Acoustic Self-Localization in a Distributed Sensor Network

IEEE Sensor Journal
Feb. 2006

2006.06.22

Outline

- Introduction
- TDOA Self-Localization
- Simulation Results
- Experimental Results
- Conclusions
- Discussions

Definition

- Self-organization is the process of determining the (x, y, z) coordinates of all nodes in the network relative to each other.

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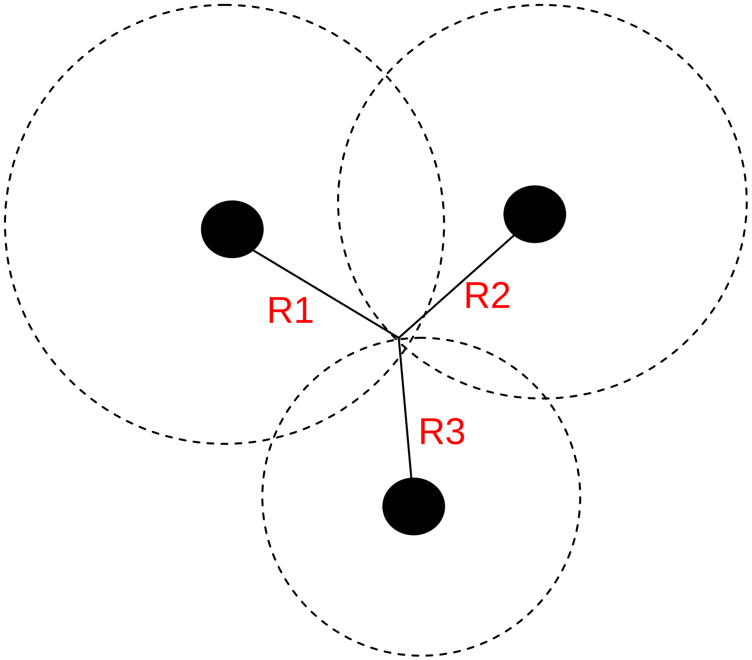
Outdoor Location Methods

- GPS



Indoor Location Methods (1/2)

- RF-based
  - RSS (Radio Signal Strength)
    - RSS is only determined by distance

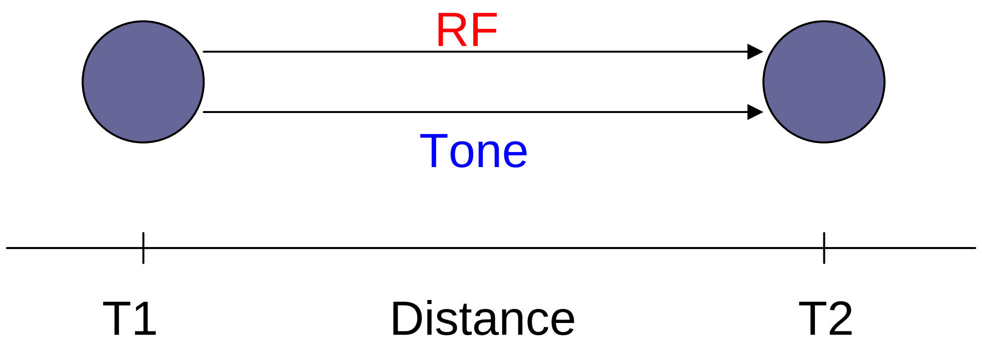
$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} \propto d^{-2} \; or \;\; d^{-4}$$

Propagation model (Free space)

- Disadvantages
  - High cost
  - Signal strength is unstable

Indoor Location Methods (2/2)

- Acoustic-based
  - TOA (Time of Arrival)



Distance = V *（T2 – T1）

  - TDOA (Time Difference of Arrival)
    - A Special case of TOA approach

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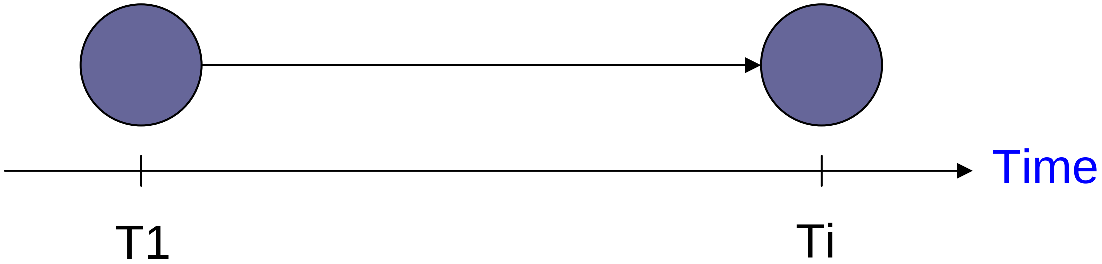
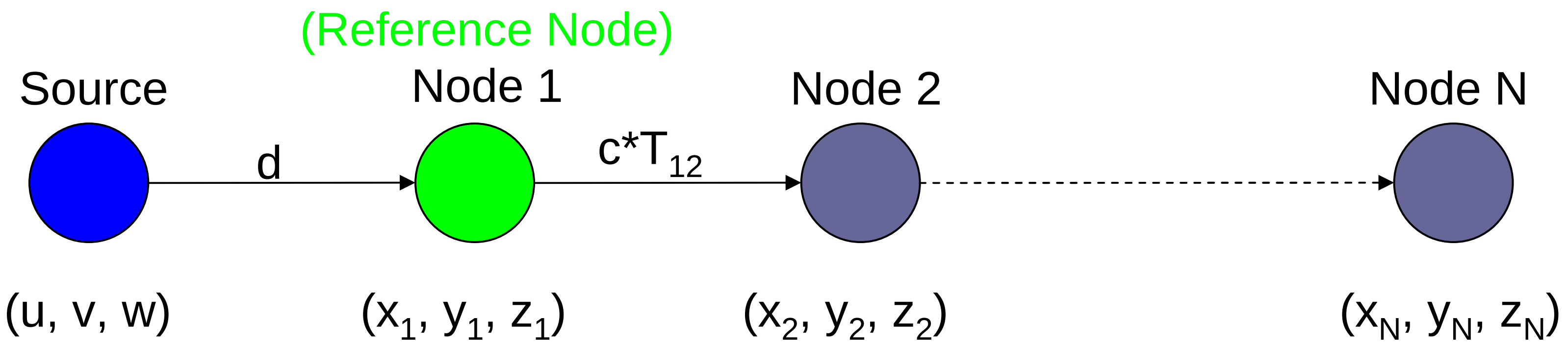
Assumptions

