Radio frequency (RF) tomography for indoor multi-target tracking

Santosh Nannuru, Yunpeng Li, Divya Alok Sharma, Mark Coates

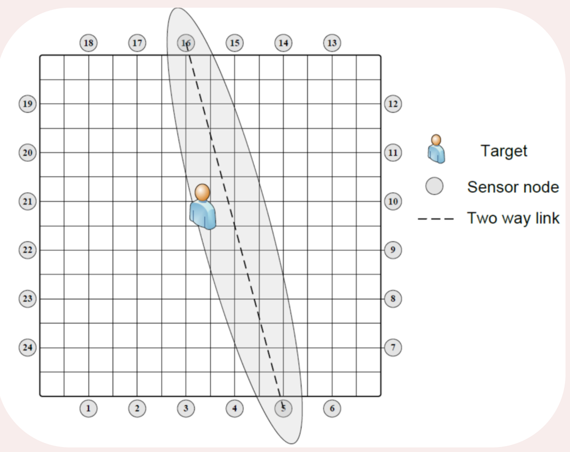
Department of Electrical and Computer Engineering, McGill University

santosh.nannuru@mail.mcgill.ca, liyp@bupt.edu.cn, divya.a.sharma@mail.mcgill.ca, coates@ece.mcgill.ca

Introduction

- Tracking of humans in indoor environments has many applications in the **healthcare** segment. They can be used for example –
  - to track doctors and nurses
  - to monitor people in old age home for prolonged inactivity
- Device free tracking is an effective and non-intrusive way to achieve this.
- It also has applications in **military surveillance, search-and-rescue operations**, etc.
- **Radio-frequency (RF) tomography** is an example of one such technology which can detect and track targets within the monitored area based on the attenuation and fluctuations caused in RF wireless transmissions.
- Wireless networks of radio-frequency sensors have the advantages – **easy deployment, inexpensive and transparent to non-metallic obstructions.**
- Indoor tracking is significantly more challenging than outdoor tracking because of the presence of multiple obstructions and this requires careful modelling of measurements.

Problem statement



- Assume N **targets** are present inside an area monitored by a network of R nodes.
- $X_k = \{x_{k,1}, x_{k,2}, \dots, x_{k,N}\}$ is the **system state** where $x_{k,n}$ is state vector of n^{th} target.
- A **Markov state evolution** model is assumed for each target.
- **Measurement** at time step k is $z_k = \bar{y} - y_k$ where $\bar{y}$ and y_k are reference and current time(k) RSS vectors generated by the $R(R-1)/2$ bidirectional links.
- The goal is to **estimate the target state** $\hat{X}_k = \{\hat{x}_{k,1}, \hat{x}_{k,2}, \dots, \hat{x}_{k,N}\}$ using all the measurements up to time k.

Measurement model

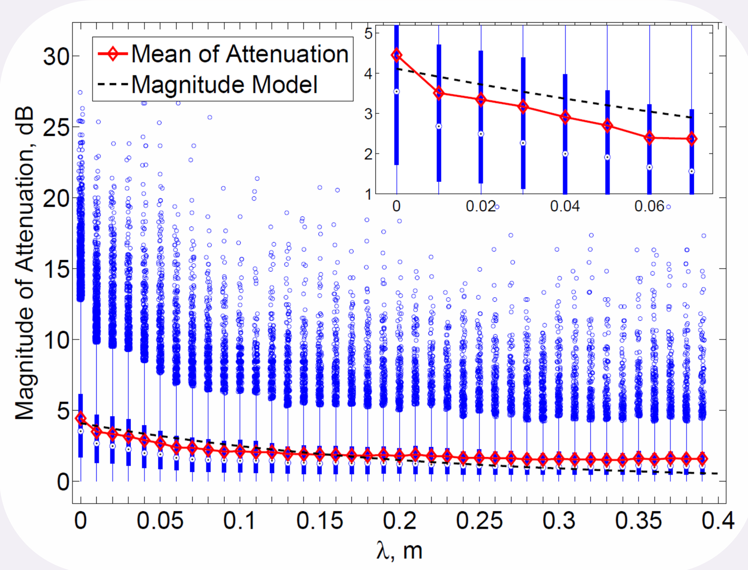
- The measurement model links the measurement vector z to the system state X.
- The **mean attenuation** on a link caused by a target at position x is modelled as

$$g(x) = \phi \exp(-\lambda(x)/\sigma_\lambda)$$

where parameters ϕ and σ_λ are based on physical properties of the targets and sensors and λ quantifies the notion of distance between target and the link.

