Robust TDOA Indoor Tracking Using Constrained Measurement Filtering and Grid-Based Filtering

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1. Background

- Indoor tracking
- UWB positioning

2. System Model

3. Enhanced Indoor Tracking Algorithm

- TDOA Constraint Generating
- Constrained TDOA Preprocessing
- Bound Contraction

4. Simulation Results

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Indoor Tracking

Applications:

- Indoor navigation system
- Equipment tracking
- Fire secure

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Technologies:

- Ultra wideband(UWB)
- Ultrasonic
- Wi-Fi
- Zigbee

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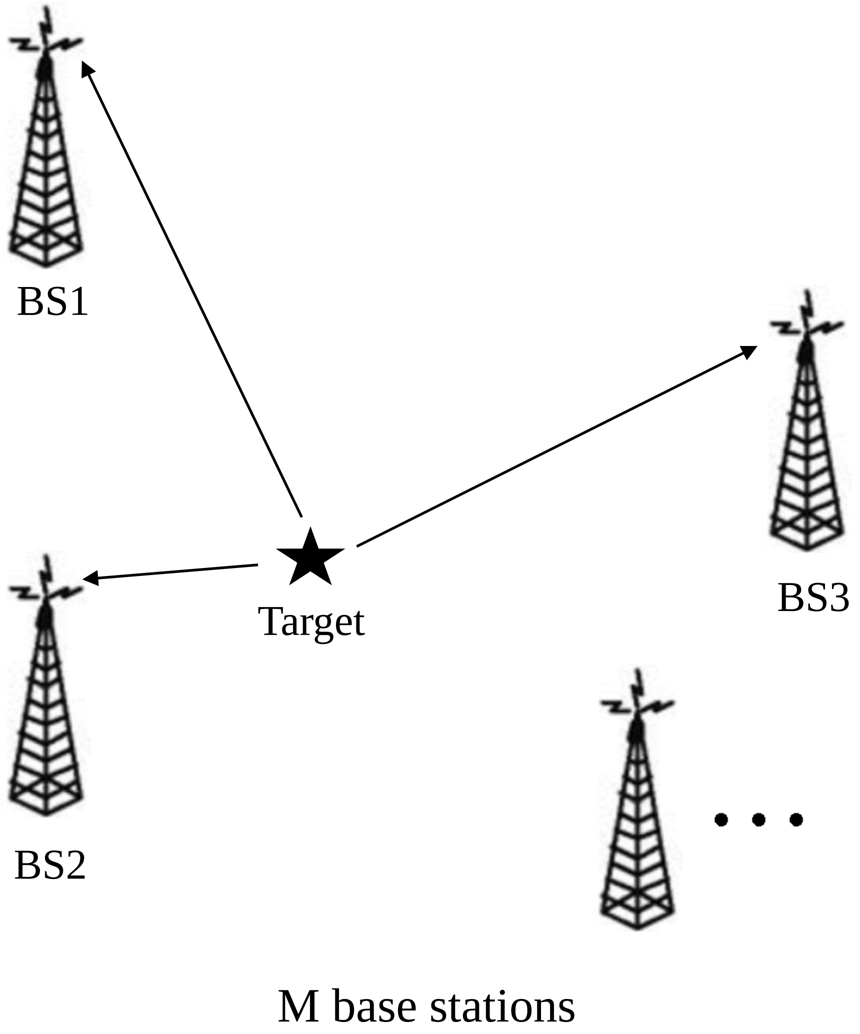
UWB

- Good signal penetration
- Low power consumption
- High ranging accuracy

UWB Positioning



Categories:

1.Time of arrival(TOA)

2.Angle of arrival(AOA)

3.Received signal strength(RSS)

4.Time difference of arrival(TDOA)

