Interference Localisation Methods using Direct Position Determination Concept

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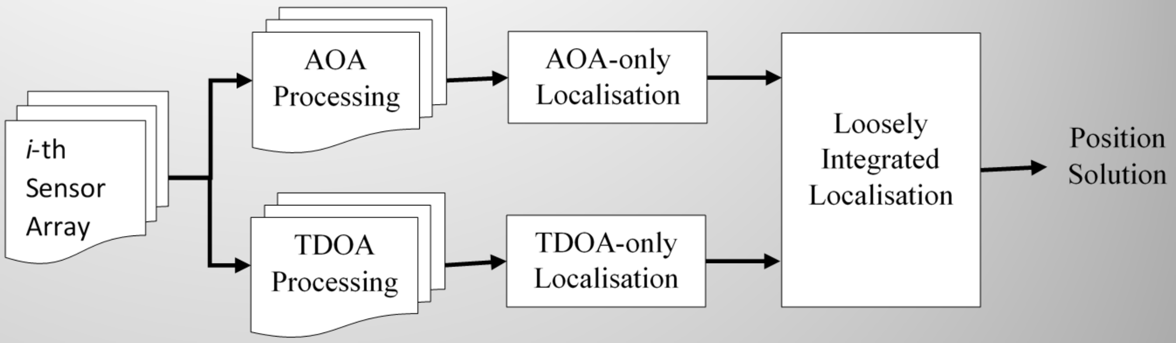
Introduction

- GNSS signals are inherently weak
- Spurious transmissions and intentional jammers in the GNSS band threatens safety critical applications that depends on GNSS
- A network of phased array sensors tuned to the GNSS band can be used to detect jammers.

Jammer Characteristics

- Narrowband
  - Strong jammer signal strength will affect receiver performance
  - Can be detected using AOA
- Wideband
  - Weak jammer signal strength is sufficient to affect receiver performance
  - Can be detected using TDOA and AOA

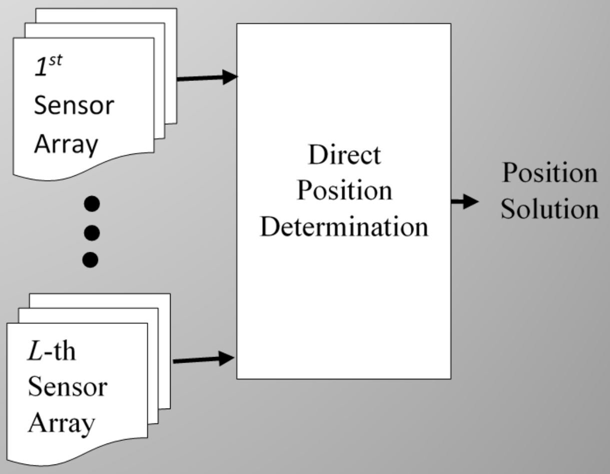
Introduction



- AOA: Angle of Arrival utilising phased array processing
- TDOA: Time Difference of Arrival utilising cross correlation
- Geo-localisation of jammer
  - AOA: Intersection of lines
  - TDOA: Intersection of hyperbolas

Direct Position Determination (DPD)

- A signal processing technique to directly localise the jammer in the position domain
- Aims to combine signal energy from all antenna elements in the network
- Provides better position resolution than conventional methods



Existing DPD Approaches

- Most DPD approaches models narrowband signals (e.g. DPD, LOST, LOST-FIND, HR-DPD)
- Assumes wideband signal as a combination of multiple narrowband channels
- These DPD algorithms does not exploit good cross-correlation properties of wideband signals

