LCS: Compressive Sensing based Device- Free Localization for Multiple Targets in Sensor Networks

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Real-world Examples

Application1

Snub-nosed monkey monitoring

Current problem:

- It is difficult for wildlife to carry tags

Application2

…

Intrusion Detection

Current problem:

- It is infeasible to install such devices on objects

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Real-world Examples

Application1

Current problem:
- It is difficult for wildlife to carry tags

Device- Free Localization is Needed!

Application2

…

Intrusion Detection

Current problem:
- It is infeasible to install such devices on objects

Challenges of Device-free Localization

Existing Methods:
- High energy cost ,e.g., RTI system in Fig 1.
- Deployment with high-density ,e.g, Fig 2.
- Poor for multiple targets , e.g, Fig 3.

Application Needs:
- Device free localization
- Sparse deployment
- Multiple target counting and localization
- Scalability

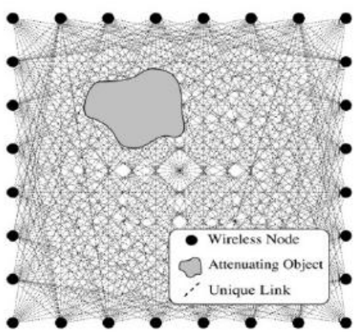

Fig. 1 Joey Wilson, *MOBILE COMPUTING*, 2010

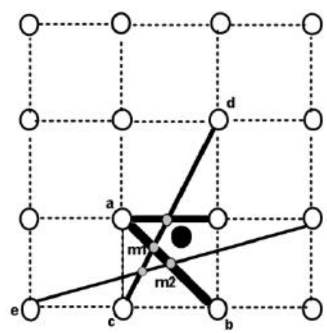

Fig. 2 Dian Zhang, *PerCom*, 2007

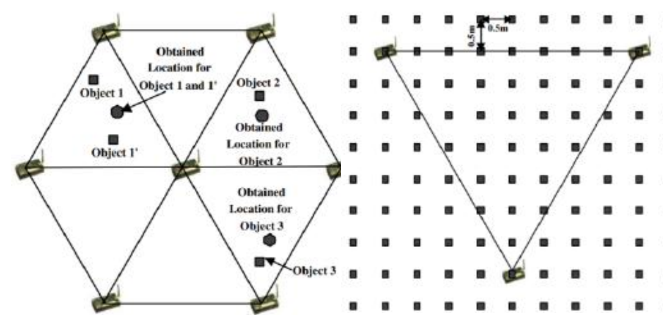

Fig. 3 Dian Zhang, *PerCom*, 2010

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Device-free Localization Based on RSSI is Not Easy

Application Requirements

Existing Methods Limitation

Key Issues

?

How to count and locate multiple targets using a device-free localization method under a large sparse deployment area ?

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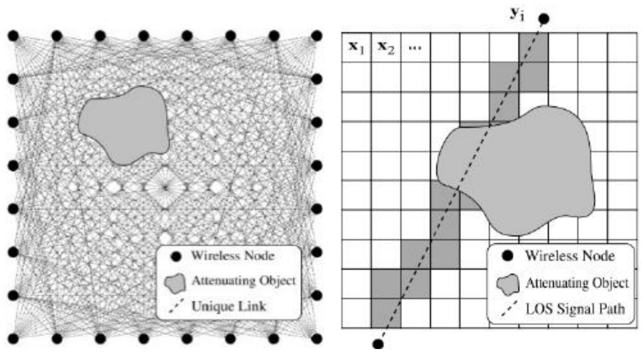
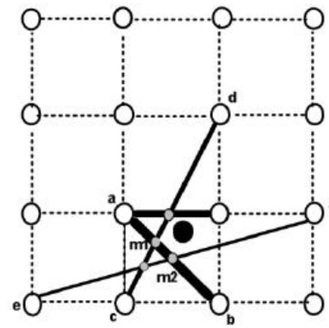
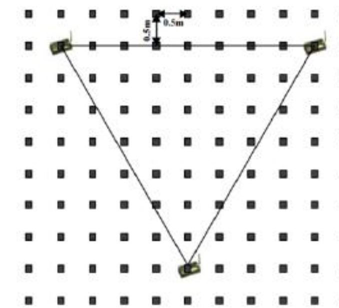
From Previous Work To LCS



Wilson, *MOBILE COMPUTING*, 2010



Zhang, *PerCom*, 2007



Zhang, *PerCom*, 2010

Let,

K *be the number of targets*

M *be the number of targets*

N *be the number of grids*

Key Observation

Sparsity

K <<N

M <N

CS based DFL is promising !