- *N* sensor nodes
- *S* acoustic sources
- The source emitting time is known
- The sources are equipped with GPS devices
- The TDOA equations are solved by a central server

Formulation



Time difference: $T_{1i} = T_i - T_1$



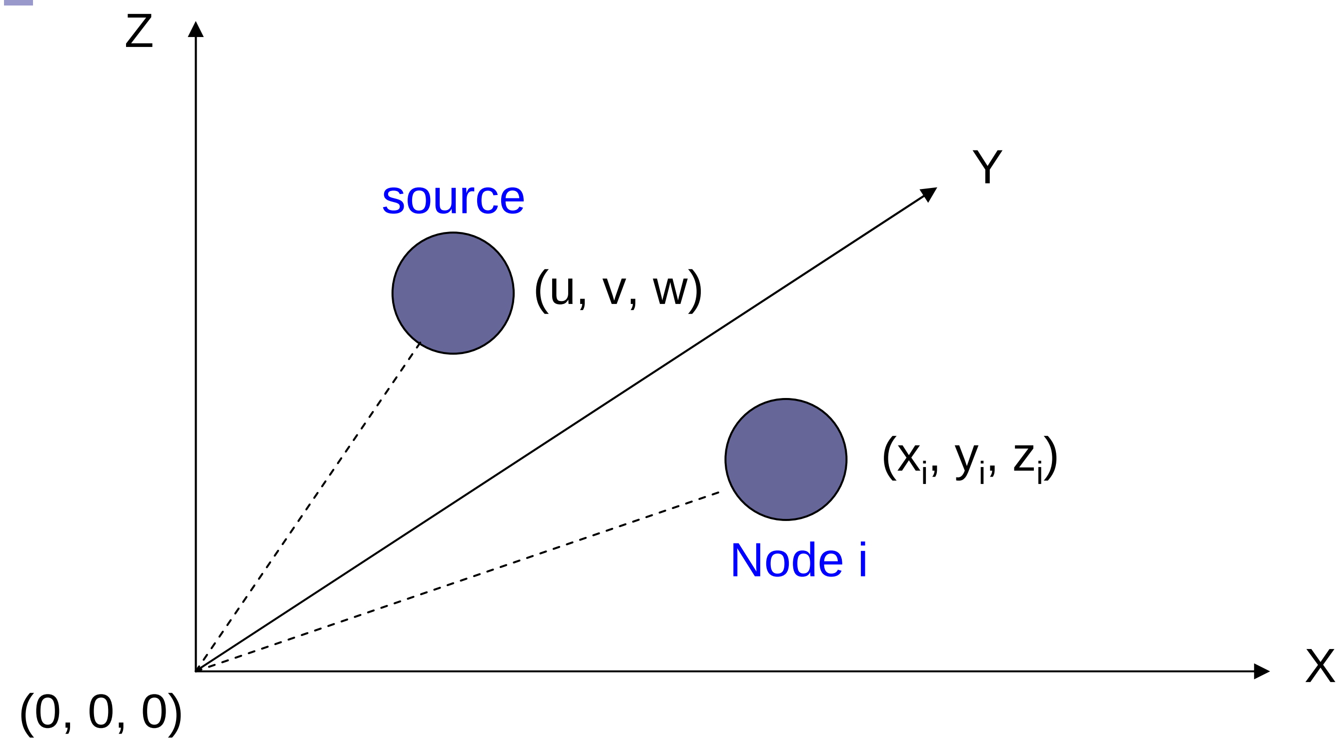
c: the speed of sound

$$
\begin{aligned}
d^2 &= (x_1 - u)^2 + (y_1 - v)^2 + (z_1 - w)^2 \\
(d + cT_{12})^2 &= (x_2 - u)^2 + (y_2 - v)^2 + (z_2 - w)^2 \\
(d + cT_{13})^2 &= (x_3 - u)^2 + (y_3 - v)^2 + (z_3 - w)^2 \\
&\vdots \\
(d + cT_{1N})^2 &= (x_N - u)^2 + (y_N - v)^2 + (z_N - w)^2
\end{aligned}
\qquad \textbf{(2)}
$$

- The locations of Source and Node 1(reference node) are known

Expanding (2), we get (3)

$$
\begin{aligned}
d^2 &= x_1^2 - 2ux_1 + u^2 + y_1^2 - 2vy_1 + v^2 \\
&\quad + z_1^2 - 2wz_1 + w^2 \\
d^2 + 2cT_{12}d + c^2T_{12}^2 &= x_2^2 - 2ux_2 + u^2 + y_2^2 - 2vy_2 + v^2 \\
&\quad + z_2^2 - 2wz_2 + w^2 \\
d^2 + 2cT_{13}d + c^2T_{13}^2 &= x_3^2 - 2ux_3 + u^2 + y_3^2 - 2vy_3 + v^2 \\
&\quad + z_3^2 - 2wz_3 + w^2 \\
&\vdots \\
d^2 + 2cT_{1N}d + c^2T_{1N}^2 &= x_N^2 - 2ux_N + u^2 + y_N^2 - 2vy_N \\
&\quad + v^2 + z_N^2 - 2wz_N + w^2. \qquad (3)
\end{aligned}
$$



$$R_i^2 = x_i^2 + y_i^2 + z_i^2 \qquad \textbf{(4)}$$
$$R_s^2 = u^2 + v^2 + w^2$$

$$d^2 - R_s^2 = R_1^2 - 2ux_1 - 2vy_1 - 2wz_1 = B \qquad \textbf{(5)}$$

Substituting (4) and (5) into all but first of (3)

$$B+2cT_{12}d+c^2T_{12}^2=R_2^2-2ux_2-2vy_2-2wz_2$$
$$B+2cT_{13}d+c^2T_{13}^2=R_3^2-2ux_3-2vy_3-2wz_3$$
$$\vdots$$
$$B+2cT_{N4}d+c^2T_{1N}^2=R_N^2-2ux_N-2vy_N-2wz_N$$

