Non-cooperative target localisation using rank based EDM approach

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Outline

- Introduction
- Problem Formulation
- Proposed Algorithm
- Results and Conclusion

Target Localisation

Locating RF emissions

To provide a greater level of situational awareness for units in an operational area

Locating their own units

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Range based

TOA, TDOA, RSS

Localisation

Distributed

Sensors perform many calculations and analysis to locate the target

Range free

Knowledge of connectivity possibilities

Centralised

Sensors pass information to Fusion centre

Mobile Ad-hoc Sensor Network (MASNET)

[1] Y. I.Wu, H.Wang, and X. Zheng, "WSN localisation using RSS in three-dimensional space; A geometric method with closed-form solution," IEEE Sensors J., vol. 16, no. 11, pp. 4397–4404, Jun. 2016.

[2] Z. Ma and K. C. Ho, "ToA localisation in the presence of random sensor position errors," in IEEE Int. Conf. Acoust., Speech and Signal Process. (ICASSP), 2011, pp. 2468–2471.

[3] P. Singh and S. Agrawal, "TDoA based node localisation in WSN using neural networks," in Int. Conf. Commun. Syst. and Network Technologies, 2013, pp. 400–404.

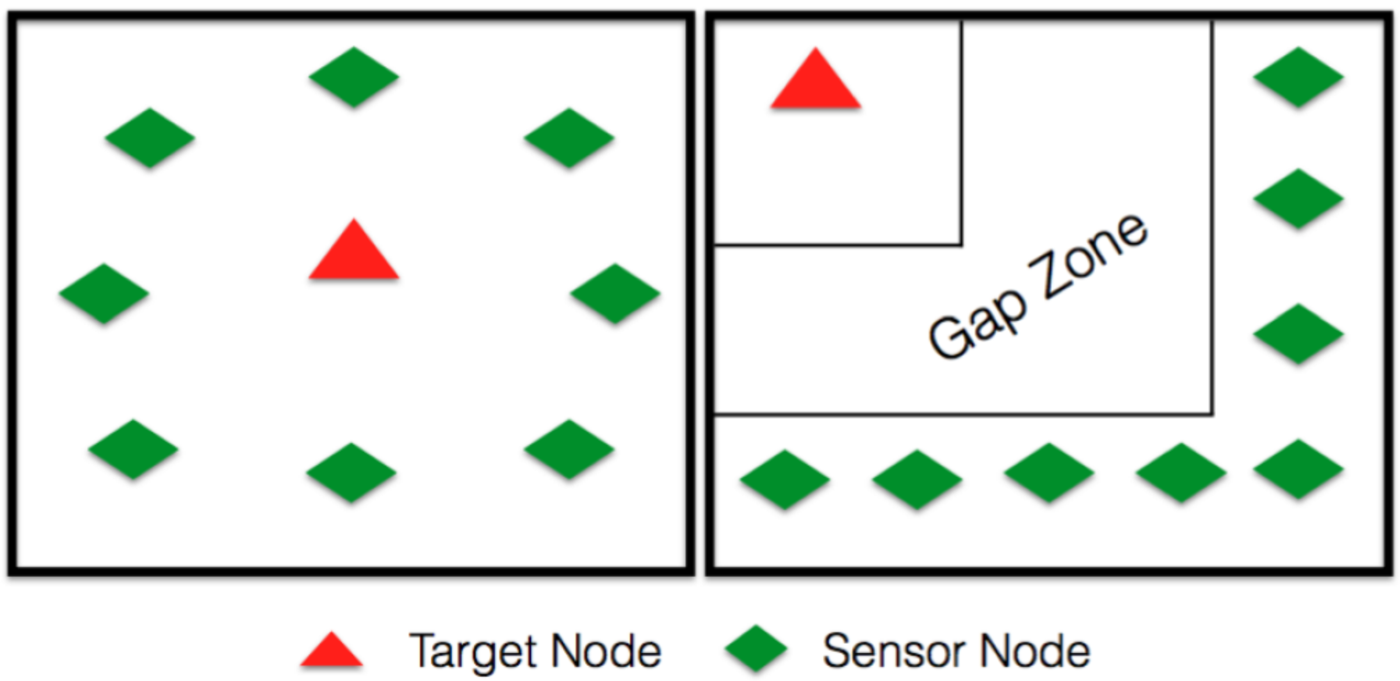
[4] A. Beck, P. Stoica, and J. Li, "Exact and approximate solutions of source localisation problems," IEEE Transactions on Signal Processing, vol. 56, no. 5, pp. 1770–1778, May 2008.