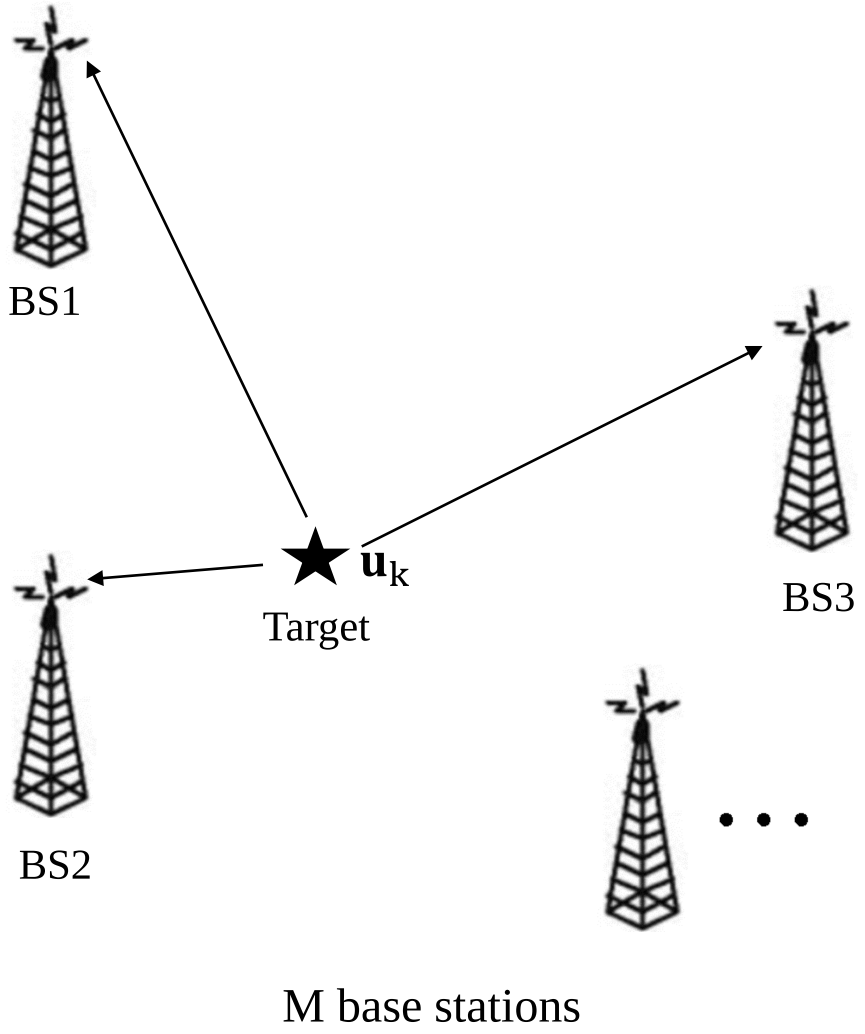
Why TDOA？

TOA: the target needs to be synchronized with base Stations(BSs).

AOA: requires antenna array.

RSS: sensitive to multipath inference, low accuracy for long distance positioning.

System Model



$\mathbf{u}_\mathrm{k}$: target position at time k

$r_{i,k}$: TDOA between BS pair i and 1

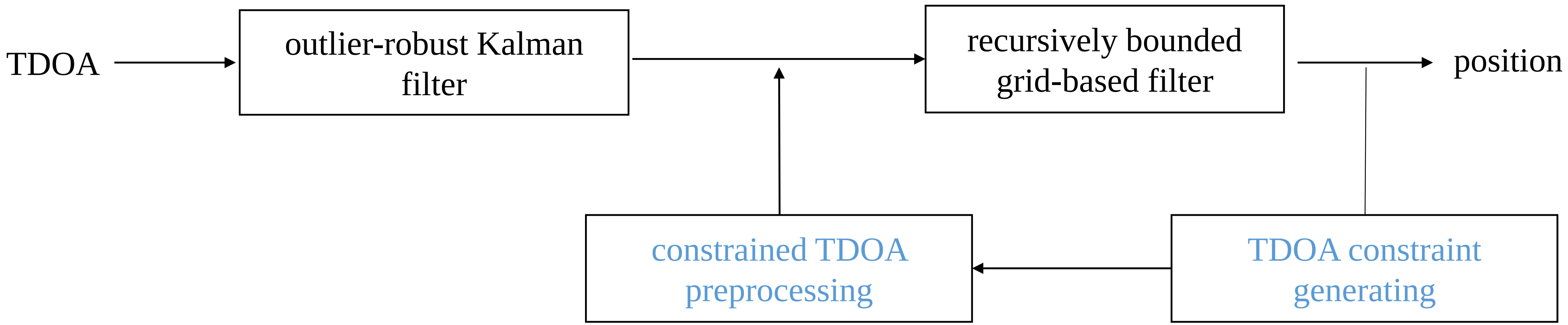
$\mathbf{r}_k = \left[r_{2,k}, r_{3,k}, \ldots, r_{\mathrm{M},k} \right]^T$: TDOA measurement vector

