theta_{\mathrm{B,M}}(\boldsymbol{p})) & \boldsymbol{\Phi}^1_{\mathrm{R,M}}(\theta_{\mathrm{R,M}}(\boldsymbol{p})) \\ \vdots & \vdots \\ \boldsymbol{\Phi}^G_{\mathrm{B,M}}(\theta_{\mathrm{B,M}}(\boldsymbol{p})) & \boldsymbol{\Phi}^G_{\mathrm{R,M}}(\theta_{\mathrm{R,M}}(\boldsymbol{p})) \end{bmatrix}}_{\boldsymbol{\Phi}(\theta_{\mathrm{B,M}}(\boldsymbol{p}),\theta_{\mathrm{R,M}}(\boldsymbol{p}))\overset{\mathrm{def}}{=}\boldsymbol{\Phi}(\boldsymbol{p})\in\mathbb{C}^{GN\times 2N}} \underbrace{\begin{bmatrix} \boldsymbol{e}_{\mathrm{B,M}} \\ \boldsymbol{e}_{\mathrm{R}} \end{bmatrix}}_{\boldsymbol{e}\in\mathbb{C}^{2N\times 1}} + \begin{bmatrix} \boldsymbol{\nu}^1 \\ \vdots \\ \boldsymbol{\nu}^G \end{bmatrix}$$

with $\boldsymbol{e}_{\mathrm{B,M}} = \sqrt{P}\alpha_{\mathrm{B,M}} \begin{bmatrix} 1 \\ \mathrm{e}^{-j\kappa_1\tau_{\mathrm{B,M}}} \\ \vdots \\ \mathrm{e}^{-j\kappa_{N-1}\tau_{\mathrm{B,M}}} \end{bmatrix}$, $\boldsymbol{e}_{\mathrm{R}} = \sqrt{P}\alpha_{\mathrm{R}} \begin{bmatrix} 1 \\ \mathrm{e}^{-j\kappa_1\tau_{\mathrm{R}}} \\ \vdots \\ \mathrm{e}^{-j\kappa_{N-1}\tau_{\mathrm{R}}} \end{bmatrix}$

depends on $\boldsymbol{p}$ via AODs

depends on $\boldsymbol{p}$ and Δ via delays

- <u>Relax dependency of **e** on delays</u> → relaxed ML estimator of position-only

$$\hat{\boldsymbol{p}}^{\mathrm{RML}} = \arg\min_{\boldsymbol{p}} \left[\min_{\boldsymbol{e}} \|\boldsymbol{y} - \boldsymbol{\Phi}\boldsymbol{e}\|^2 \right]$$

$$\hat{\boldsymbol{e}}^{\mathrm{RML}} = (\boldsymbol{\Phi}^{\mathsf{H}}(\boldsymbol{p})\boldsymbol{\Phi}(\boldsymbol{p}))^{-1}\boldsymbol{\Phi}^{\mathsf{H}}(\boldsymbol{p})\boldsymbol{y}$$

(Pseudoinverse only requires G ≥ 2)

$$\hat{\boldsymbol{p}}^{\mathrm{RML}} = \arg\min_{\boldsymbol{p}} \|\boldsymbol{P}^{\perp}_{\boldsymbol{\Phi}(\boldsymbol{p})}\boldsymbol{y}\|^2$$