[5] L. Gui, A. Wei, and T. Val, "A range-free localization protocol for wireless sensor networks," in Int. Symp. Wireless Commun. Syst. (ISWCS), Paris, 2012, pp. 496–500.

System Model

Centralised Range based Localisation

Mixed

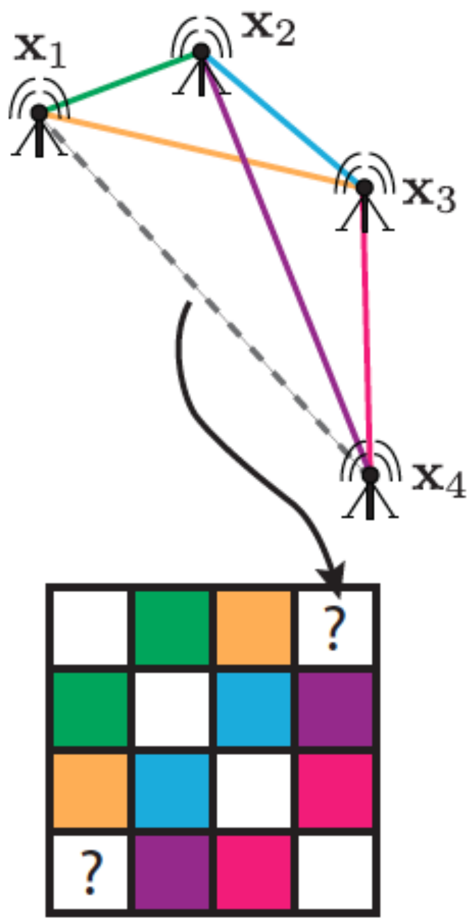


Separated

- Each sensor acquires the time information of the received signal and transmit it to the fusion centre
- The fusion centre converts this information to the corresponding distances between target and sensors nodes

Problem Formulation

- Euclidean Distance Matrix (EDM) have useful properties and are used in applications such as crystallography, acoustics,…
- EDM is a symmetric hollow matrix of squared distance between points
- Rank of an EDM is at most “d+2”, where d is the dimensional space



Two sets of distance problems

- Distances are noisy ≡ All sensors detect
- Some distances are missing ≡ Not all sensors detect