For
1 source
N nodes

We can get

- (N-1) equations
- 4(N-1) unknowns
  (R_i^2, x_i, y_i, z_i)

Then →

We need more sources at different locations to solve this equations

For S sources and a single node

$$B_a + 2cT_{1ia}d + c^2T_{1ia}^2 = R_i^2 - 2u_a x_i - 2v_a y_i - 2w_a z_i$$
$$B_b + 2cT_{1ib}d + c^2T_{1ib}^2 = R_i^2 - 2u_b x_i - 2v_b y_i - 2w_b z_i$$
$$\vdots$$
$$B_c + 2cT_{1ic}d + c^2T_{1ic}^2 = R_i^2 - 2u_c x_i - 2v_c y_i - 2w_c z_i$$
$$\vdots$$

S={ a, b, c, …}

Node i, i=2, 3,…N

It can be interpreted as a set of S linear equations with four unknowns

$$\mathbf{A}_i \mathbf{x}_i = \mathbf{b}_i$$

where

$$\mathbf{A}_i = \begin{bmatrix} 1 & -2u_a & -2v_a & -2w_a \\ 1 & -2u_b & -2v_b & -2w_b \\ \vdots & \vdots & \vdots & \vdots \end{bmatrix}$$

$$\mathbf{b}_i = \begin{bmatrix} B_a + 2cT_{1ia}d + c^2T_{1ia}^2 \\ B_b + 2cT_{1ib}d + c^2T_{1ib}^2 \\ \vdots \end{bmatrix}$$

and the unknown vector of the form

$$\mathbf{x}_i = \left\{ R_i^2 \quad x_i \quad y_i \quad z_i \right\}^T.$$

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Inaccurate Factors

- Clock synchronization
- TOA measurements
  - Source location error
  - TOA measurement error
- Speed of sound

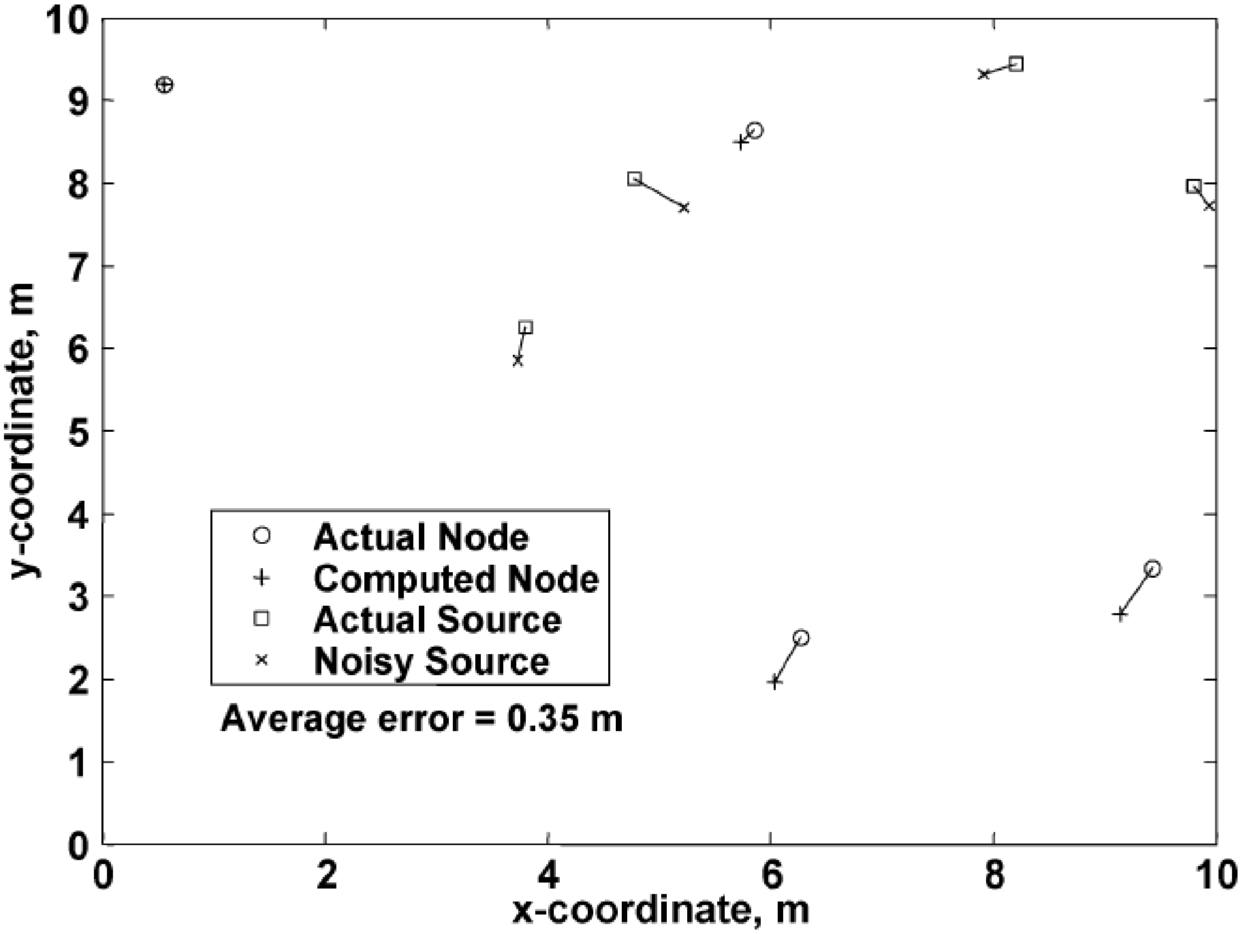
V= 331 + 0.6 T
or
V = 331*sqrt(1+T/273)

