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An Application of Relative Node Positioning Using Ultra-Wideband Distance Estimates

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AGENDA

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- Introduction
  - Absolute Positioning
  - Relative Positioning
- Distance Estimation via UWB Signals
- Applied Method
  - Classical MDS
  - Procrustes Analysis
- Application
  - Deployed Network
  - Setup
  - Results
- Conclusions and Future Work

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Node Positioning in Wireless Sensor Networks

Monitoring	Tracking	Control
Soldier Surveillance	Health Personnel	Industrial Processes

A Crucial Issue for Military, Civilian and Industrial Areas √

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Node Positioning

Absolute

- A known global/local reference system,
- To create the reference system
  - Anchors with known positions a priori
  - Anchors equipped with GNSS receivers

Relative

- NOT require any prior position information or an external infrastructure such as GNSS signals, landmarks or beacons
- Relies only on the pairwise distances between nodes!!!

DISTANCE ESTIMATION via UWB SIGNALS

UWB is one of the most promising RF Technologies for relative positioning

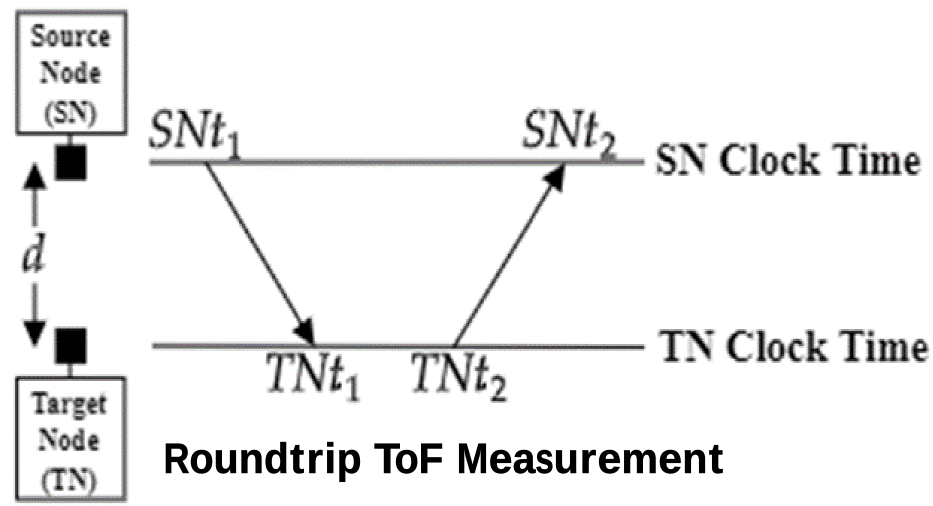
- ✓ Much more precise than others such as Wi-Fi, Bluetooth, etc.
- ✓ Penetration through obstacles
- ✓ Immunity to multipath fading thanks to the high time resolution

One-Way Time of Flight (ToF)

- Nodes need to have accurately synchronized clocks!!!

Roundtrip Time of Flight (ToF)

- Nodes use their own clocks to compute the roundtrip propagation time.
  Much more appealing!!!



Roundtrip ToF Measurement

$$d = c \times \frac{(SNt_2 - SNt_1) - (TNt_2 - TNt_1)}{2}$$

Our method assumes that

- ✓ We have a network which is not fully-connected but it contains fully-connected subnetworks!!!

Our method applies

- ✓ Multidimensional Scaling (MDS) – Part I
  - o Local relative maps for fully-connected subnetworks are obtained by applying MDS

- ✓ Procrustes Analysis – Part II
  - o By merging these local maps via Procrustes analysis, a global map for the entire network is created.

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What does the MDS algorithm provide for relative positioning purposes?

- ✓ MDS provides a map for a fully-connected network using the pairwise distances between the nodes in the network
- ✓ MDS eliminates the translational freedom, but, not the rotational one. Thus, MDS can not provide the axes orientation!!!

Classical MDS Algorithm:

Step 1. Given the pairwise distances between nodes, d_{ij}, set up the matrix of squared distances D such that

$$D=\begin{bmatrix} 0 & d_{12}^2 & \cdots & d_{1n}^2 \\ d_{21}^2 & 0 & \cdots & d_{2n}^2 \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1}^2 & d_{n2}^2 & \cdots & 0 \end{bmatrix}$$

Step 2. Construct nxn centering matrix C

$$C=I-\frac{1}{n}J$$

where I and J are identity and all-ones matrices, respectively, with nxn sizes.