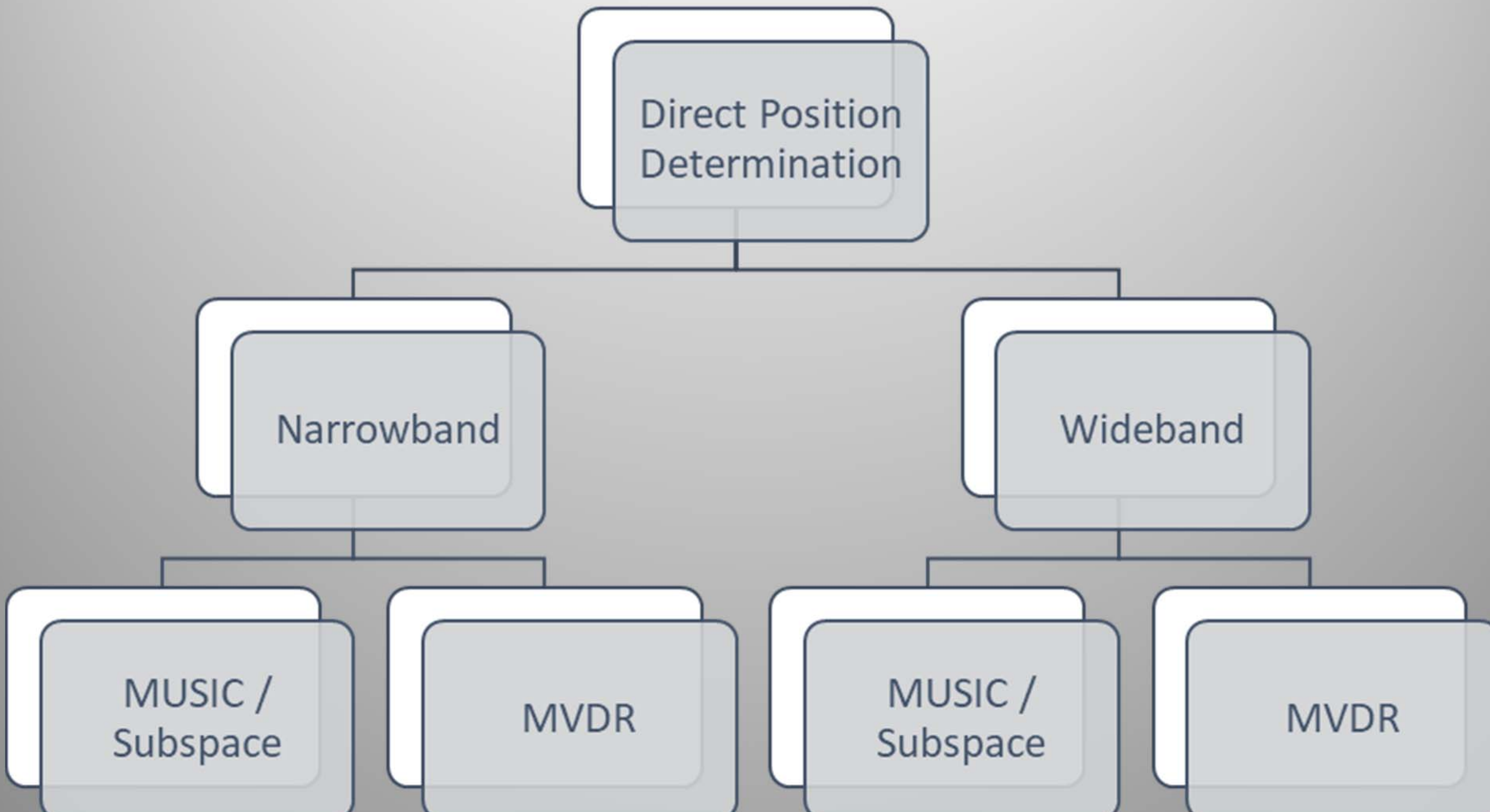
$$\mathbf{r}_\ell(j,k) = \sum_{q=1}^{Q} b_{\ell q}\mathbf{a}_\ell(\mathbf{p}_q)s_q(j,k)e^{-i\omega_j[\tau_\ell(\mathbf{p}_q)+t_q^{(0)}]} + \mathbf{n}_\ell(j,k),$$

$$j = 1,2,\ldots,J;\ k = 1,2,\ldots,K,$$

$$\bar{s}_q(j,k) \triangleq s_q(j,k)e^{-i\omega_j t_q^{(0)}},$$

$$\bar{\mathbf{a}}_\ell(j,\mathbf{p}_q,b_{\ell q}) \triangleq b_{\ell q}\mathbf{a}_\ell(\mathbf{p}_q)e^{-i\omega_j\tau_\ell(\mathbf{p}_q)}.$$

Taxonomy of DPD Methods



TARGET 1/2

- Signal model:

$$r_l(t) = \sum_{q=1}^{Q} \alpha_{l,q} \boldsymbol{a}_l(\boldsymbol{p}_q) s_q\left(t - \tau_{l,q}(\boldsymbol{p}_q)\right) + \boldsymbol{n}_l(t)$$
$$= \boldsymbol{A}_l \boldsymbol{\Omega}_l \boldsymbol{s}_l(t) + \boldsymbol{n}_l(t)$$