$\mathbf{h}_k$: true TDOA at time k

$\mathbf{r}_k$

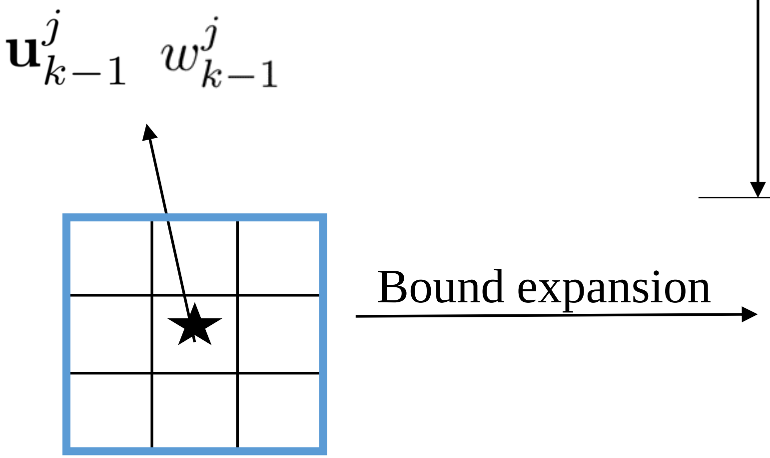
estimating $\mathbf{u}_\mathrm{k}$

Enhanced Indoor Tracking Algorithm

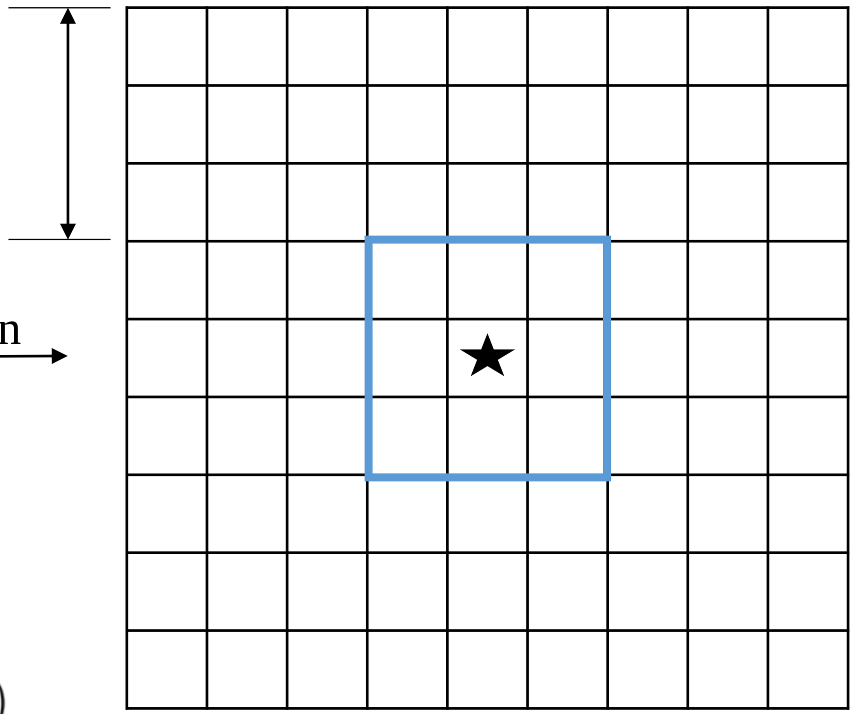


Enhanced Indoor Tracking Algorithm

1. TDOA Constraint Generating



(N_{k-1} grids)



(N_k grids)

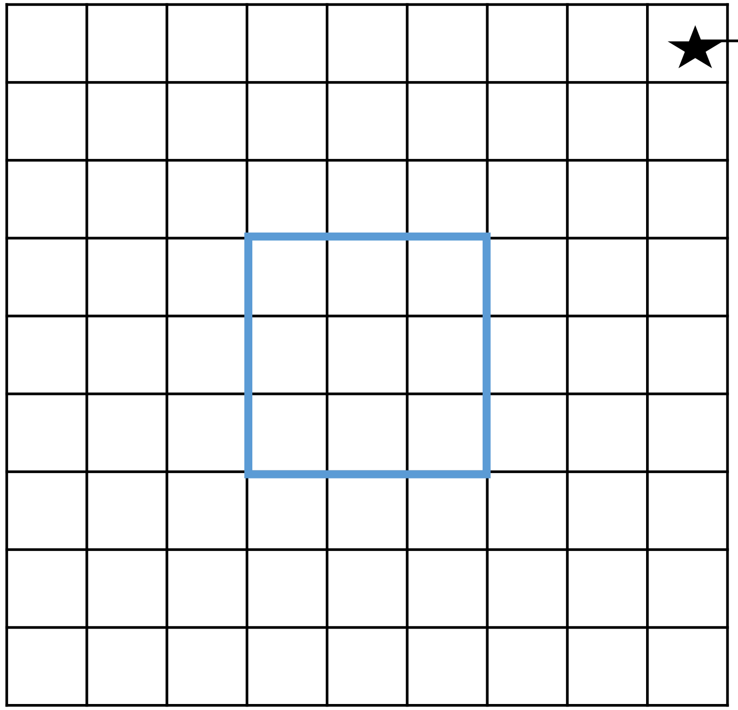
$$p\left(\mathbf{u}_{k-1} \middle| \mathbf{r}_1, \ldots, \mathbf{r}_{k-1}\right) = \sum_{j=1}^{N_{k-1}} w_{k-1}^{j} \delta(\mathbf{u}_{k-1} - \mathbf{u}_{k-1}^{j})$$