Step 3. Apply double centering to remove the means from each rows and columns of D and to obtain symmetric positive semi-definite matrix N with the size nxn

$$N=-\frac{1}{2}CDC$$

Step 4. Determine the m largest eigenvalues $\lambda_1, \lambda_2, \ldots, \lambda_m$ and corresponding eigenvectors $\vec{e}_1, \vec{e}_2, \ldots, \vec{e}_m$ of N where m is the number of dimensions identified by the sensor network structure. For example, m=2 for two-dimensional networks and m=3 for three-dimensional networks.

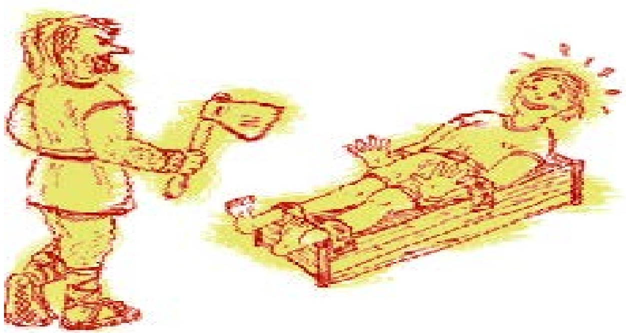
Step 5. Finally, the relative positions of n sensor nodes are derived from the mxn coordinate matrix X

$$X=\Lambda^{1/2}E^T$$

where $\Lambda^{1/2} = \mathrm{diag}(\sqrt{\lambda_1}, \sqrt{\lambda_2}, \ldots, \sqrt{\lambda_m})$, E is the matrix of corresponding m eigenvectors of N, and the superscript ^{T} denotes the transpose of a matrix.

Who is Procrustes?

- ✓ An innkeeper in Greek Mythology who made his guests fit the size of an iron bed
  - o By stretching them if they were too short
  - o By chopping off their extremities if they were too long.



Picture taken from «GENERALIZED PROCRUSTES ANALYSIS AND ITS APPLICATIONS IN PHOTOGRAMMETRY», M. Devrim AKCA, 2003

What is Procrustes analysis? Of Course Mathematically ☺

- ✓ Matching one representation to another and producing a measure for this matching
- ✓ Finding rigid motions (i.e., reflection, rotation and translation) and isotropic dilation.

APPLICATION – Deployed Network

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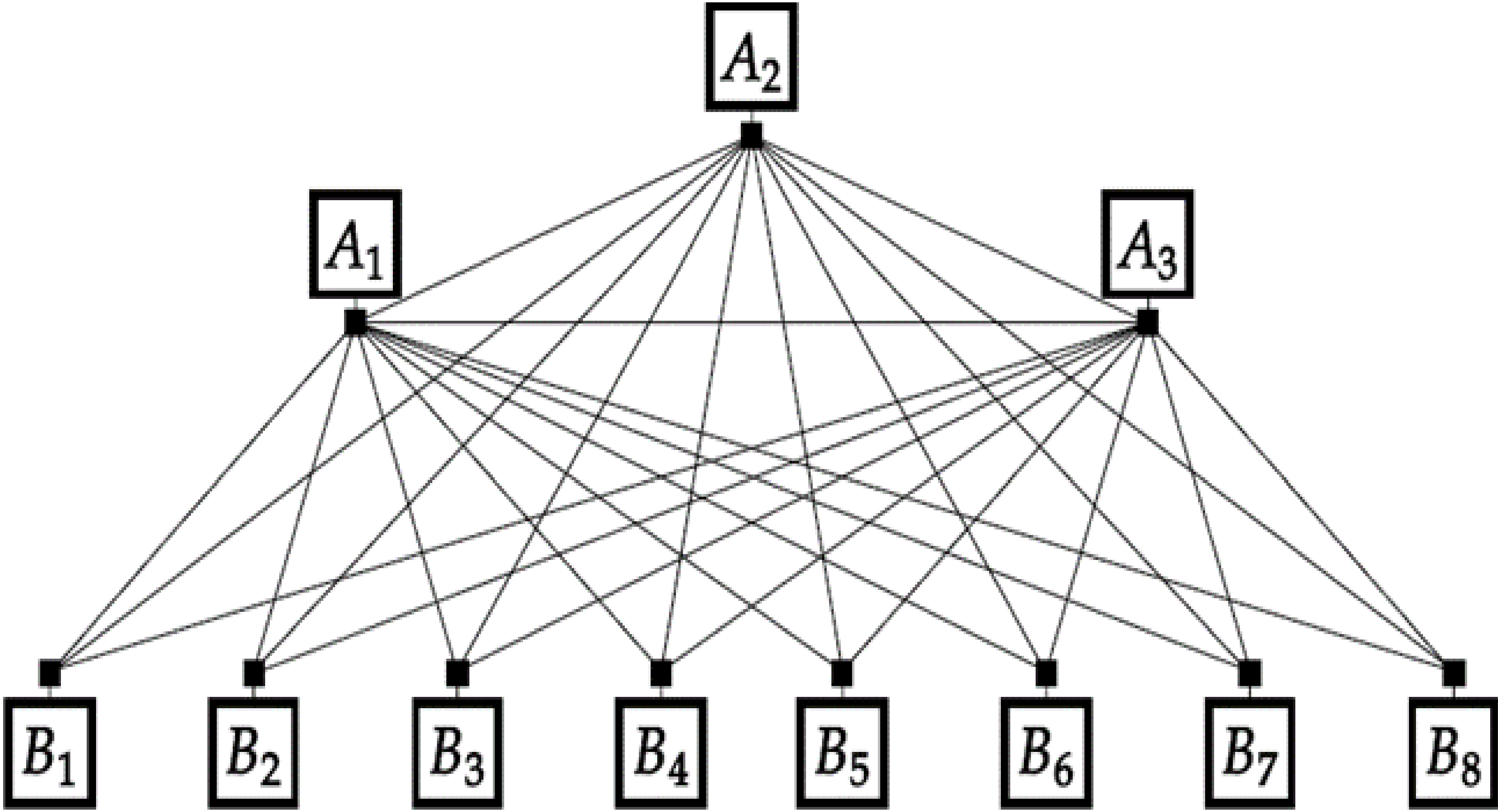