- Eigen-decomposition

$$\boldsymbol{x}_{i,j}(t,\tau) = \left[\boldsymbol{r}_i^T(t) \quad \boldsymbol{r}_j^T(t+\tau)\right]^T$$
$$\boldsymbol{R}_x(\tau) = \mathbb{E}_t\left(\boldsymbol{x}_{i,j}(t,\tau)\boldsymbol{x}_{i,j}^H(t,\tau)\right)$$
$$\boldsymbol{R}_x(\tau) = \begin{bmatrix} \boldsymbol{R}_{ii} & \boldsymbol{R}_{ij}(\tau) \\ \boldsymbol{R}_{ji}(-\tau) & \boldsymbol{R}_{jj} \end{bmatrix} + \boldsymbol{R}_n$$
$$\boldsymbol{R}_{ii}^+ = \boldsymbol{\Pi}_i \boldsymbol{\Sigma}^{-1} \boldsymbol{\Pi}_i^H \qquad \boldsymbol{R}_{ii} = \boldsymbol{\Pi}_i \boldsymbol{\Sigma} \boldsymbol{\Pi}_i^H$$

Correct eigendecomposition requires Q < M

- Form noise subspace

$$\boldsymbol{G}_{ij}(\tau) = \boldsymbol{I}_M - \boldsymbol{R}_{ii}^+ \boldsymbol{R}_{ij}(-\tau) \boldsymbol{R}_{jj}^+ \boldsymbol{R}_{ji}(\tau)$$

TARGET 2/2

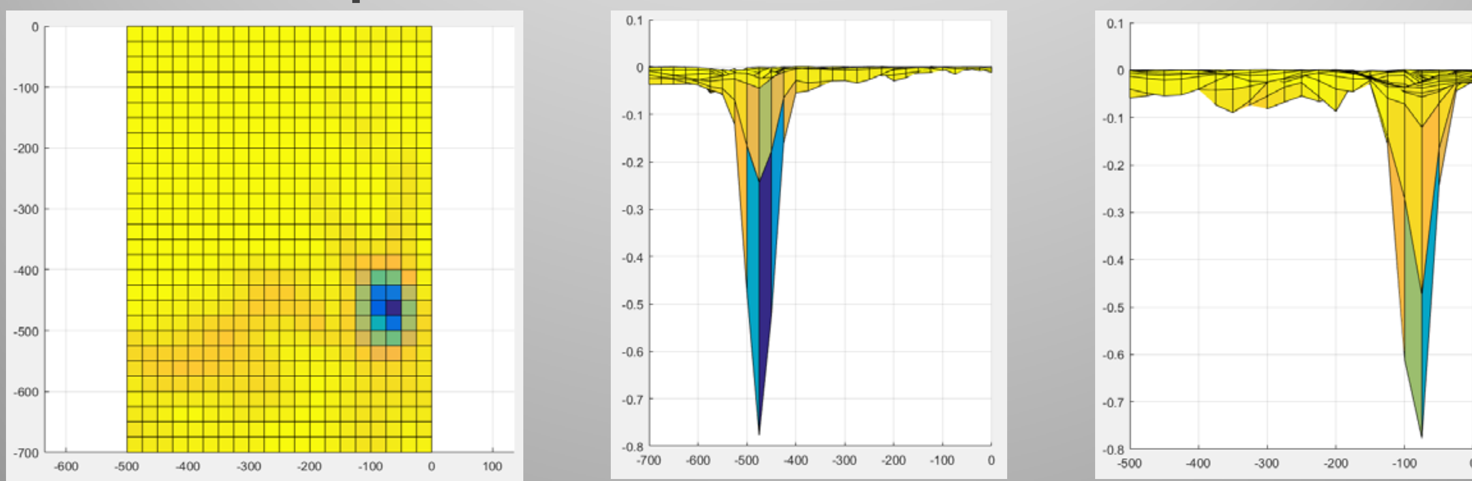
- Cost function:

$$\widehat{\boldsymbol{p}_q} = \underset{\boldsymbol{p}\in P}{\operatorname{argmin}} \frac{1}{L(L-1)} \sum_{i\neq j} J_{T,ij}(\boldsymbol{p}_q) \quad \forall i,j \in [1,L]$$

where

$$J_{T,ij}(\boldsymbol{p}_q) = \frac{\boldsymbol{a}_i^H(\boldsymbol{p}_q)\boldsymbol{G}_{ij}(\tau(\boldsymbol{p}_q))\boldsymbol{a}_i(\boldsymbol{p}_q)}{\boldsymbol{a}_i^H(\boldsymbol{p}_q)\boldsymbol{a}_i(\boldsymbol{p}_q)}$$