T: temperature

Simulation results

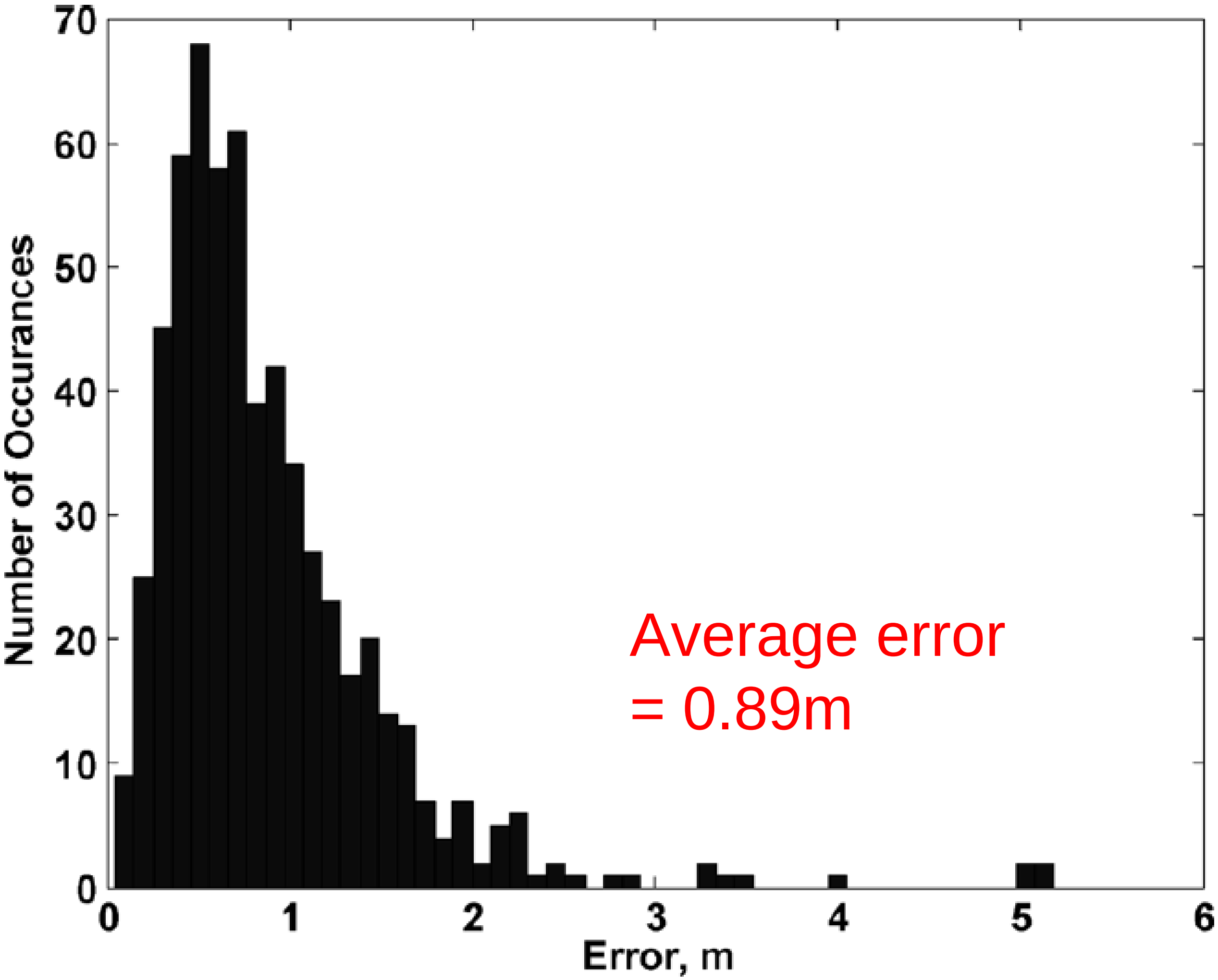
Within a 10m per side cube

S=4
N=4

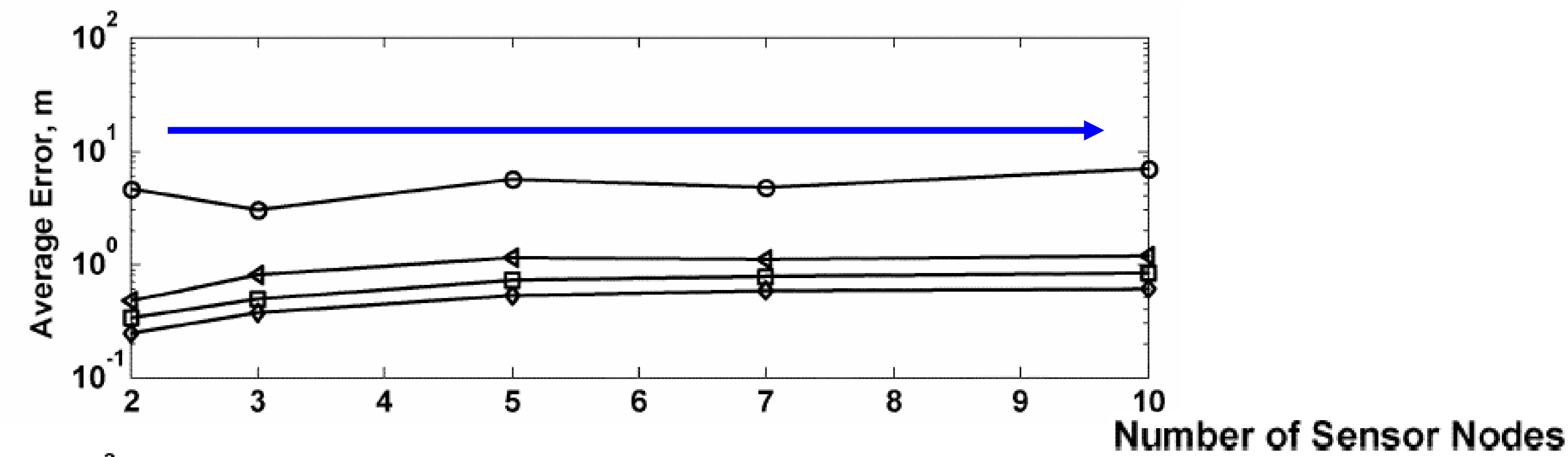