EVB1000 Module

APPLICATION - Setup

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Actual
UWB Estimates
MDS + Procrustes

Nodes	A_1	A_2	A_3	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
A_1	0	10.48 10.71 10.71	6.27 6.47 6.46	9.08 9.15 9.15	7.89 8.03 8.01	5.91 6.06 5.99	3.80 3.92 3.88	3.06 3.21 3.12	2.55 2.69 2.57	6.63 6.76 6.76	5.43 5.62 5.57
A_2	10.48 10.71 10.71	0	5.94 6.21 6.21	3.80 3.96 3.93	2.68 2.86 2.83	4.80 5.01 4.91	7.52 7.73 7.72	7.42 7.62 7.60	8.42 8.63 8.61	4.69 4.87 4.88	5.13 5.33 5.29
A_3	6.27 6.47 6.46	5.94 6.21 6.21	0	3.06 3.13 3.04	3.50 3.63 3.61	4.24 4.40 4.40	2.47 2.65 2.58	3.84 4.00 3.96	5.53 5.74 5.75	1.34 1.35 1.43	2.47 2.59 2.49
B_1	9.08 9.15 9.15	3.80 3.96 3.93	3.06 3.13 3.04	0	2.68 ---2.59	5.09 --- 5.03	5.40 --- 5.40	6.27 --- 6.23	7.80 --- 7.84	2.47 --- 2.40	4.03 --- 3.87
B_2	7.89 8.03 8.01	2.68 2.86 2.83	3.50 3.63 3.61	2.68 --- 2.59	0	2.68 --- 2.72	4.84 --- 4.89	4.84 --- 4.89	6.03 --- 6.14	2.16 --- 2.19	2.47 --- 2.48
B_3	5.91 6.06 5.99	4.80 5.01 4.91	4.24 4.40 4.40	5.09 --- 5.03	2.68 --- 2.72	0	4.03 --- 4.05	3.00 --- 3.04	3.65 --- 3.71	3.23 --- 3.28	1.80 --- 1.94
B_4	3.80 3.92 3.88	7.52 7.73 7.72	2.47 2.65 2.58	5.40 --- 5.40	4.84 --- 4.89	4.03 --- 4.05	0	1.90 --- 1.88	3.50 --- 3.57	3.06 --- 3.11	2.55 --- 2.52
B_5	3.06 3.21 3.12	7.42 7.62 7.60	3.84 4.00 3.93	6.27 --- 6.23	4.84 --- 4.89	3.00 --- 3.04	1.90 --- 1.88	0	1.70 --- 1.79	3.80 --- 3.84	2.40 --- 2.48
B_6	2.55 2.69 2.57	8.42 8.63 8.61	5.53 5.74 5.75	7.80 --- 7.84	6.03 --- 6.14	3.65 --- 3.71	3.50 --- 3.57	1.70 --- 1.79	0	5.37 --- 5.49	3.80 --- 3.97
B_7	6.63 6.76 6.76	4.69 4.87 4.88	1.34 1.35 1.43	2.47 --- 2.40	2.16 --- 2.19	3.23 --- 3.28	3.06 --- 3.11	3.80 --- 3.84	5.37 --- 5.49	0	1.70 --- 1.61
B_8	5.43 5.62 5.57	5.13 5.33 5.29	2.47 2.59 2.49	4.03 --- 3.87	2.47 --- 2.48	1.80 --- 1.94	2.55 --- 2.52	2.40 --- 2.48	3.80 --- 3.97	1.70 --- 1.61	0

