University Defence Research Centre (UDRC)
In Signal Processing

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[C2] Arrayed MIMO Radar

Theme: Detection, Localisation and Tracking

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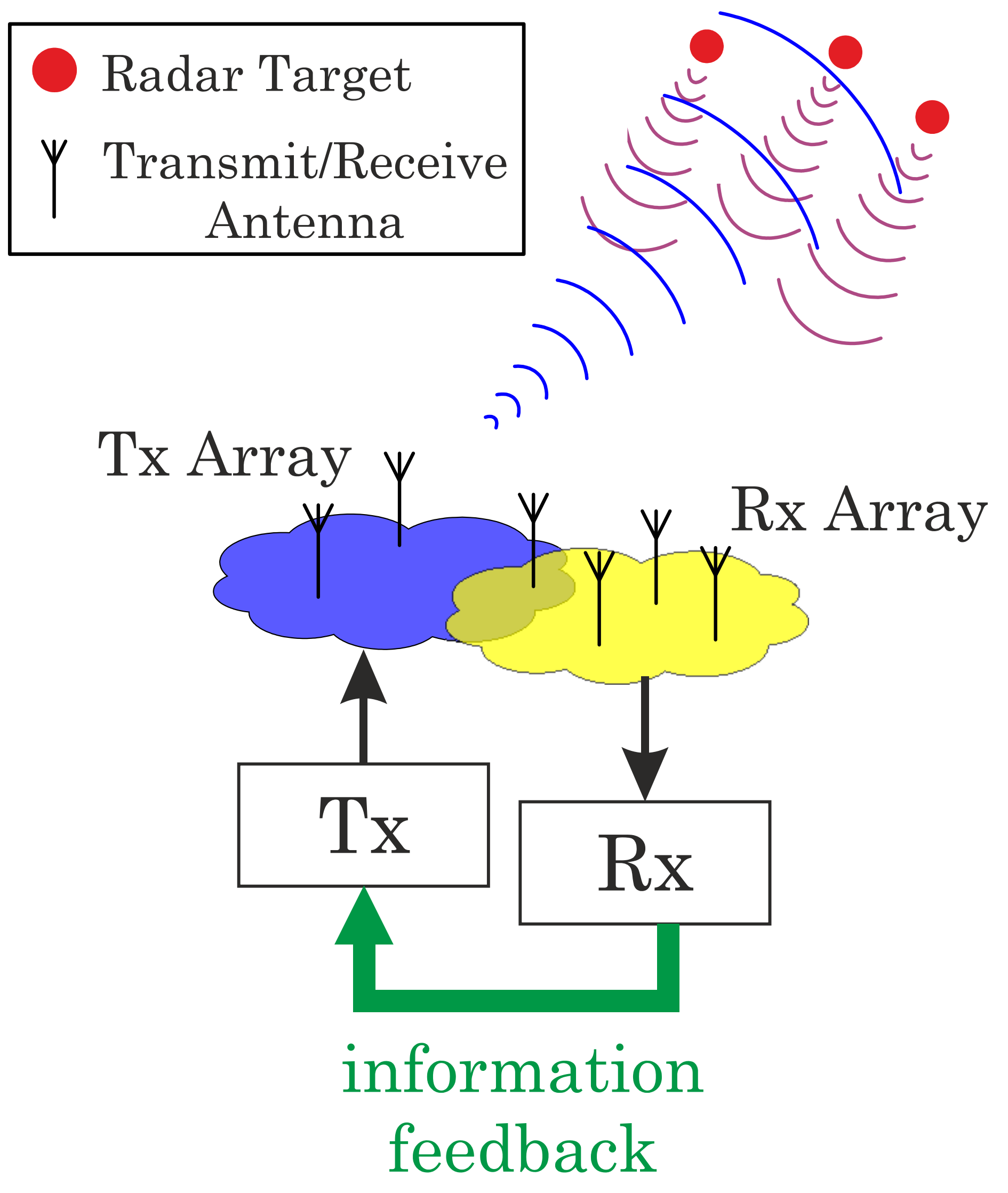
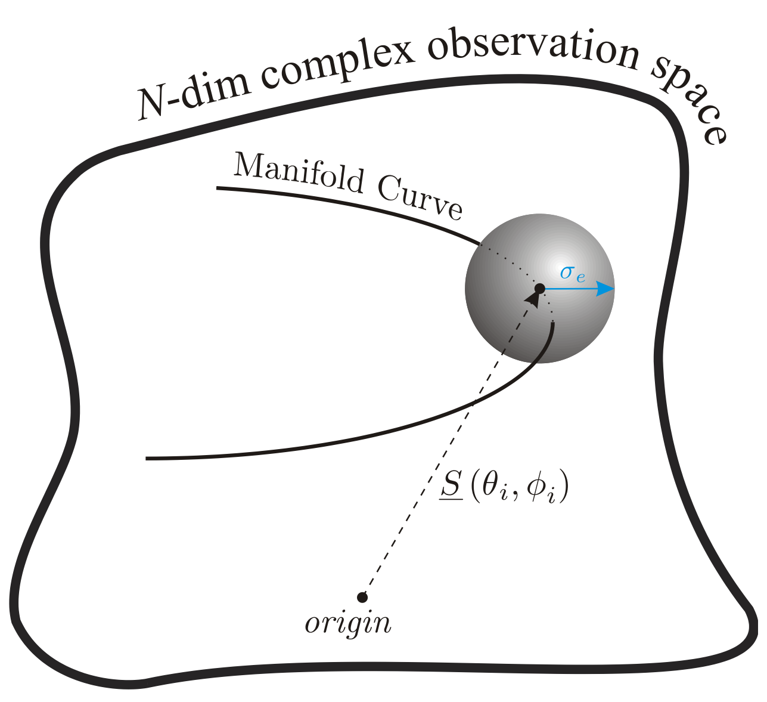
Project Aims