$$D = \begin{bmatrix} D_T & D_{TS} \\ D_{ST} & D_S \end{bmatrix}$$

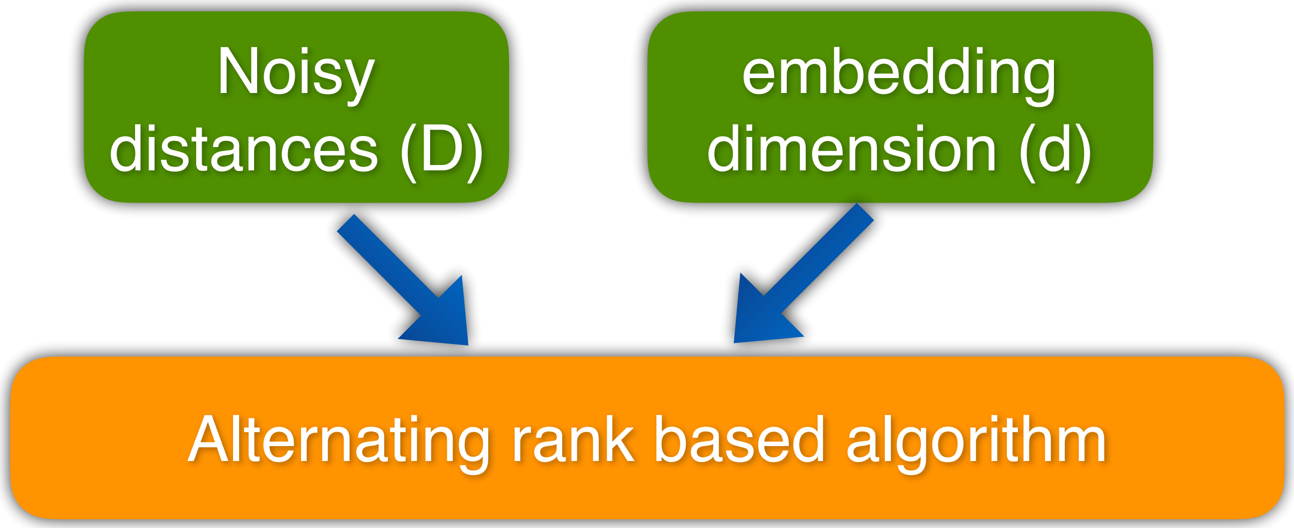
D_T : distances between target nodes

D_{TS} : distances between target and sensor nodes

D_S : distances between sensor nodes (known)

[8] I. Dokmanic, R. Parhizkar, J. Ranieri, and M. Vetterli, “Euclidean distance matrices: Essential theory, algorithms, and applications,” IEEE Signal Processing Mag., vol. 32, no. 6, pp. 12–30, Nov. 2015.

Alternating Rank based EDM



- After algorithm's convergence, the relative positions for target and sensors are computed
- These positions may be rotated and/or translated
- Exploiting Procrustes Analysis, the absolute position of target is computed

Algorithm 1 Alternating Rank Based EDM Algorithm

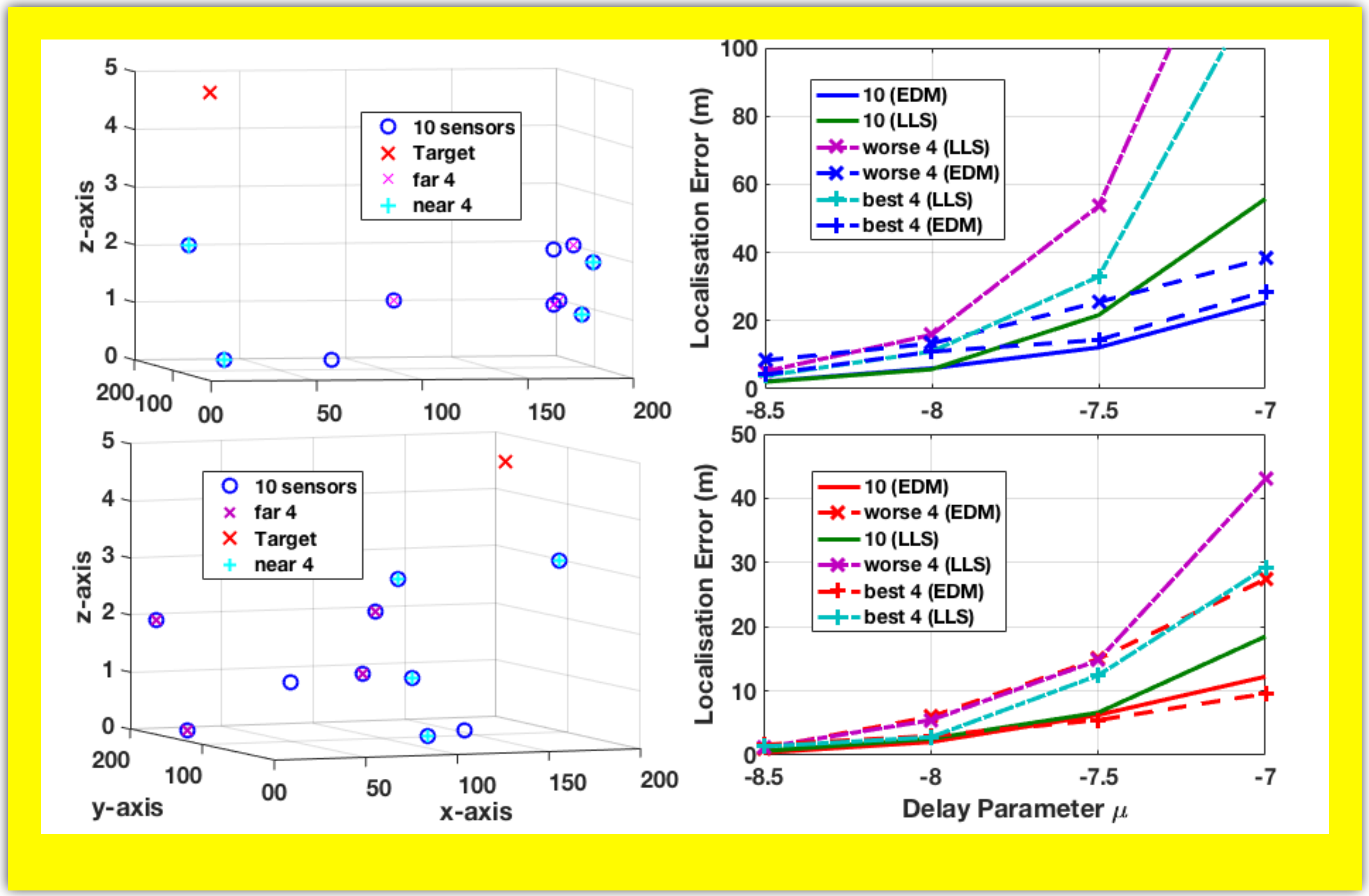
Inputs: D, W, d, max.tolerance
Output: E