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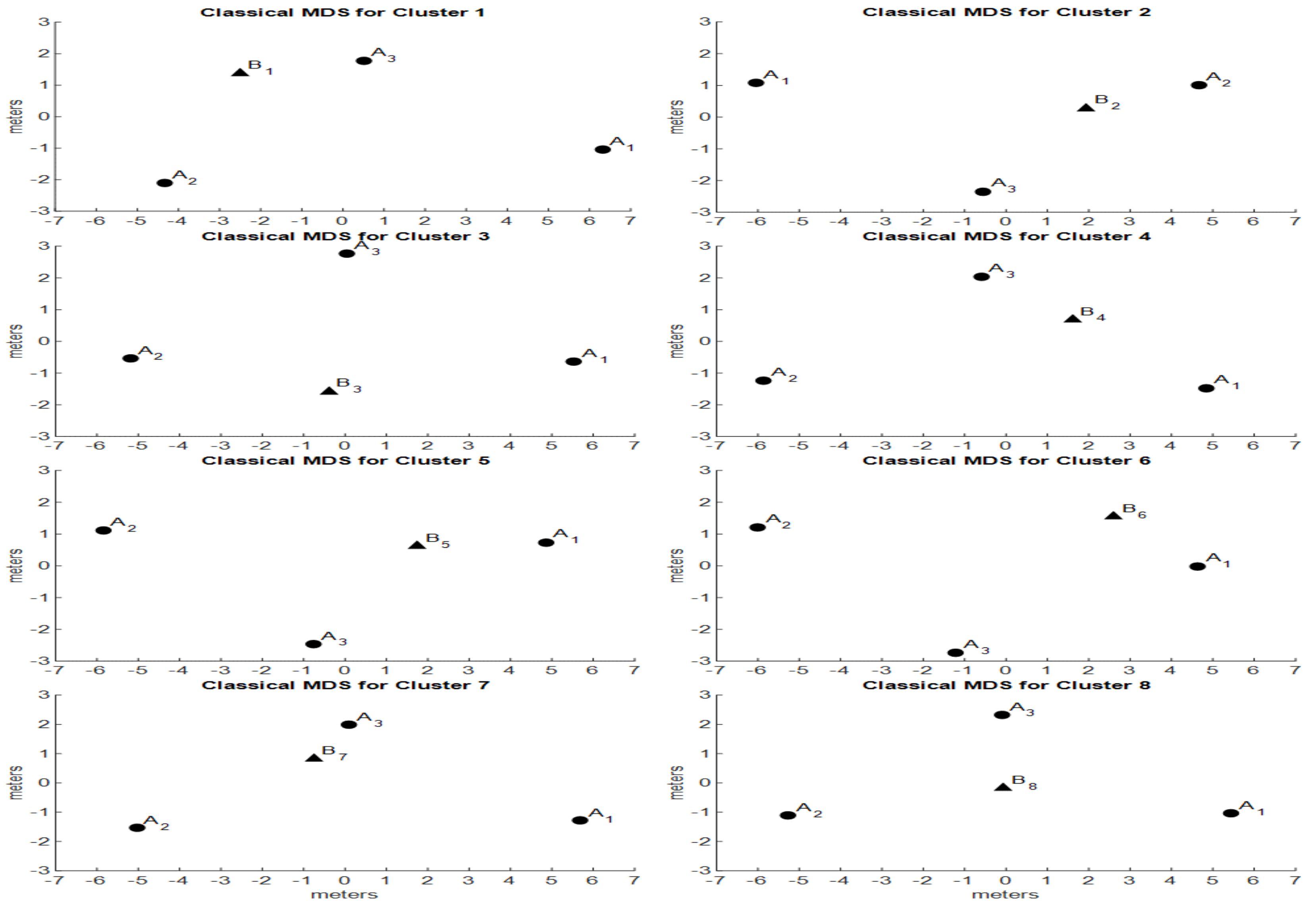
Classical MDS for Cluster 1
Classical MDS for Cluster 2
Classical MDS for Cluster 3
Classical MDS for Cluster 4
Classical MDS for Cluster 5
Classical MDS for Cluster 6
Classical MDS for Cluster 7
Classical MDS for Cluster 8
meters
meters
A1
A2
A3
B1
B2
B3
B4
B5
B6
B7
B8