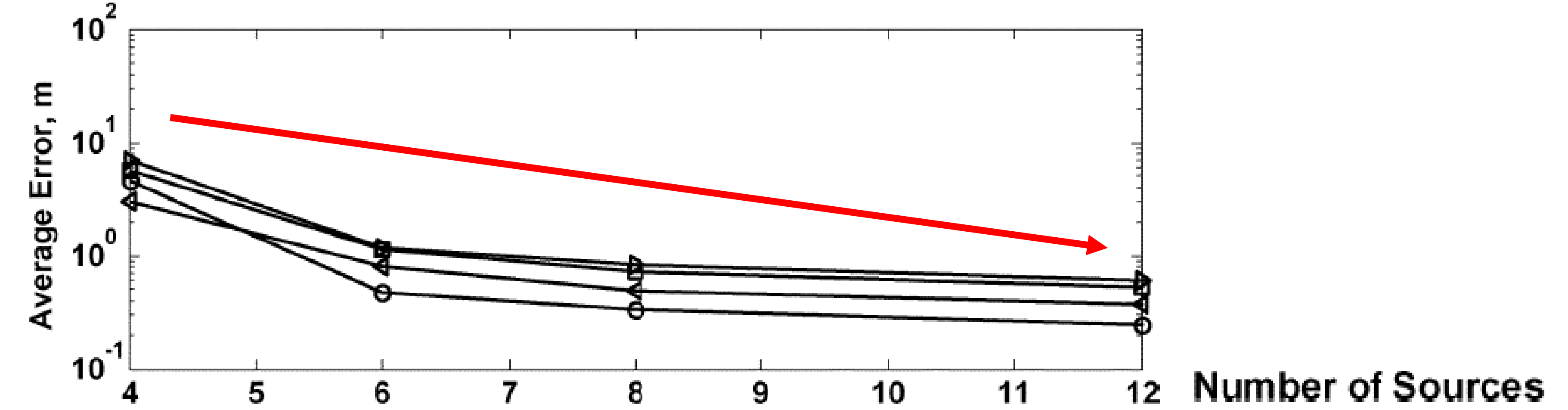
Simulation results

500 trials
S=8
N=7

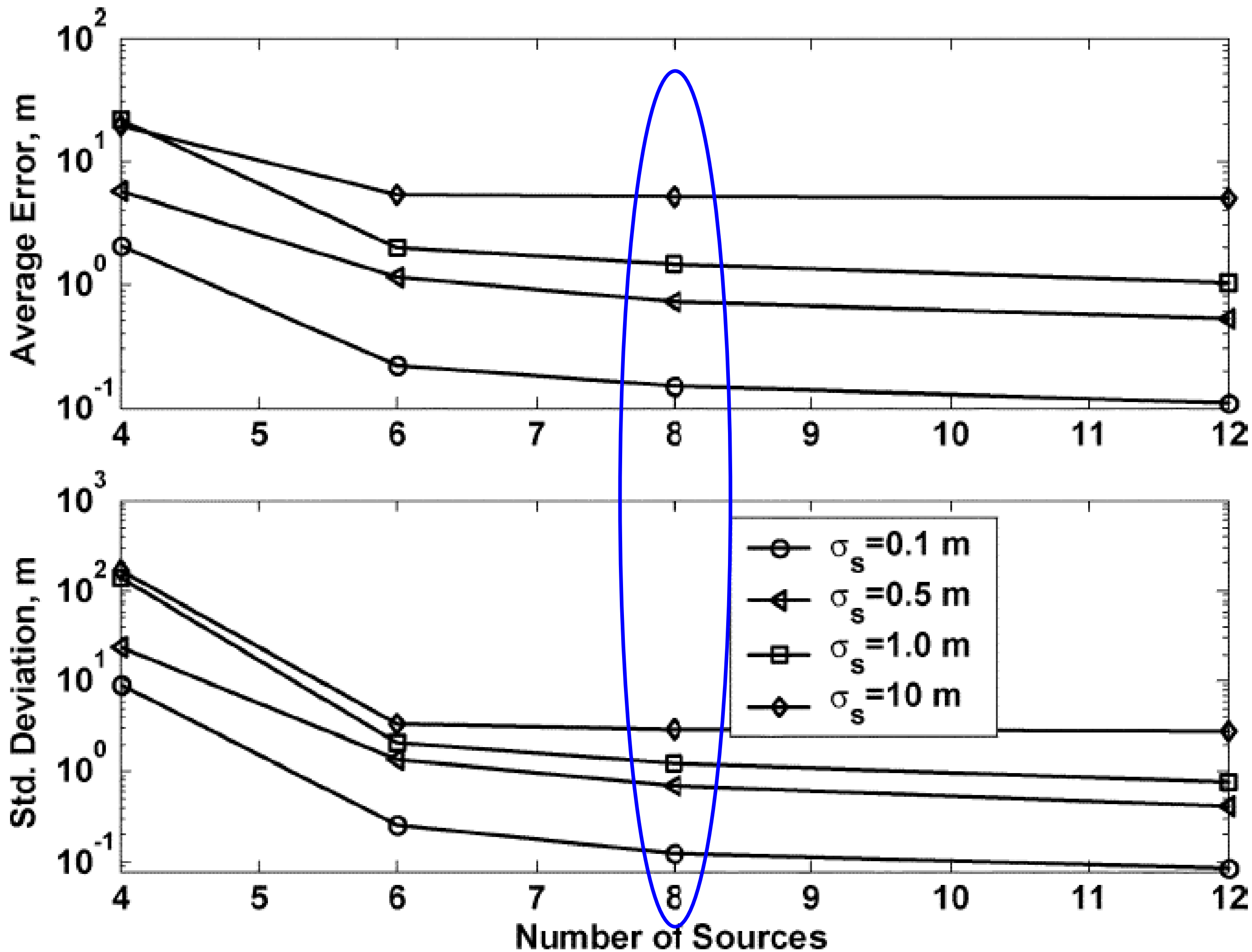


The impacts of sources and sensor nodes