- Targets
  - Multiple, closely-spaced
  - Stationary/moving
  - Detect, resolve and estimate parameters
- Transmitter (Tx)
  - Array geometry: linear, planar, 3D
  - Waveform design
- Receiver (Rx)
  - Array geometry: linear, planar, 3D
  - Parameter estimation
- Feedback Channel (Rx to Tx)
  - Collaborative methods

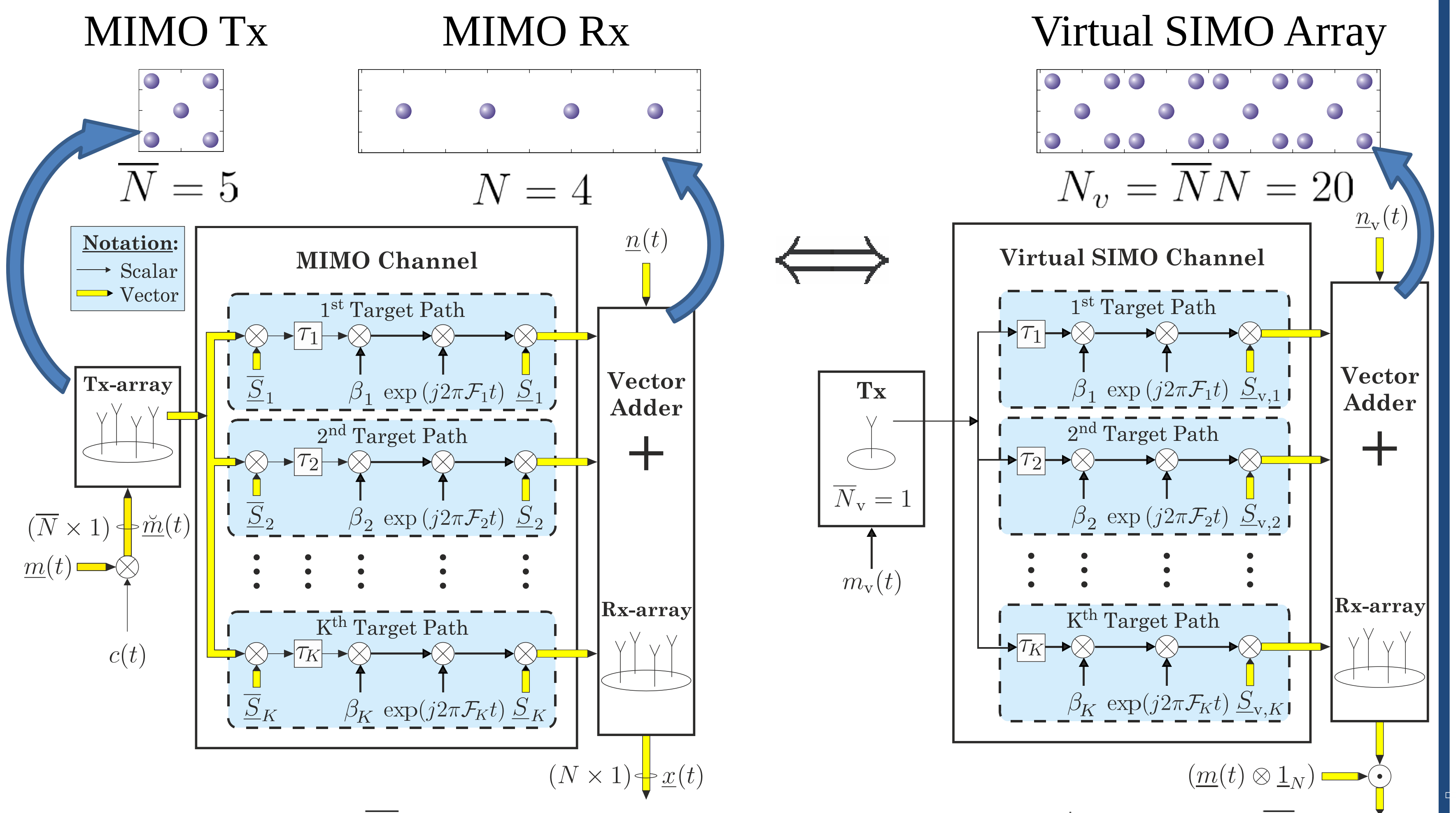
Theoretical Performance Bounds



- Uncertainty Hyperspheres of radius σ_e
  - Model the uncertainty remaining in the system after L snapshots (see figure):
  - $\sigma_e = \frac{1}{\sqrt{2(\mathrm{SNR}\times L)C}}$
- The Parameter C ($0 < C \leq 1$)
  - C models any additional uncertainty introduced by a practical MIMO radar parameter estimation algorithm.
  - Ideal algorithm: $C = 1$
- Detection/resolution performance bounds are a function of:
  - $\Delta\theta_{det,res} = \mathrm{f}\left\{\text{array geometry}, \sigma_e\right\}$
- Virtual SIMO representation allows direct analysis of MIMO radar systems.

- **Publication**: H. Commin and A. Manikas, “The Figure of Merit ‘C’ for Comparing Superresolution Direction-Finding Algorithms”, *SSPD* 2010.