APPLICATION – Results – Part II - Procrustes

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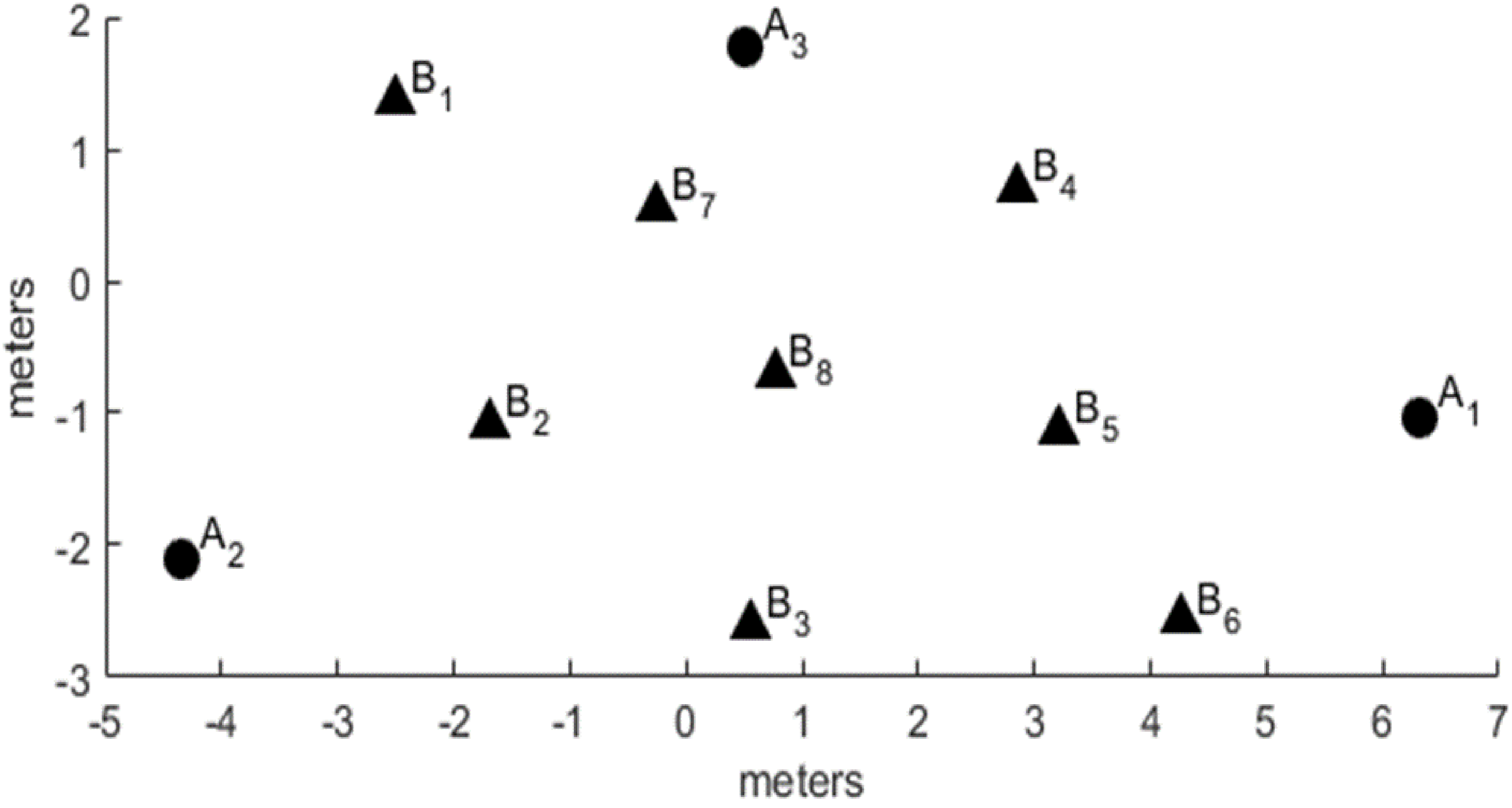

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Application results show that

The method provides the following abilities

- ✓ to build relative local maps of fully-connected subnetworks,
- ✓ to merge these local maps together by using their common nodes to obtain a relative global map of the entire network,
- ✓ To obtain pairwise distances among unconnected nodes which cannot be estimated via UWB signals.

For future work

The method will be studied for

- ✓ Three-dimensional networks,
- ✓ Evaluating the real-time application costs such as power consumption, time complexity, etc.

Thanks for your consideration!!!
Questions?