Initialization and Definitions:

$\mathbf{D}_{\mathbf{1}\mathbf{1}^T-\mathbf{W}} \leftarrow \phi$ Initialize unknown entries
$\mathbf{J} \leftarrow \mathbf{I} - \frac{1}{k}\mathbf{1}\mathbf{1}^T$ Define Geometric centering matrix
repeat
  $\mathbf{G} \leftarrow \frac{-1}{2}\mathbf{JDJ}$ Compute Gram Matrix
  $\mathbf{U}, [\lambda]_{i=1}^{k} \leftarrow \text{EVD}(\mathbf{G})$ Eigenvalue Decomposition
  $\sum \leftarrow diag(\lambda_1, ...\lambda_d, 0, ...0)$
  Compute $\mathbf{G} \leftarrow \mathbf{U} \sum \mathbf{U}^T$
  Compute $\mathbf{E} = \text{diag}(\mathbf{G})\mathbf{1}^T - 2\mathbf{G} + \mathbf{1}diag(\mathbf{G})$
  Compute $e_1 = ||\mathbf{E} - \mathbf{D}||_F$
  $\mathbf{E}_\mathbf{W} \leftarrow \mathbf{D}_\mathbf{W}$ Enforce known entries
  $\mathbf{E}_\mathbf{I} \leftarrow 0$ Set Diagonal to zero
  $(\mathbf{E})_- \leftarrow 0$ Assign zeros to the negative entries
  Compute $e_2 = ||\mathbf{E} - \mathbf{D}||_F$
  if $(e_1 < \text{max. tolerance}) \vee (e_2 < \text{max.tolerance})$ **then**
    return E
  else
    $\mathbf{D} \leftarrow \mathbf{E}$
  end if
until Convergence or MaxIter
$\widehat{\mathbf{X}} = \sum^{1/2} \mathbf{U}^T$

[8] I. Dokmanic, R. Parhizkar, J. Ranieri, and M. Vetterli, "Euclidean distance matrices: Essential theory, algorithms, and applications," IEEE Signal Processing Mag., vol. 32, no. 6, pp. 12–30, Nov. 2015.