- Gridded position domain search:



(left) X-Y, (middle) Y-Z and (right) X-Z domain plot of the test statistic (z-axis) vs position space (x,y-axis)

Limitations of TARGET

- Requires assumed knowledge of Q
- Limited number of detectable sources
- Lack sensitivity
  - Does not fully utilise signal energy from all antenna elements within the array

Cross-correlation DPD (1/2)

- Global Covariance Matrix

$$y(t,\boldsymbol{\tau}(\boldsymbol{\rho})) = \begin{bmatrix} \boldsymbol{r}_1^T(t) & \boldsymbol{r}_2^T(t+\tau_{1,2}) & \cdots & \boldsymbol{r}_L^T(t+\tau_{1,L}) \end{bmatrix}^T$$

(Ctrl)

Its corresponding covariance matrix is

$$\boldsymbol{R}_y(\boldsymbol{\tau}) = \mathbb{E}_t\left(\boldsymbol{y}(t,\boldsymbol{\tau})\boldsymbol{y}^H(t,\boldsymbol{\tau})\right)$$

$$\boldsymbol{R}_y(\boldsymbol{\tau}(\boldsymbol{\rho})) = \begin{bmatrix} \boldsymbol{R}_{11} & \boldsymbol{R}_{12}(\tau_{1,2}) & \cdots & \boldsymbol{R}_{1L}(\tau_{1,L}) \\ \boldsymbol{R}_{21}(-\tau_{1,2}) & \boldsymbol{R}_{22} & \cdots & \boldsymbol{R}_{2L}(\tau_{2,L}) \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{R}_{L1}(-\tau_{1,L}) & \boldsymbol{R}_{L2}(-\tau_{2,L}) & \cdots & \boldsymbol{R}_{LL} \end{bmatrix} + \boldsymbol{R}_n$$

- Modified Global Covariance Matrix

$$\widetilde{\boldsymbol{R}}_y(\boldsymbol{\tau}(\boldsymbol{\rho})) = \begin{bmatrix} \boldsymbol{0}_{M\times M} & \boldsymbol{R}_{12}(\tau_{1,2}) & \cdots & \boldsymbol{R}_{1L}(\tau_{1,L}) \\ \boldsymbol{R}_{21}(-\tau_{1,2}) & \boldsymbol{0}_{M\times M} & \cdots & \boldsymbol{R}_{2L}(\tau_{2,L}) \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{R}_{L1}(-\tau_{1,L}) & \boldsymbol{R}_{L2}(-\tau_{2,L}) & \cdots & \boldsymbol{0}_{M\times M} \end{bmatrix}$$

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Cross-correlation DPD (2/2)

- Eigen decomposition and cost function

$$J_{ccDPD}(\boldsymbol{\rho}) = \lambda_{min}\left(\left(\boldsymbol{A}^H(\boldsymbol{\rho})\boldsymbol{A}(\boldsymbol{\rho})\right)^{-1}\boldsymbol{A}^H(\boldsymbol{\rho})\bar{\mathbf{F}}_{\tilde{R}_y}(\boldsymbol{\rho})\boldsymbol{A}(\boldsymbol{\rho})\right)$$

where

$$\bar{\mathbf{F}}_{\tilde{R}_y}(\boldsymbol{\rho}) = \boldsymbol{I}_{LM} - \boldsymbol{H}(\rho)\boldsymbol{G}(\rho)\boldsymbol{G}^H(\rho)\boldsymbol{H}^H(\rho)$$

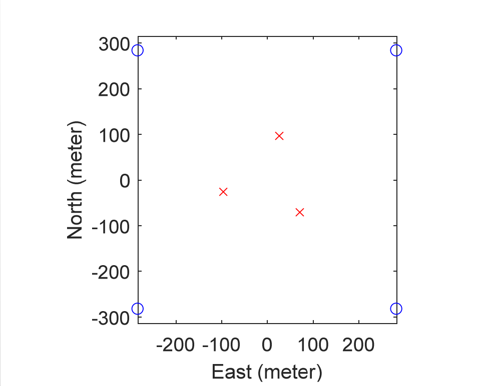
$$\boldsymbol{G}(\rho) = \mathbf{e}_{\tilde{R}_y}(\boldsymbol{\rho})\boldsymbol{\Sigma}_{\tilde{R}_y}\mathbf{e}^H_{\tilde{R}_y}(\boldsymbol{\rho})$$