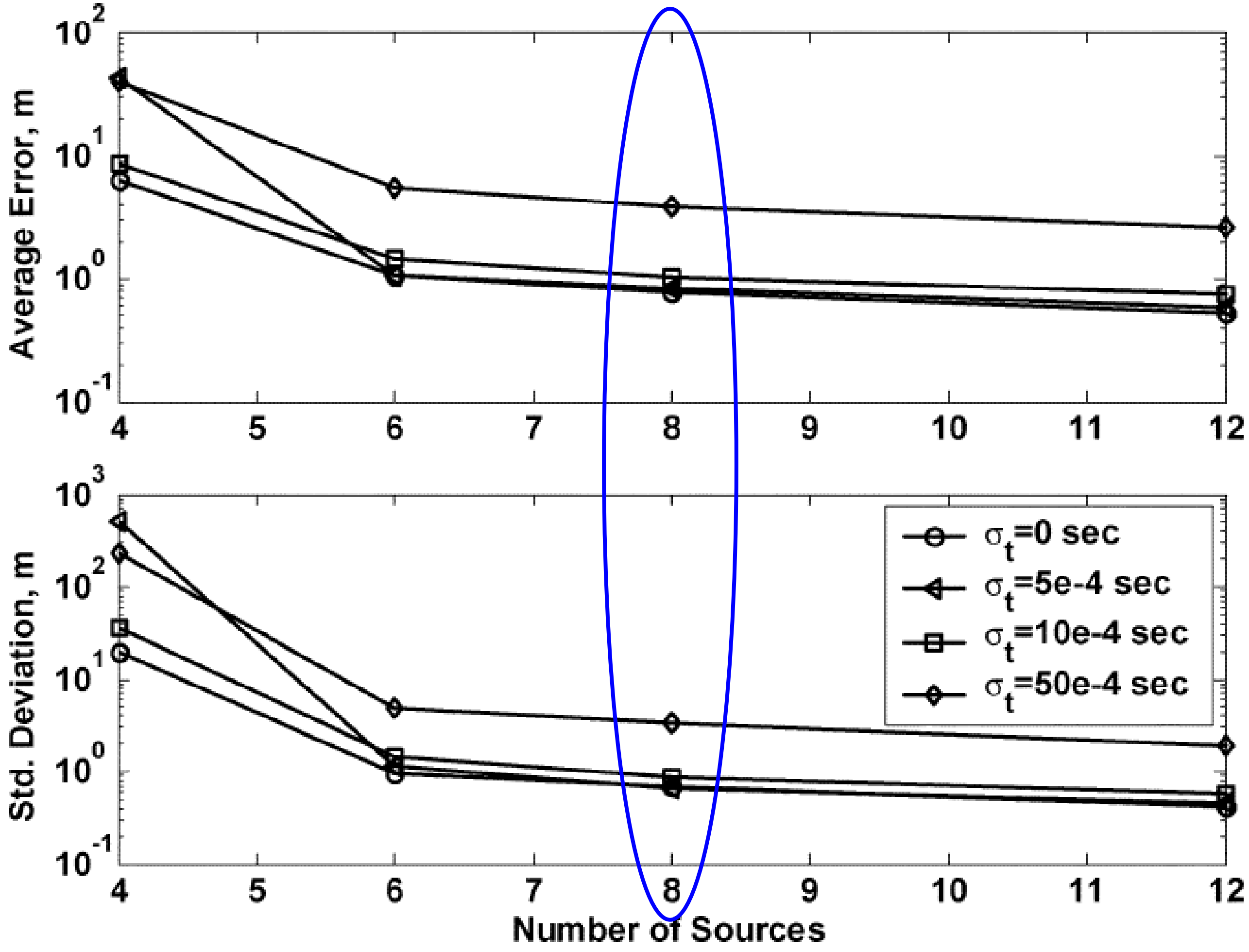




The impact of source location error



The impact of TOA measurement error



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