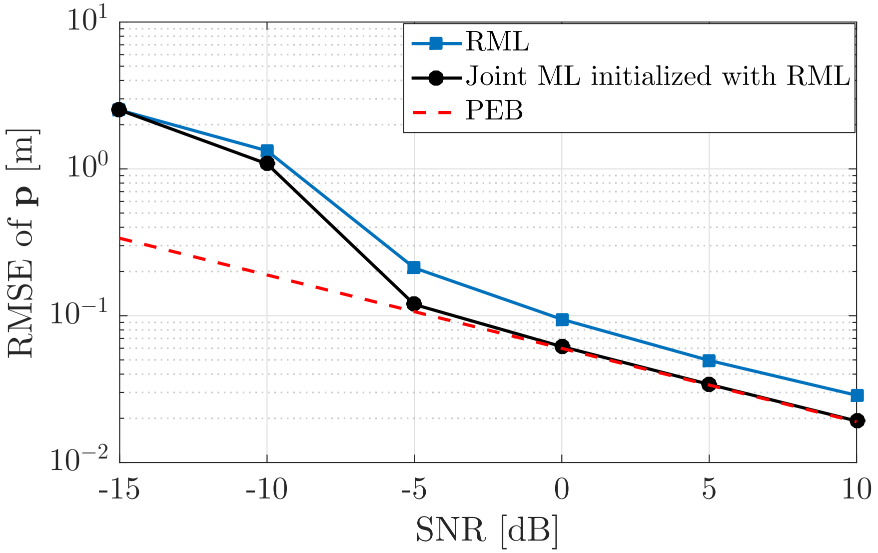
Use $\hat{\boldsymbol{p}}^{\mathrm{RML}}$ in $\hat{\boldsymbol{e}}^{\mathrm{RML}}(\hat{\boldsymbol{p}}^{\mathrm{RML}})$ and estimate delays via FFT

$$\hat{\Delta}^{\mathrm{RML}} = \frac{1}{2}\left[\hat{\tau}^{\mathrm{RML}}_{\mathrm{B,M}} - \|\hat{\boldsymbol{p}}^{\mathrm{RML}}\|/c + \hat{\tau}^{\mathrm{RML}}_{\mathrm{R}} - (\|\boldsymbol{r}\| + \|\boldsymbol{r} - \hat{\boldsymbol{p}}^{\mathrm{RML}}\|)/c\right]$$

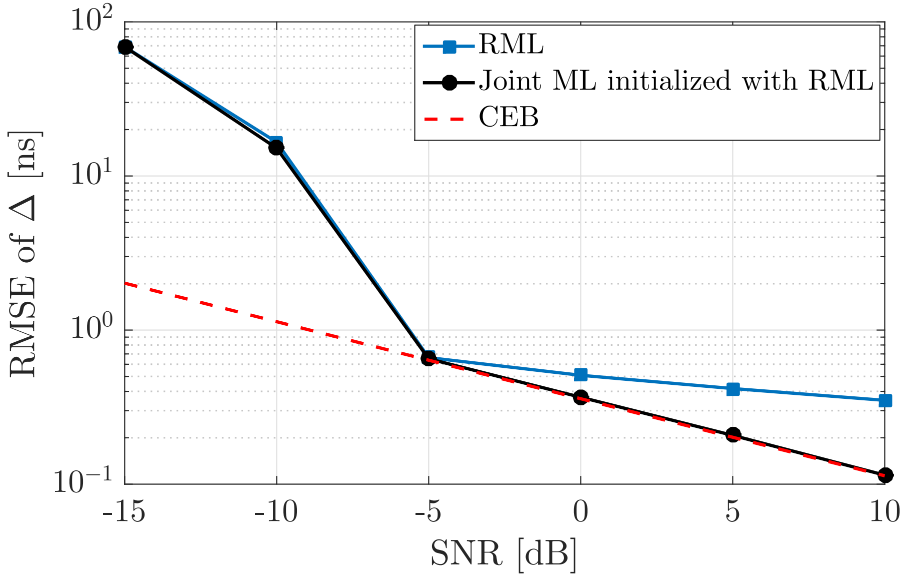
Results

Simulation setup:

f_c	60 GHz
B	40 MHz
G	5
N	30
N_{BS}	20
N_R	20
M	$N_{BS}/2$
$\boldsymbol{F}$	1 beam towards $\theta_{B,R}$ and $M-1$ uniform coverage
RIS phase shifts	0 or π



- RML achieves good performance already at -5 dB SNR
- ..but does not strictly attain the PEB
- JML exhibits excellent performance



- almost same trend as for ***p***
- slightly wider gap of RML with CEB due to suboptimality of FFT

…in case of random RIS weights, <u>smaller N_R can be compensated by increasing G</u>

A. Fascista, A. Coluccia, H. Wymeersch, and G. Seco-Granados: "RIS-aided Joint Localization and Synchronization with a Single-Antenna MmWave Receiver'', accepted for IEEE ICASSP 2021.

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ngiyabonga
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Баярлалаа
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kia ora
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তোমাকে ধন্যবাদ
감사합니다
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