Equivalent ‘Virtual’ SIMO Representation



$$\underline{\overline{S}}(\theta) \in \mathfrak{C}^{\overline{N}},\ \underline{S}(\theta) \in \mathfrak{C}^{N}$$

$$\underline{S}_v(\theta) = (\underline{\overline{S}}^* \otimes \underline{S}) \in \mathfrak{C}^{\overline{N}N}$$

- Note: A bar over a symbol denotes a transmit parameter
- Structure of virtual array can be deduced from:

$$\underline{x}(t) = (\underline{1}_{\overline{N}}^T \otimes \mathbb{I}_N)\ \underbrace{\left((\underline{m}(t)\otimes \underline{1}_N) \odot \sum_{k=1}^{K} \beta_k \exp(j2\pi\mathcal{F}t)\left(\underline{\overline{S}}_k^* \otimes \underline{S}_k\right) c(t-\tau_k) + \underline{n}_v(t)\right)}_{=\underline{x}_v(t)\in\mathfrak{C}^{N\overline{N}\times 1}}$$

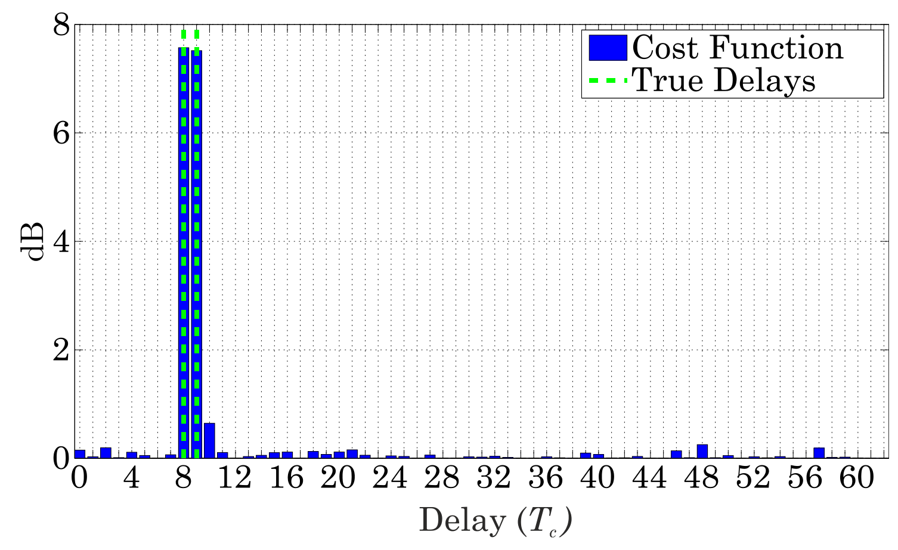
- Allows full transmit-receive MIMO system geometry to be completely characterised, using the virtual SIMO array manifold

- **Publication**: H. Commin and A. Manikas, “Virtual SIMO Radar Modelling in Arrayed MIMO Radar”, *SSPD* 2012.