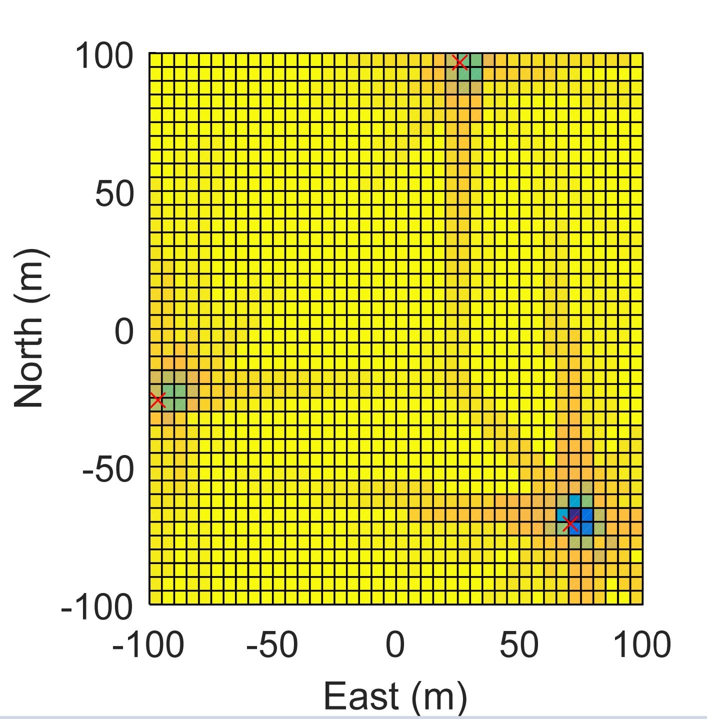
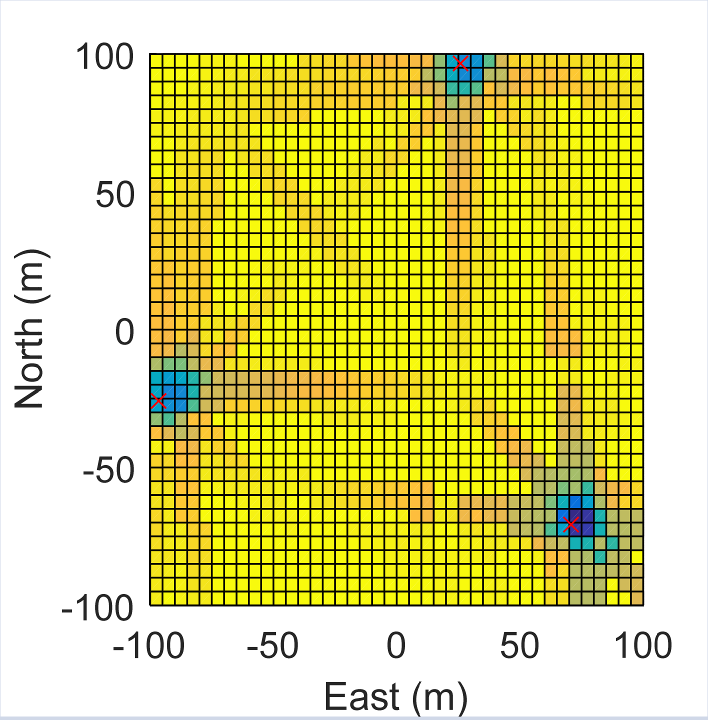
$$\boldsymbol{H}(\rho) = \mathbf{e}_{R_y}(\boldsymbol{\rho})\boldsymbol{\Sigma}^{-1}_{R_y}\mathbf{e}^H_{R_y}(\boldsymbol{\rho})$$

and

$$\boldsymbol{A}(\boldsymbol{\rho}) = \begin{bmatrix} \boldsymbol{a}_1(\boldsymbol{\rho}) & \cdots & \mathbf{0}_{M\times 1} \\ \vdots & \ddots & \vdots \\ \mathbf{0}_{M\times 1} & \cdots & \boldsymbol{a}_L(\boldsymbol{\rho}) \end{bmatrix}_{LM\times L}$$