Results

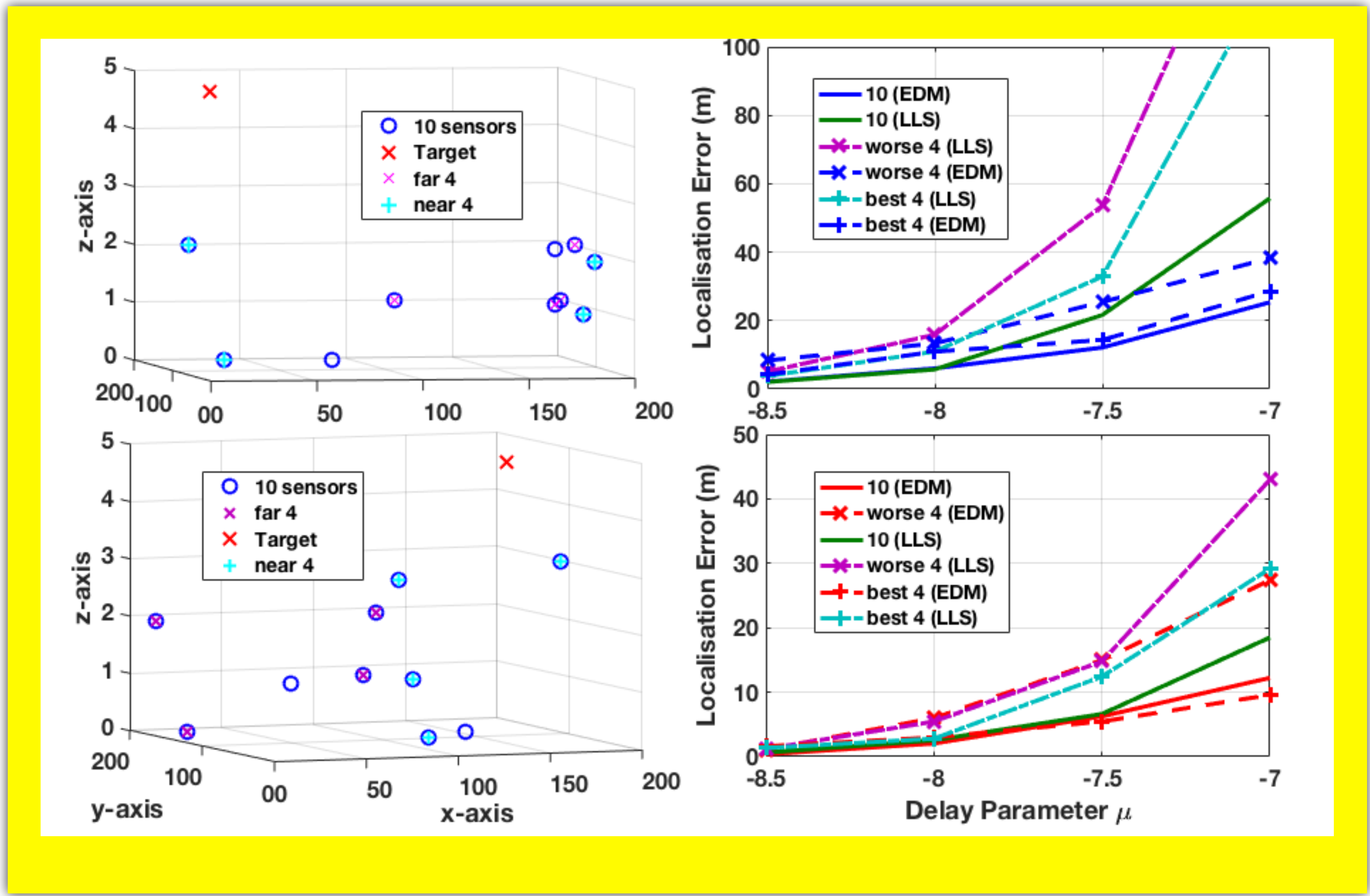


- Localisation error is the distance between the estimated and actual target positions.
- The delay parameter is the mean of exponential random variable
- Low delay values corresponds to less noise and vice versa