- For multiple targets the mean attenuation is modelled as

$$g(X) = \sum_{i=1}^{N} g(x_i)$$



- **Multi-path effects** in indoor environment results in a link experiencing either attenuation or amplification when a target is nearby.
- Hence we **model the magnitude** of deviation of signal strength vector $y = |z|$ as the mean attenuation corrupted by Gaussian noise $p(y|X) \propto \mathcal{N}(g(X), \sigma_w^2 I_{M\times M})$.

Algorithms

- Tracking is achieved using **particle implementation** of various filters.
- The **pseudo code** for the different filters is outlined below

Sampling Importance Resampling (SIR)

```
initialize particles {X^(i)};
while tracking do
    foreach particle do
        propagate particle;
        update weight;
    end
    resample;
end
```

Markov Chain Monte Carlo (MCMC)

```
initialize MCMC chain X^(i);
while tracking do
    foreach mcmc step do
        propose new particle;
        accept or reject;
    end
end
```

Additive Likelihood Moment (ALM)

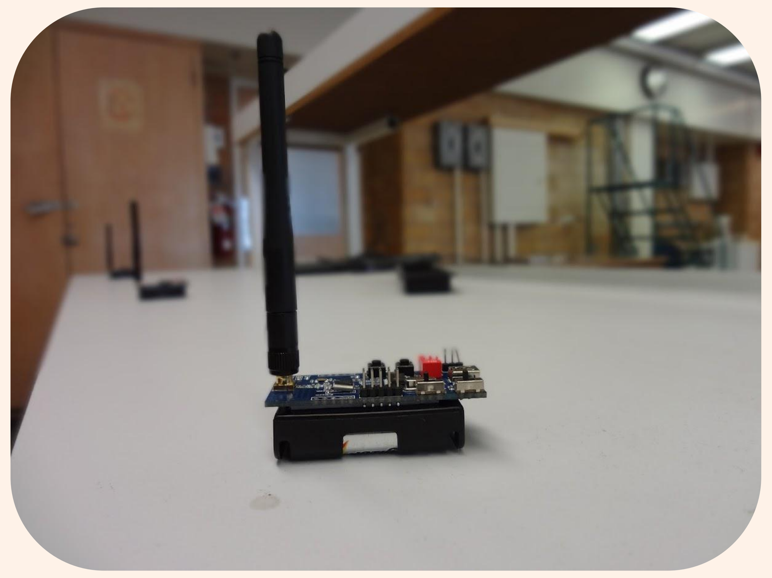
```
initialize particles {x^(i)};
while tracking do
    foreach particle do
        propagate particle;
        update weight;
    end
    resample;
    cluster particles with k-means;
end
```

Multiple Particle Filter (MPF)

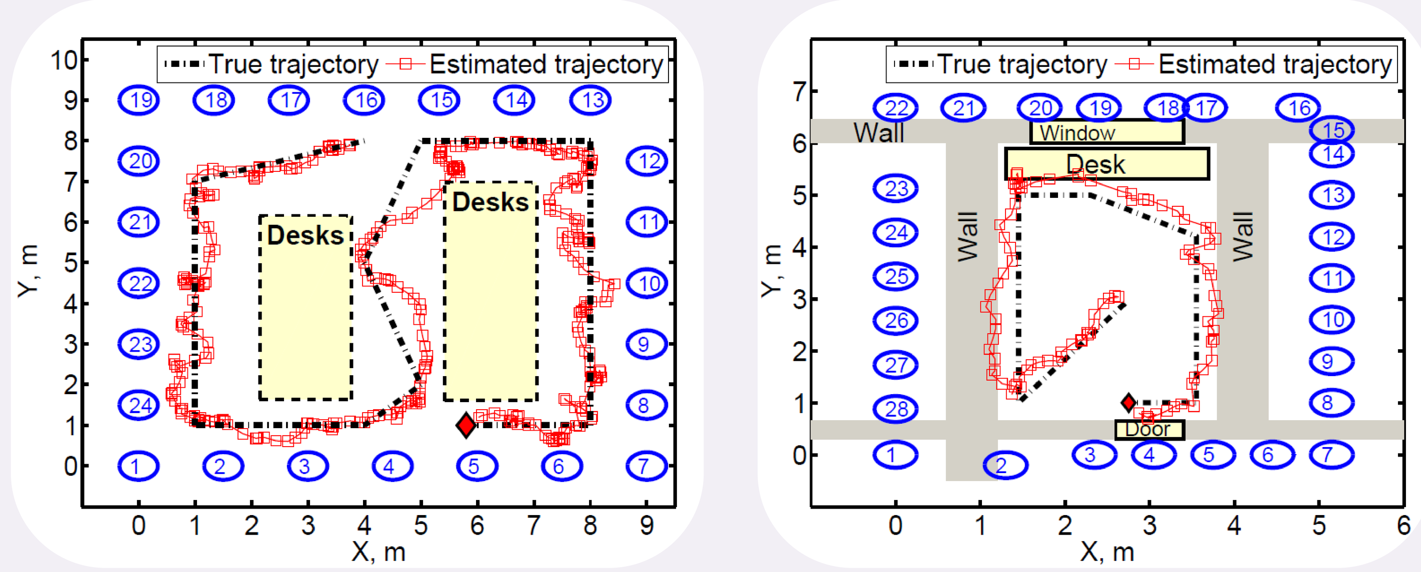
```
initialize particles {x^(i)};
while tracking do
    foreach target do
        foreach particle do
            propagate particle;
        end
        estimate location;
    end
    foreach target do
        foreach particle do
            update weight;
        end
        resample;
    end
end
```