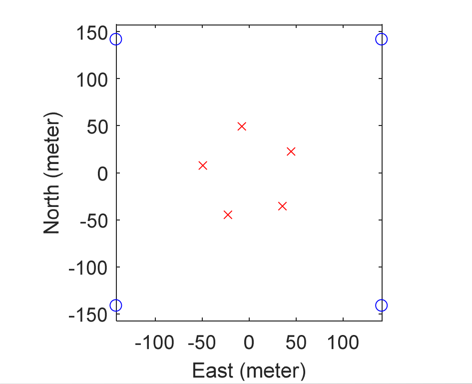
Multiple Jammer

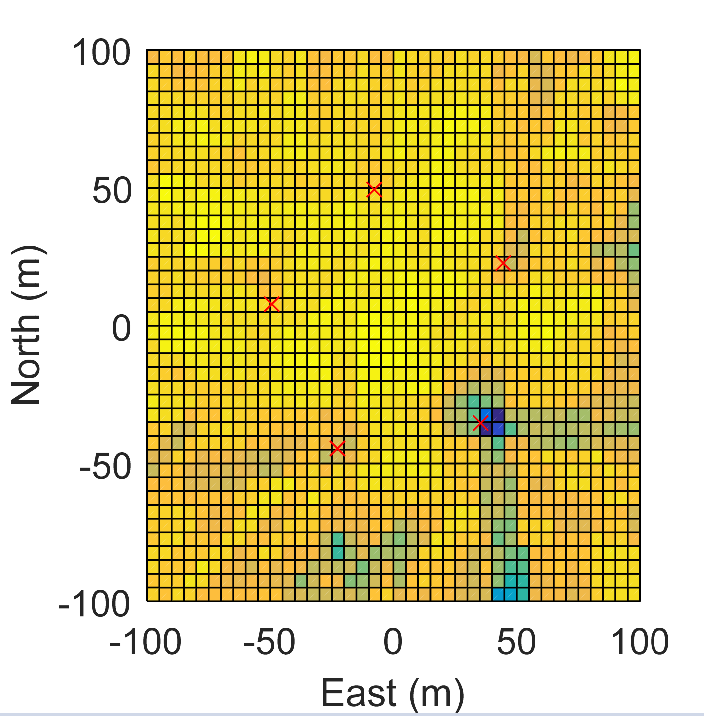
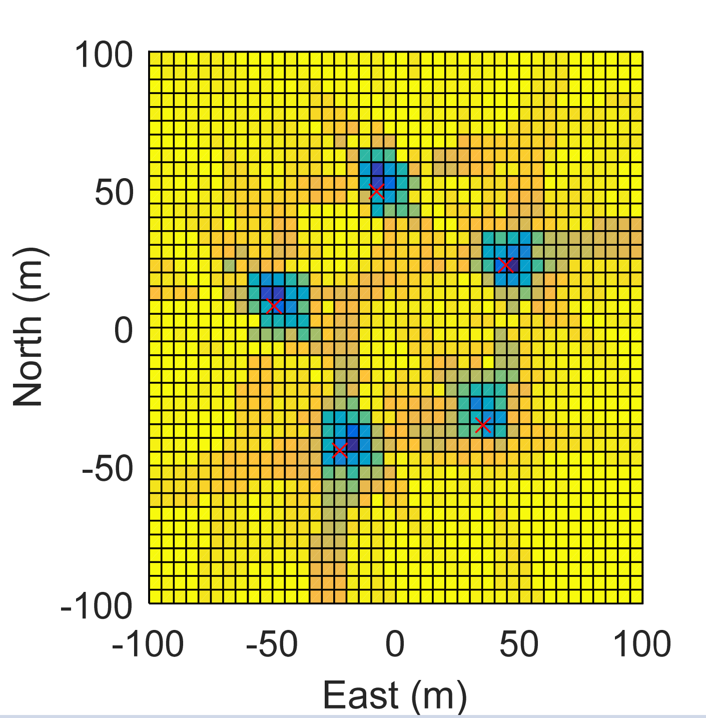