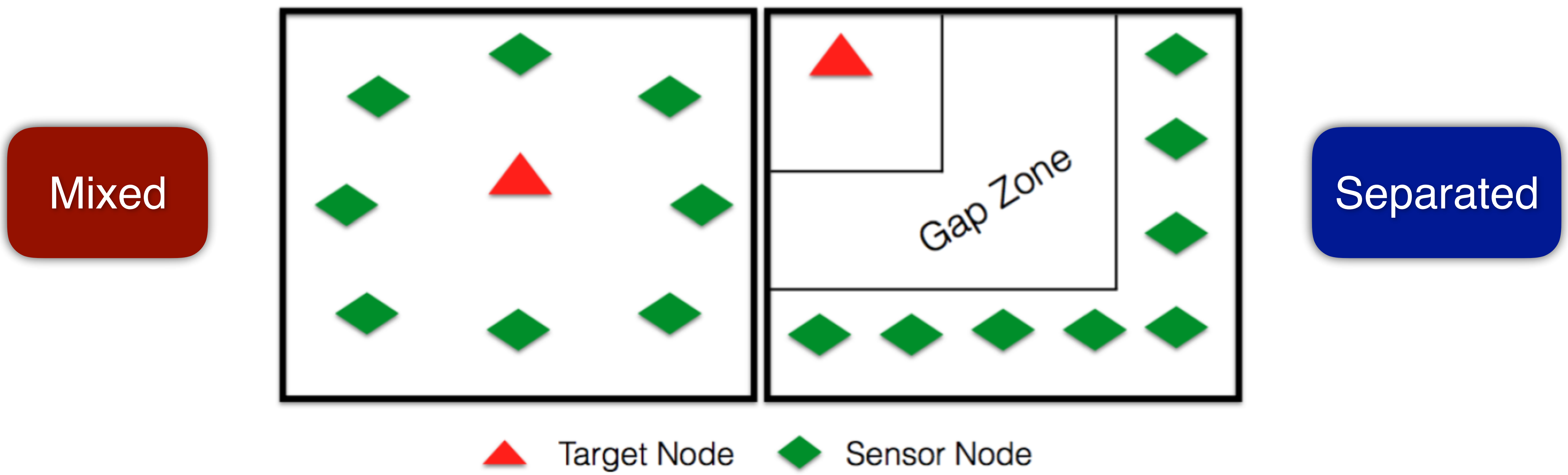
[12] WINNER II Channel Models Part I. Deliverable D1.1.2 Radio Channel Models, ver 1.2, 30.9.2007.

[13] WINNER II Channel Models Part II. Deliverable D1.1.2 Radio Channel Measurement and Analysis Results, ver 1.1, 30.9.2007.

Results



- Localisation error is larger for separated than mixed
- Localisation error using all ten and four sensors are close enough in low noise region
- LLS is worse than EDM due to outliers resulting from larger errors in the measured distances