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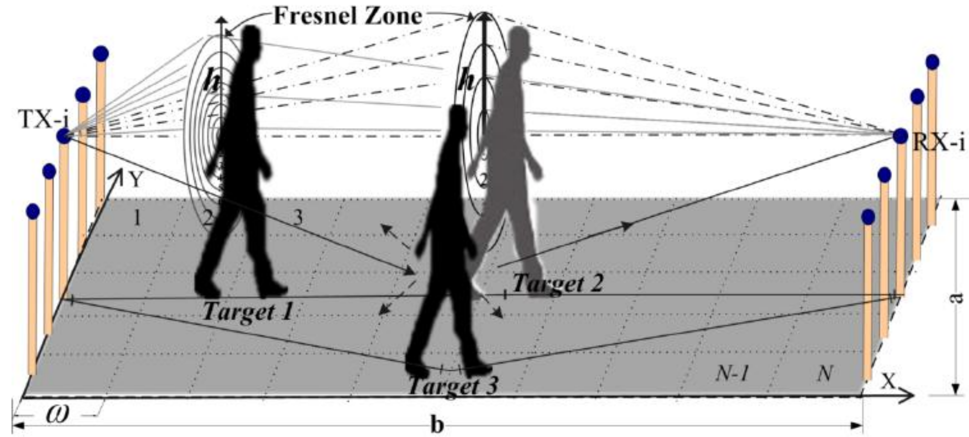
The Deployment of LCS

Set Up:

Monitor area *a × b*
Side length *ω*
Grids number *N (=ab/ ω^2)*
Transceiver pairs *M (=a/ ω)*
Targets number *K*



The RSS dynamic measurement is used to quantify the interferences caused by the target:

$$\Delta R_{i,j} = R_{i,j} - F_i$$

RSS dynamic measurement

RSS of ***link i*** *at the absence of any target*

RSS of ***link i*** *when a target locates at* ***grid j***

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The Model of LCS

The location of targets is:

$$\Theta = [\theta_1, \theta_2, \cdots, \theta_j, \cdots \theta_N]^T$$

where $\theta_j \in \{0,1\}$. If there is one target located at grid j, $\theta_j=1$; otherwise $\theta_j=0$.

The vector Θ has k -sparse nature which meets CS

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Based on compressive sensing:

$$\underbrace{Y_{M\times 1}}_{\textit{RSS of M nodes}} = \overbrace{A_{M\times N}}^{\textit{sensing matrix}} \cdot \underbrace{\Theta_{N\times 1}}_{\textit{sparse vector}} + \overbrace{n}^{\textit{noise}}$$

$$A_{M\times N} = \begin{bmatrix} \Delta R_{1,1} & \Delta R_{1,2} & \cdots & \Delta R_{1,N} \\ \Delta R_{2,1} & \Delta R_{2,2} & \cdots & \vdots \\ \vdots & \vdots & \Delta R_{i,j} & \vdots \\ \Delta R_{M,1} & \cdots & \cdots & \Delta R_{M,N} \end{bmatrix}$$

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The Model of LCS

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Based on compressive sensing:

sensing matrix *noise*

$$Y_{M\times 1} = A_{M\times N} \cdot \Theta_{N\times 1} + n$$

RSS of M nodes *sparse vector*

Estimate locations:

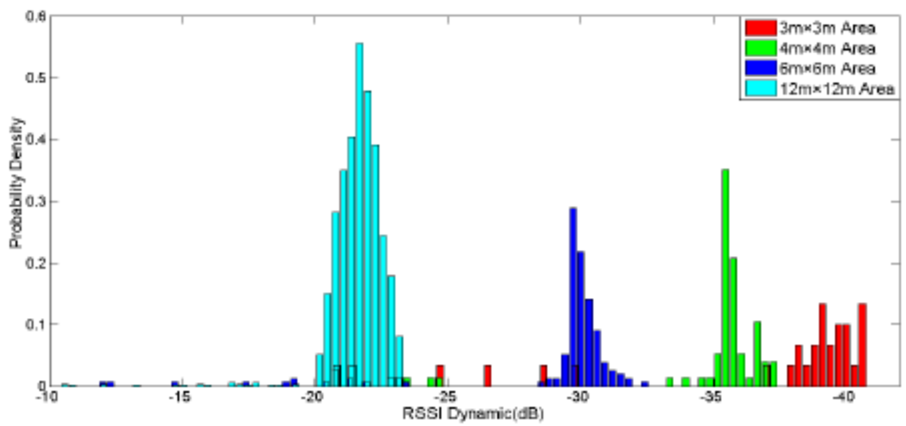
$$\min \|\Theta\|_{\ell_1} \quad \text{subject to} \quad \|A\Theta - Y\|_{\ell_2} < \varepsilon$$

Localization Under Large-Scale

Drawbacks of above method

It cannot cover the large-scale area due to the limitation of the transmission range.

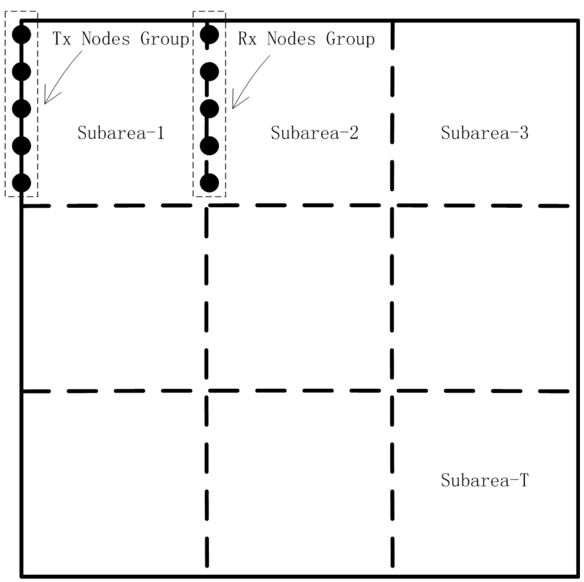
The noise may submerge the RSS dynamics caused by targets.



Localization Under Large-Scale

Large-scale area:

- *Covered by T equal size subareas.*
- *Subarea-t has the M by N sensing matrix A_t*
- *K targets are scattered in the total area*



Sensing matrix A_{total} of total area:

$$A_{total} = \begin{bmatrix} A_1 & 0 & \dots & 0 \\ 0 & A_2 & \dots & 0 \\ \dots & \dots & A_t & \dots \\ 0 & 0 & \dots & A_T \end{bmatrix}_{MT \times NT}$$

Unknown vector of K targets:

$$\Theta_{total} = \left[\Theta_1; \Theta_2; \cdots \Theta_t; \cdots; \Theta_T\right]^T$$

where θ_t denotes the location of targets in subarea-t.

Then CS can be applied to locate K targets from large area.

Localization Accuracy and Formulation Validity

How to choose ω ?

Theorem 3.1: The sufficient condition to achieve high localization accuracy is that the grid side length ω satisfies

$$\sqrt{ab/K}\,10^{-\frac{1}{2}\sqrt{\frac{a}{bK}}} < \omega < \sqrt{ab/K}\,, \tag{9}$$

where K is the number of targets , and $a \times b$ is the size of areas.

Does A obey RIP?

Theorem 3.2: When the number of sensors M=O($k$log (N/k)), the probability for A (after normalization) to satisfy

$$1-\delta \le \|Ax\|_{\ell_2}^2 \Big/ \|x\|_{\ell_2}^2 \le 1+\delta \tag{15}$$

for all k-sparse vector x tends to 1 (i.e., A obeys RIP).

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Performance Evaluation: Setup

- **Implementation**
  - Sensor nodes: MICAZ with Chipcon CC2420 and it is 0.95m off the ground.
  - Experiment site: a playground of size 12m × 12m.
  - Targets: 12 people with the height of 1.75m.