TARGET	ccDPD
	

SNR = 0dB

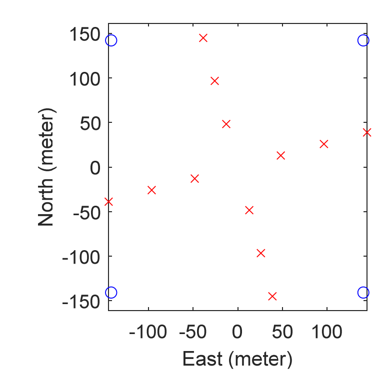
Heavy Background 8x GNSS Signals

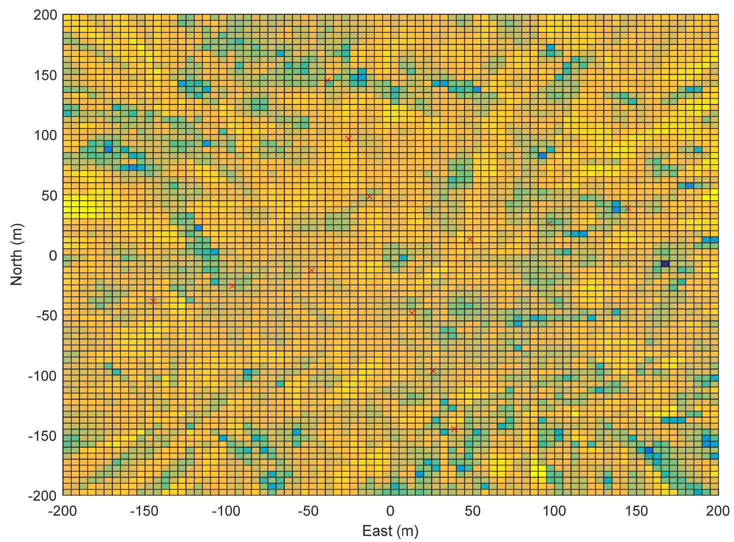
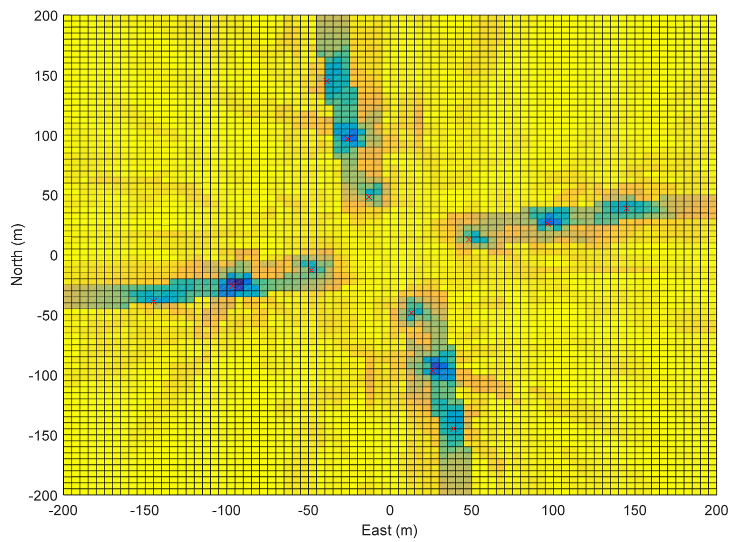


TARGET	ccDPD
	

SNR = -10dB

Large Number of Sources (Ns = 12)