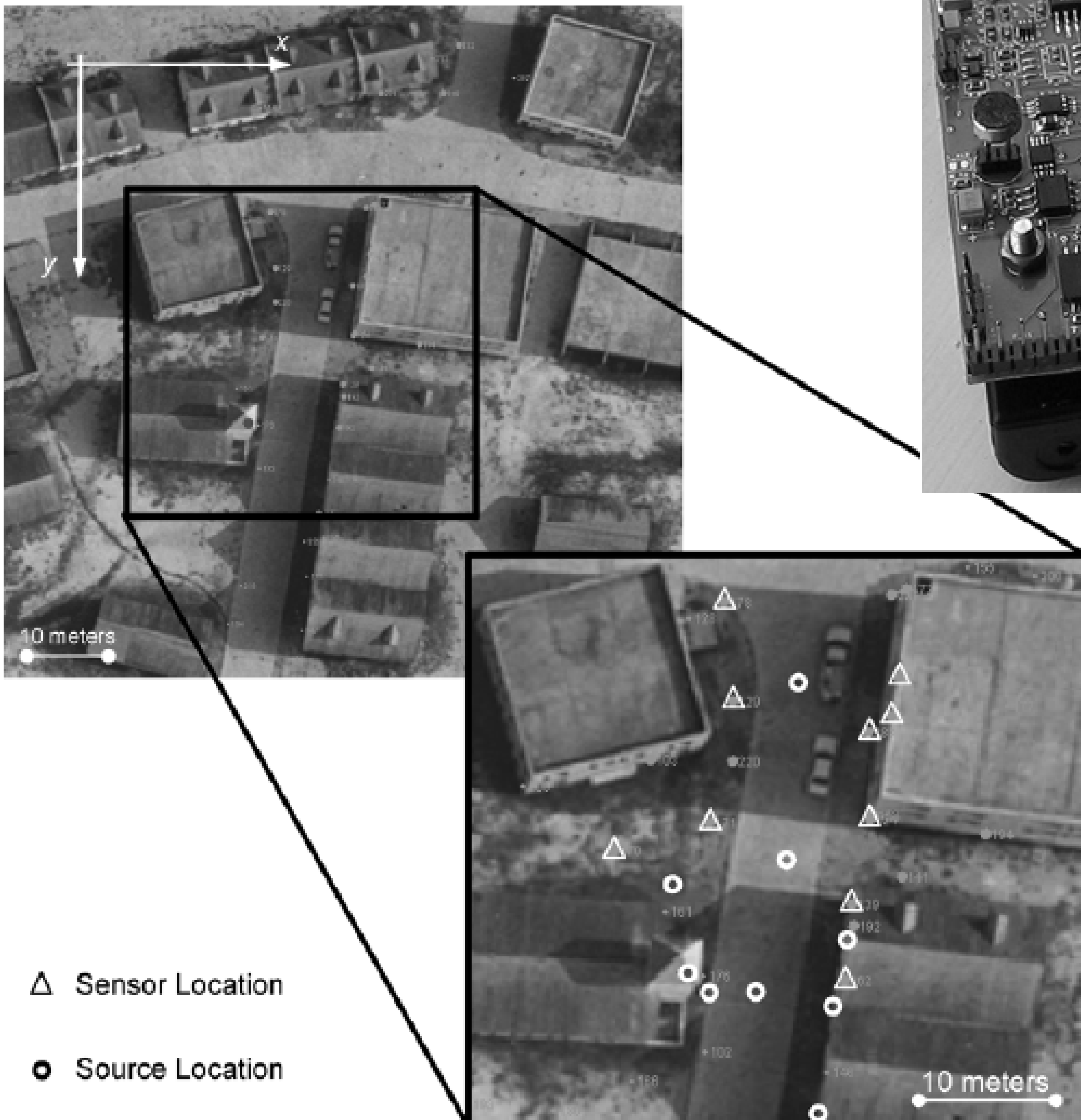
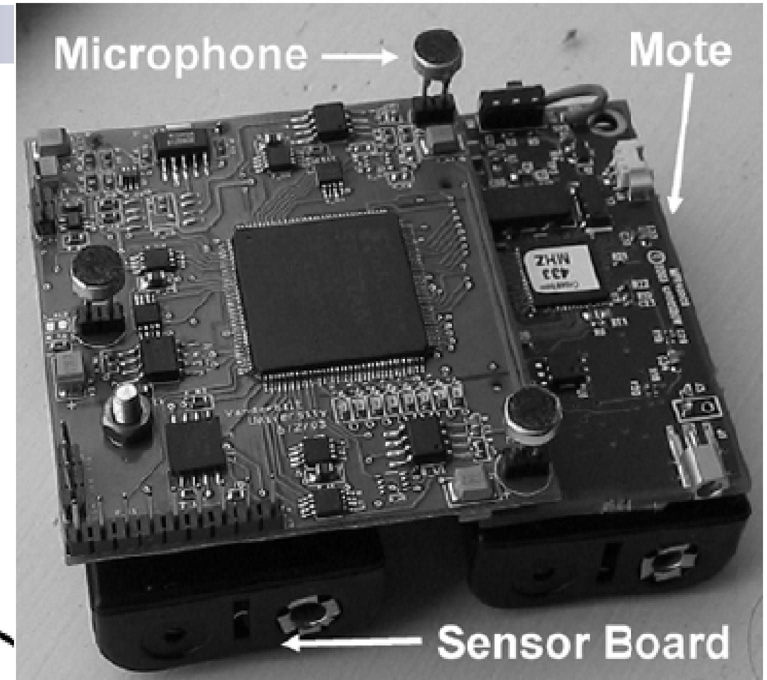
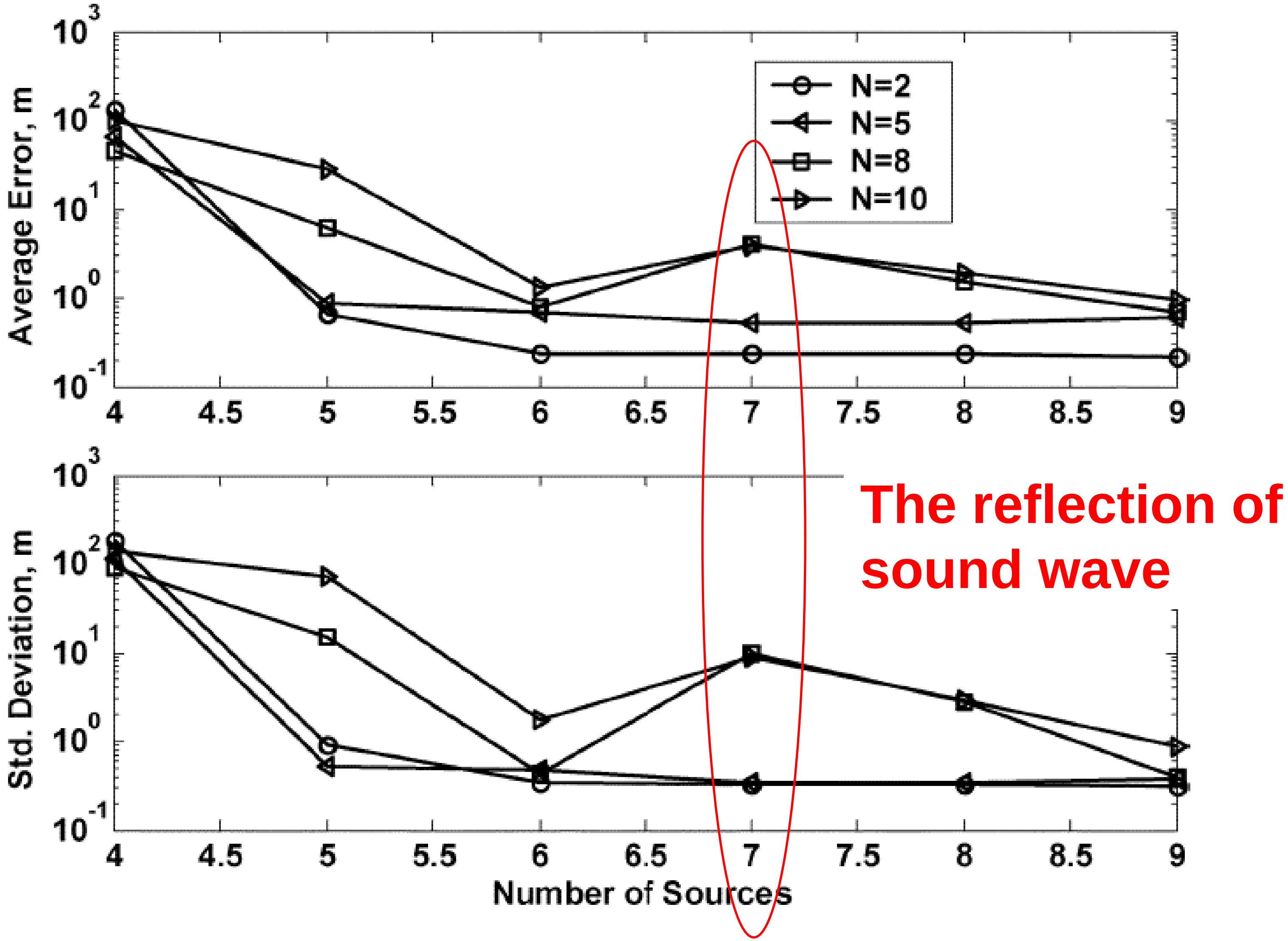
Experimental environment