TABLE I. EXPERIMENTAL PARAMENTERS

	Subarea number (T)	**Subarea size (A)**	**Subarea links number (M)**	**Subarea grids number (N)**
Exp. 1	1	12m×12m	24	576
Exp. 2	4	6m×6m	12	144
Exp. 3	9	4m×4m	8	64
Exp. 4	16	3m×3m	6	36

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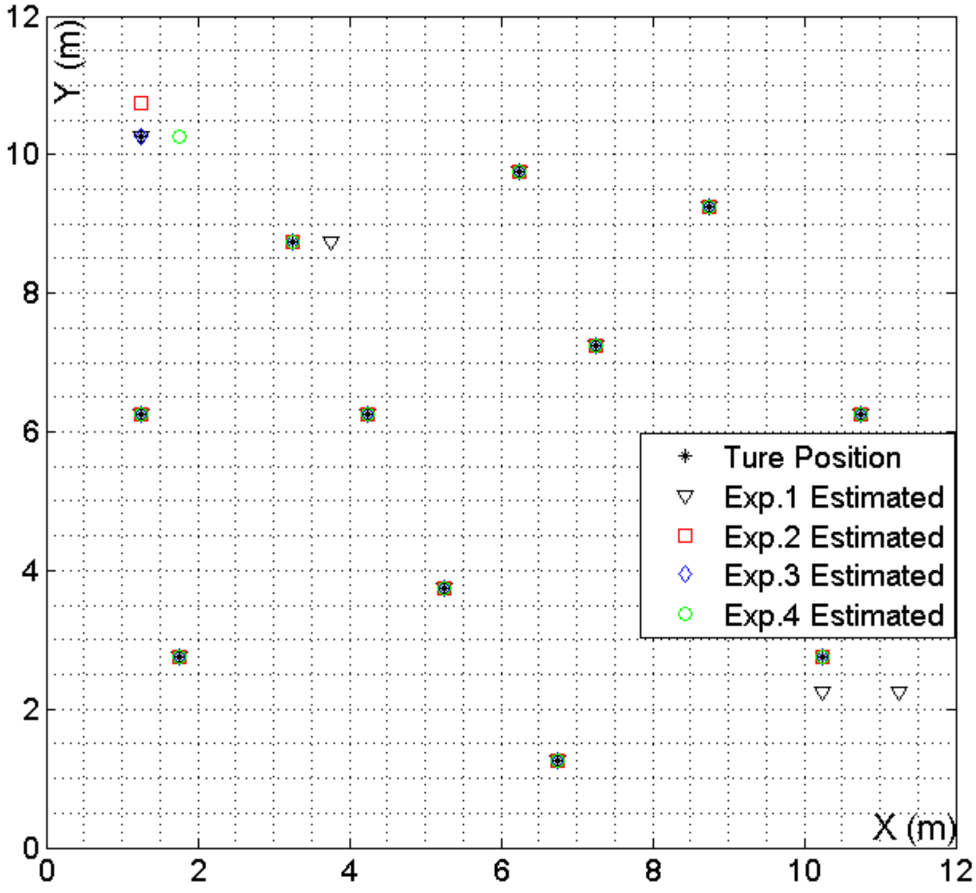
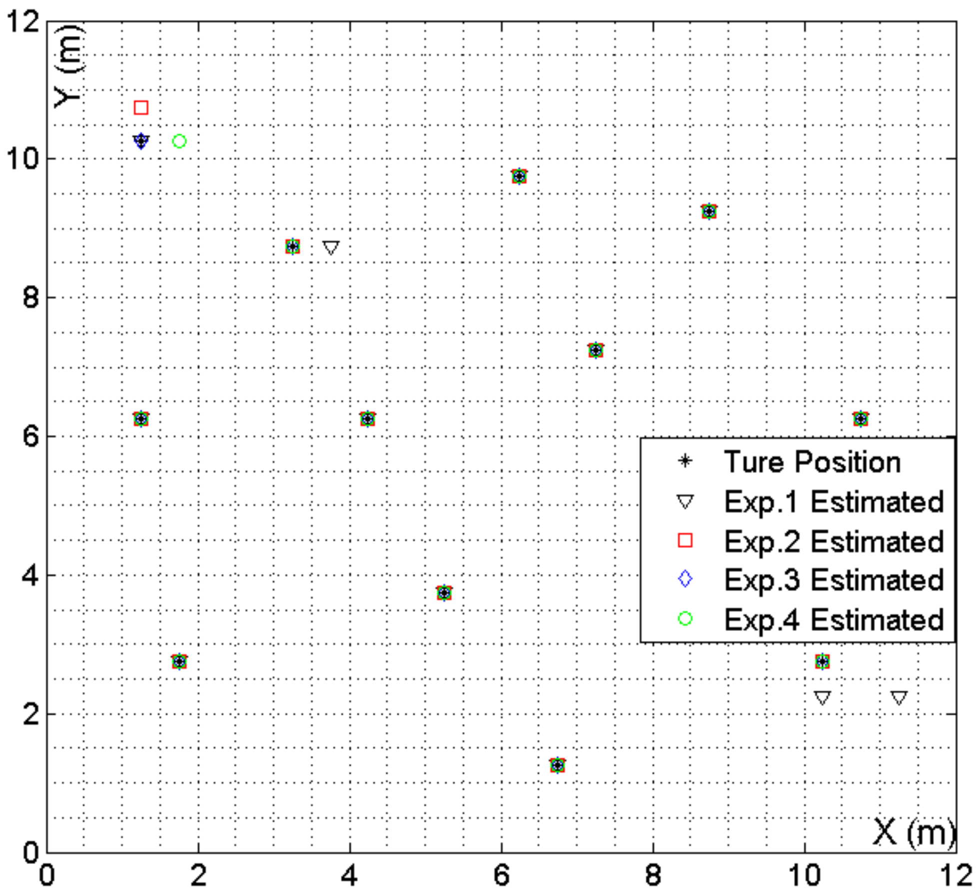
Experimental Verification