TARGET	ccDPD
	

SNR = -10dB

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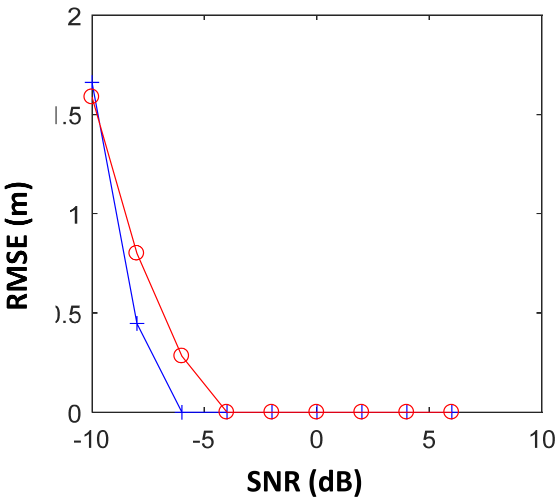
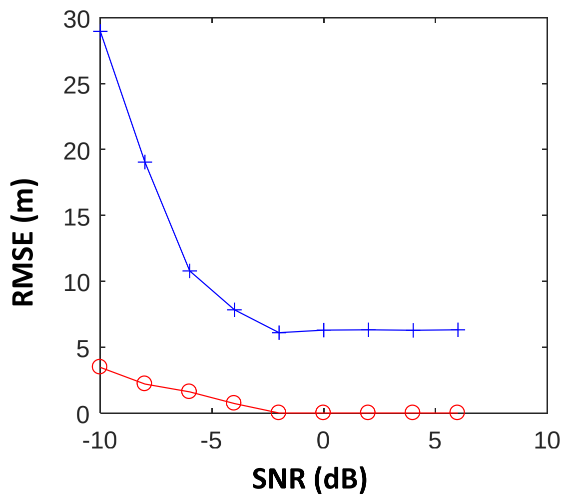
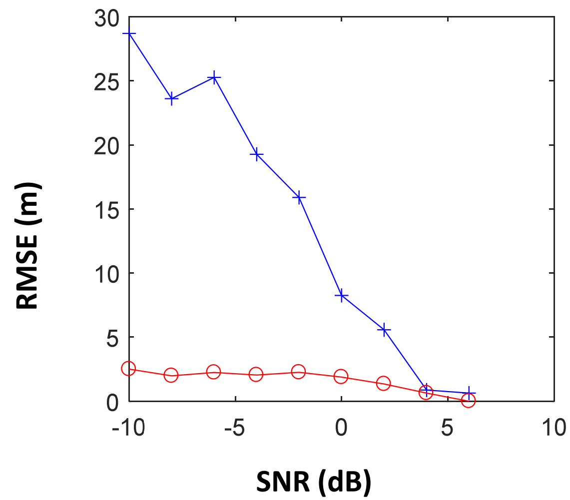
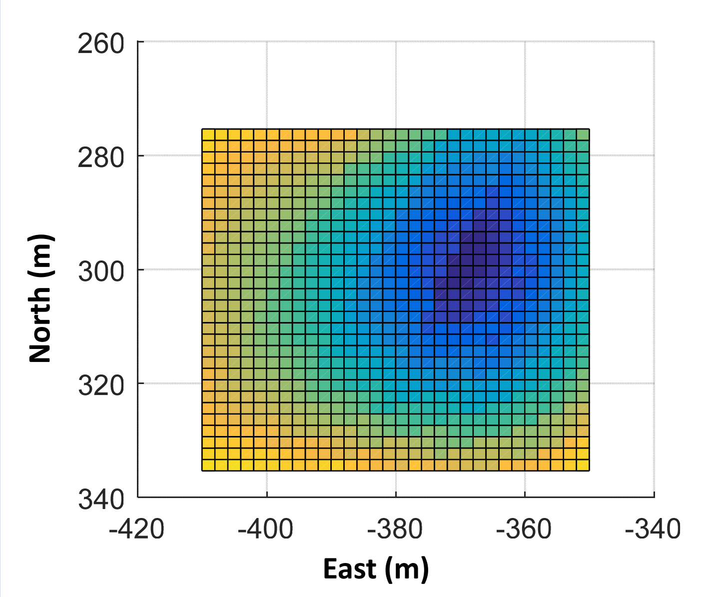
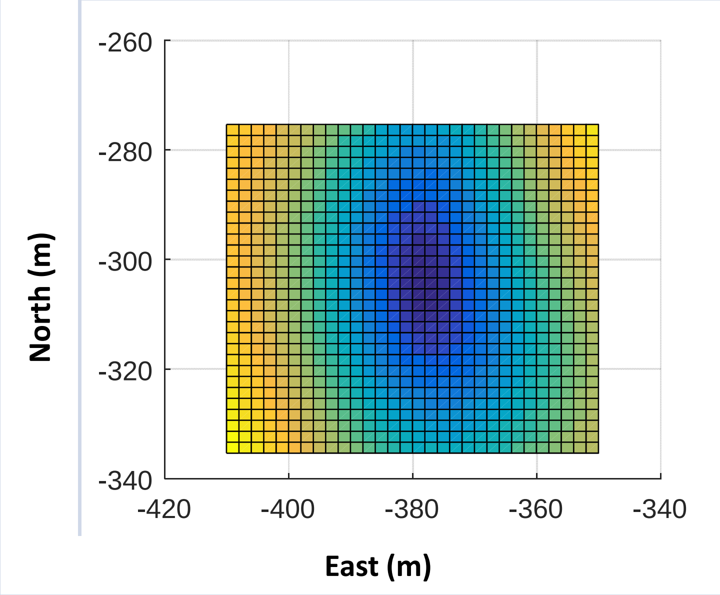
Performance Evaluation

Multiple Jammer	Heavy Background GNSS Signals	Large number of sources
		

Field Data Results

TARGET	ccDPD
	

SNR = -10dB

Conclusion

- Derived a taxonomy and compared various DPD approaches
- Proposed ccDPD method has superior SNR sensitivity in comparison to recent methods
- Proposed ccDPD method can localise more sources than TARGET

Questions?

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