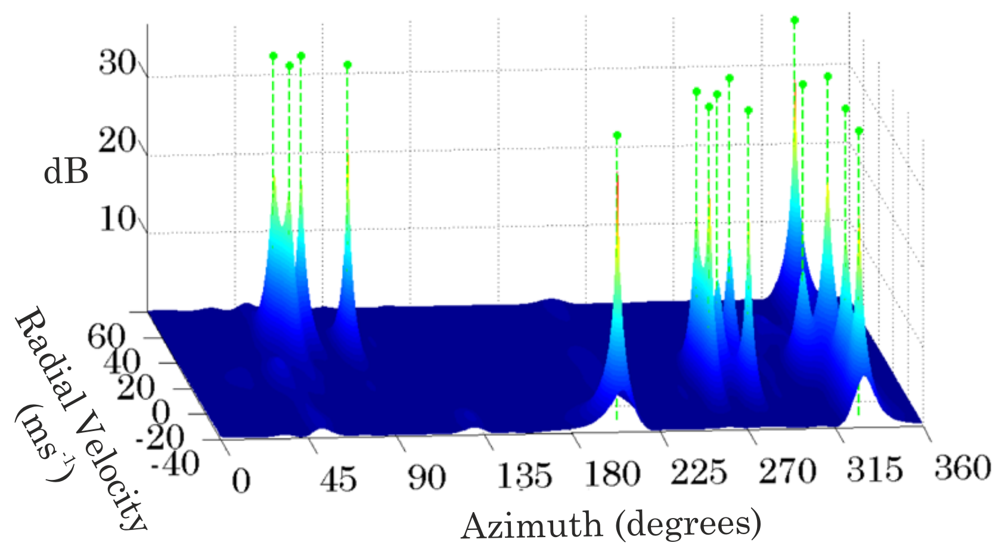
Joint DOA, Doppler and Delay Estimation

- Three-parameter search partitioned into computationally-efficient two-stage subspace-based (delay, then DOA-Doppler) estimation
- Complex fading coefficient estimation follows straightforwardly
- Simulation Example: (with true parameters shown in green)
  - K = 27 targets, tightly clustered in just two unique delays ($8T_c$ and $9T_c$)
  - Planar MIMO array configuration, with $\overline{N}$ = 5 (X-shaped), N = 8 (linear)

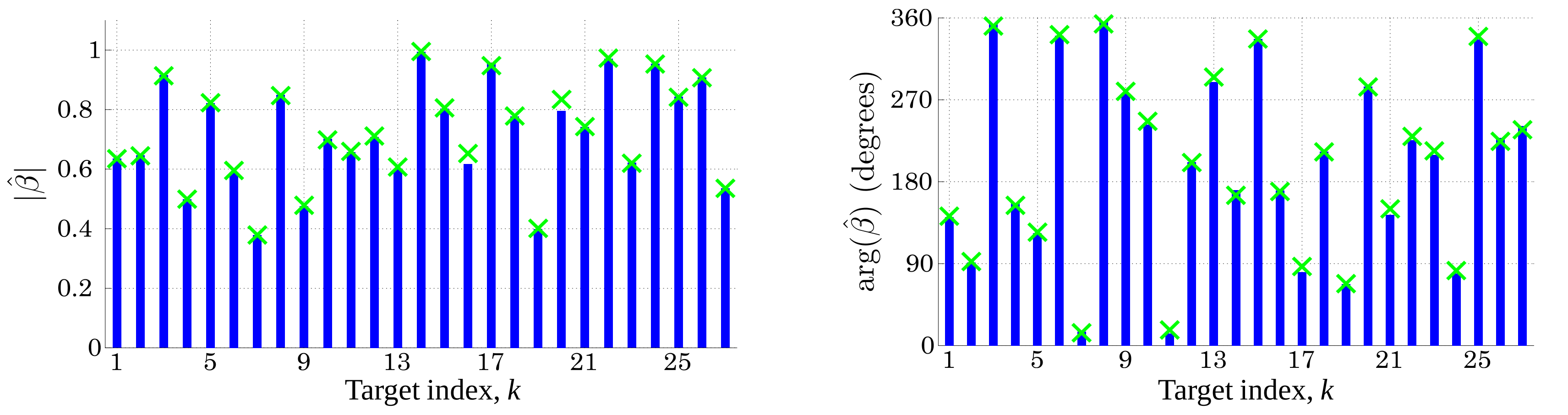
- Step1: Delay estimation. Two unique delays correctly identified:



- Step 2: For each delay, joint DOA-Doppler estimation, e.g. for $\tau = 9T_c$:



- Step 3: Having estimated all other target parameters, complex path fading coefficients (magnitude and phase) are accurately estimated for all 27 targets:



- **Publication**: H. Commin and A. Manikas, “Spatiotemporal Arrayed MIMO Radar: Joint Doppler, Delay and DOA Estimation”, *IEEE Transactions on Signal Processing [Submitted]*.

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