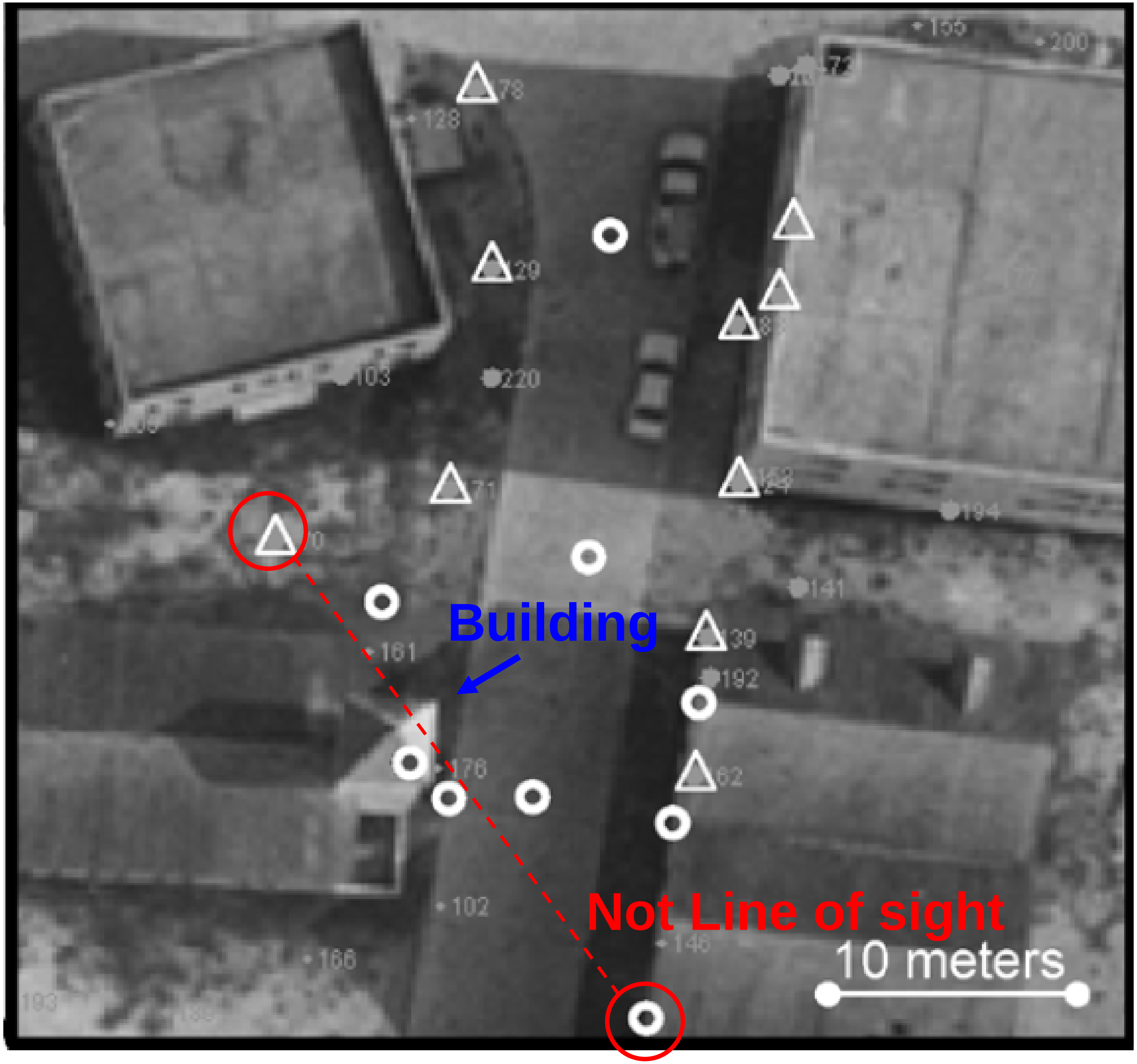
- At the U.S. Army's Dismounted Battle Space Lab Military Operations in Urban Terrain (MOUT)
- N = 56 mica2 motes
- S = 9 rifle fires at different locations
- Node clock synchronization is ready


x
y
10 meters
10 meters
Sensor Location
Source Location


Microphone
Mote
Sensor Board

Experimental Results





Building
Not Line of sight
10 meters

Conclusions

- Previous methods use sensor nodes to locate the sources
- In this paper, the positions of sensor nodes are located by sources
- The solution accuracy is strongly dependent on the number of sources and the location error of sources
- Increasing the number of sources will decrease the location error
- Increasing the number of sensor nodes will increase the error

References

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[2] G. Simon, M. Maroti, A. Ledeczi, G. Balogh, B. Kusy, A. Nadas, G. Pap, J. Sallai, and K. Frampton, “Sensor network-based countersniper system,” presented at the SenSys Conf., Baltimore, MD, Nov. 2004.

[3] Ákos Lédeczi…al, “Multiple Simultaneous Acoustic Source Localization in Urban Terrain,” The Fourth International Symposium on Information Processing in Sensor Networks, IEEE IPSN, 2005.