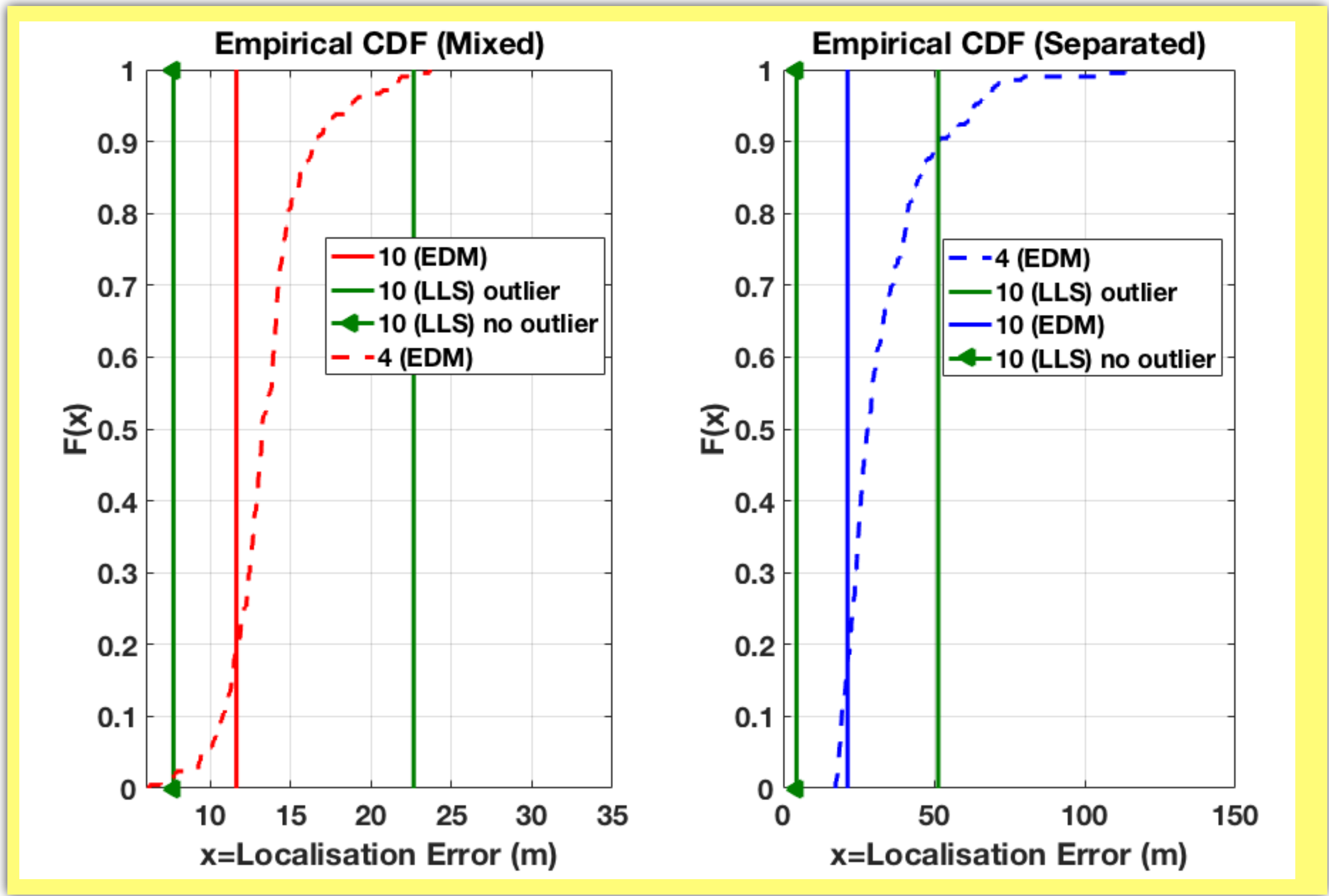


- The sensor nodes in the separated scenario experience similar receiving time information, hence similar distance measurements.
- This leads to an EDM which is not well separated in terms of distances and hence not well conditioned.

[17] K. Ball, “Eigenvalues of euclidean distance matrices,” Journal of Approximation Theory, vol. 68, no. 1, pp. 74–82, 1992.

Results

- For no outlier case, we assume that all sensors experience similar delay
- **Delay distribution for no outlier case is uniform with small standard deviation**



In some rare cases, using EDM can lead to better performance for chosen four sensors than using all ten sensors
Reason : Chosen four sensors are close to the target and experiencing overall small delay

Conclusion

- At high delay values the proposed algorithm outperforms the conventional LLS algorithm
- Localisation error depends on the amount of delay and the operating scenario for the sensors (separated or mixed)
- The sensor nodes in the separated scenario experience similar receiving time information which results in larger localisation error than in the mixed scenario
- The proposed algorithm is less sensitive to outliers

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