Experimental setup

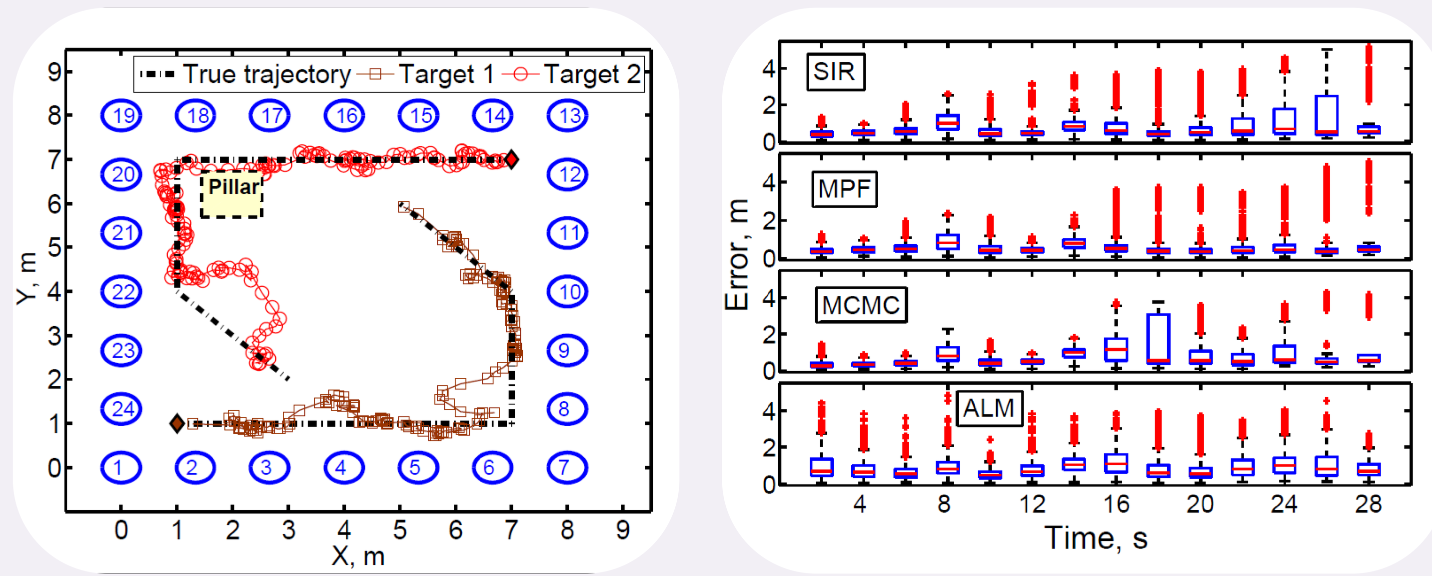
- Experiments performed at **three sites** having different nature of indoor obstructions.
- A network of **24/28 sensors** is used to collect data.
- The sensor nodes are using system-on-chip (SoC) **TI CC 2530** transceivers.



Results



True and estimated target trajectories for single target tracking in two different indoor environments – with heavy desks **(left)**, through-the-wall tracking **(right)**



(Left) True and estimated trajectory when two targets are present.
(Right) Box-and-whisker plot of the error over time for different methods when two targets are present inside the network.

References

[1] S. Nannuru, Y. Li, Y. Zeng, M. Coates, and B. Yang, "Radio frequency tomography for passive indoor multi-target tracking," 2012, submitted to IEEE *Trans. Mobile Computing*.

[2] S. Nannuru, Y. Li, M. Coates, and B. Yang, "Multi-target device-free tracking using radio frequency tomography," in *ISSNIP*, Adelaide, Dec. 2011.

Acknowledgements