Experimental Verification



Performance metrics :

$$\text{Counting error} = \frac{\text{miss} - \text{counted target number}}{\text{total target number } N}$$

$$\text{localization error} = \frac{\text{distance between true and estimated}}{\text{grid side length } \omega}$$

Results:

The worst performance of the 4 experiments (i.e., Exp. 1) is that *Counting error* = 33.3% and *Localization error* = 8.3%.

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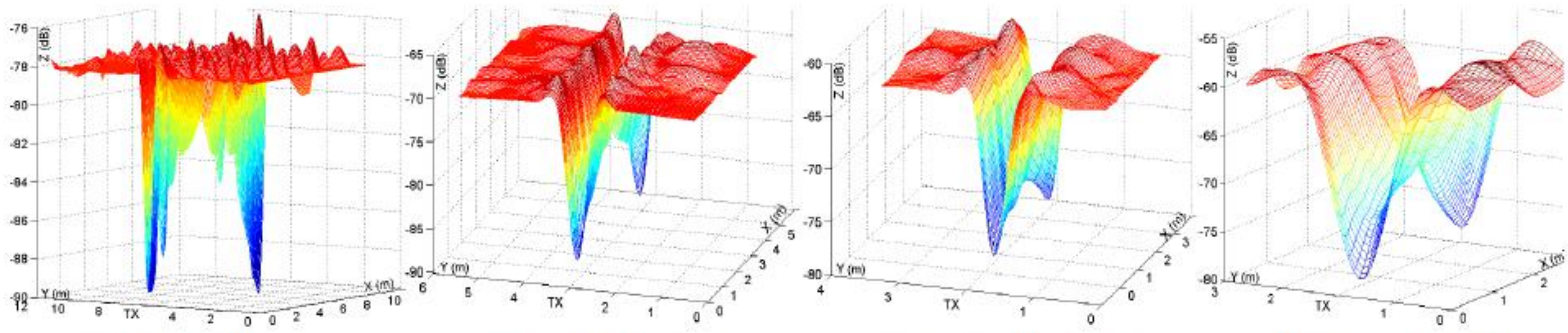
Assumption of LCS

Assume that if a particular link be interfered then it must be interfered by only one target.

This can be easily satisfied in practice since the effective location area is limited, please refer to figures below:



(a) Exp.1 Link length=12m (b) Exp.2 Link length=6m (c) Exp.3 Link length=4m (d) Exp.4 Link length=3m

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Conclusions

- Proposed a CS based multiple target device-free localization method and proved that the product of the sensing matrix obeys RIP.
- Develop a approach to locate targets in a large area and show how to choose the grid size to achieve high localization accuracy.
- Performance of the LCS method has been evaluated through extensive experiments.