$\mathbf{u}_{k-1}^{j}$: position of the j_{th} grid at time k-1

w_{k-1}^{j} : weight of the j_{th} grid at time k-1

Enhanced Indoor Tracking Algorithm

1. TDOA Constraint Generating(Cont'd)



Expanded bounds

TDOA constraints

$$L_k^i \le \phi_{i-1}^T \mathbf{h}_k \le U_k^i,$$
$$i = 2, 3, \ldots, M$$

L_k^i, U_k^i : lower and upper bound of true TDOA between BS pair i and 1

ϕ_{i-1}^T : the $i-1_{th}$ column of $(M-1)\times(M-1)$ identity matrix

Enhanced Indoor Tracking Algorithm

2. Constrained TDOA Preprocessing

$$L_k^i \leq \boldsymbol{\phi}_{i-1}^T \mathbf{h}_k \leq U_k^i,$$

$$i = 2, 3, \dots, M$$

imposing TDOA constraints

TDOA $\mathbf{r}_k$ → outlier-robust Kalman filter → $q(\mathbf{h}_k) = \mathcal{N}(\hat{\mathbf{r}}_k, \mathbf{Q}_{\hat{\mathbf{r}}_k})$

mitigate NLOS errors

$\hat{\mathbf{r}}_k$: mean

$\mathbf{Q}_{\hat{\mathbf{r}}_k}$: covariance

Apply sequentially *M*-1 inequality constraints

$$L_k^2 \leq \boldsymbol{\phi}_1^T \mathbf{h}_k \leq U_k^2$$

$$q(\mathbf{h}_k) = \mathcal{N}(\hat{\mathbf{r}}_k, \mathbf{Q}_{\hat{\mathbf{r}}_k})$$

Enhanced Indoor Tracking Algorithm

2. Constrained TDOA Preprocessing(Cont'd)

$$L_k^2 \le \boldsymbol{\phi}_1^T \mathbf{h}_k \le U_k^2$$

$$\Big\downarrow \text{ imposing TDOA constraints}$$

$$q(\mathbf{h}_k) = \mathcal{N}(\hat{\mathbf{r}}_k, \mathbf{Q}_{\hat{\mathbf{r}}_k})$$

Transformation:

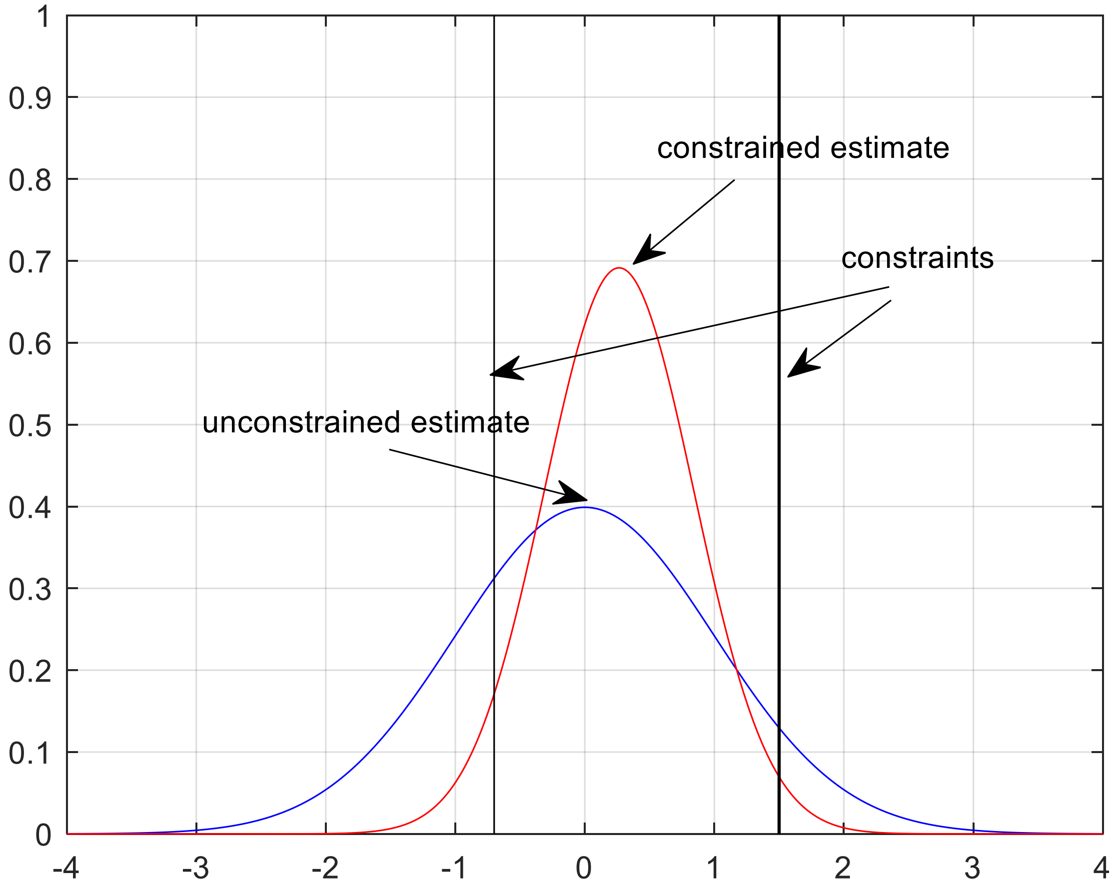
$$\mathbf{z} = \mathbf{V}\mathbf{W}^{-1/2}\mathbf{U}^T(\mathbf{h}_k - \hat{\mathbf{r}}_k)$$

$$\mathbf{Q}_{\hat{\mathbf{r}}_k} = \mathbf{U}\mathbf{W}\mathbf{U}^T$$

$$\mathbf{V}\mathbf{W}^{1/2}\mathbf{U}^T\boldsymbol{\phi}_1 = \begin{bmatrix} (\boldsymbol{\phi}_1^T \mathbf{Q}_{\hat{\mathbf{r}}_k}\boldsymbol{\phi}_1)^{1/2} & 0 & \dots & 0 \end{bmatrix}^T$$

$$\alpha \le \begin{bmatrix} 1 & 0 & \dots & 0 \end{bmatrix} \mathbf{z} \le \beta$$

$$\alpha = \frac{L_k^2 - \boldsymbol{\phi}_1^T \hat{\mathbf{r}}_k}{(\boldsymbol{\phi}_1^T \mathbf{Q}_{\hat{\mathbf{r}}_k}\boldsymbol{\phi}_1)^{1/2}} \qquad \beta = \frac{U_k^2 - \boldsymbol{\phi}_1^T \hat{\mathbf{r}}_k}{(\boldsymbol{\phi}_1^T \mathbf{Q}_{\hat{\mathbf{r}}_k}\boldsymbol{\phi}_1)^{1/2}}$$



Enhanced Indoor Tracking Algorithm

2. Constrained TDOA Preprocessing

Estimation of $\mathbf{z}$ after applying the first inequality constraint

$$\boldsymbol{\mu} = [\ \mu \quad 0 \quad \ldots \quad 0\ ]^T$$

$$\boldsymbol{\Sigma} = \begin{bmatrix} \sigma^2 & & & \\ & 1 & & \\ & & \ddots & \\ & & & 1 \end{bmatrix} \xrightarrow{\text{inverse transformation}} \begin{aligned} \tilde{\mathbf{r}}_k &= \mathbf{U}\mathbf{W}^{1/2}\mathbf{V}^T\boldsymbol{\mu} + \hat{\mathbf{r}}_k \\ \mathbf{Q}_{\tilde{\mathbf{r}}_k} &= \mathbf{U}\mathbf{W}^{1/2}\mathbf{V}^T\boldsymbol{\Sigma}\mathbf{V}\mathbf{W}^{1/2}\mathbf{U}^T \end{aligned}$$

Estimation of $\mathbf{h}_k$ after applying the first inequality constraint

$$q(\mathbf{h}_k) = \mathcal{N}(\tilde{\mathbf{r}}_k, \mathbf{Q}_{\tilde{\mathbf{r}}_k})$$

Apply sequentially remaining *M*-2 inequality constraints

Enhanced Indoor Tracking Algorithm

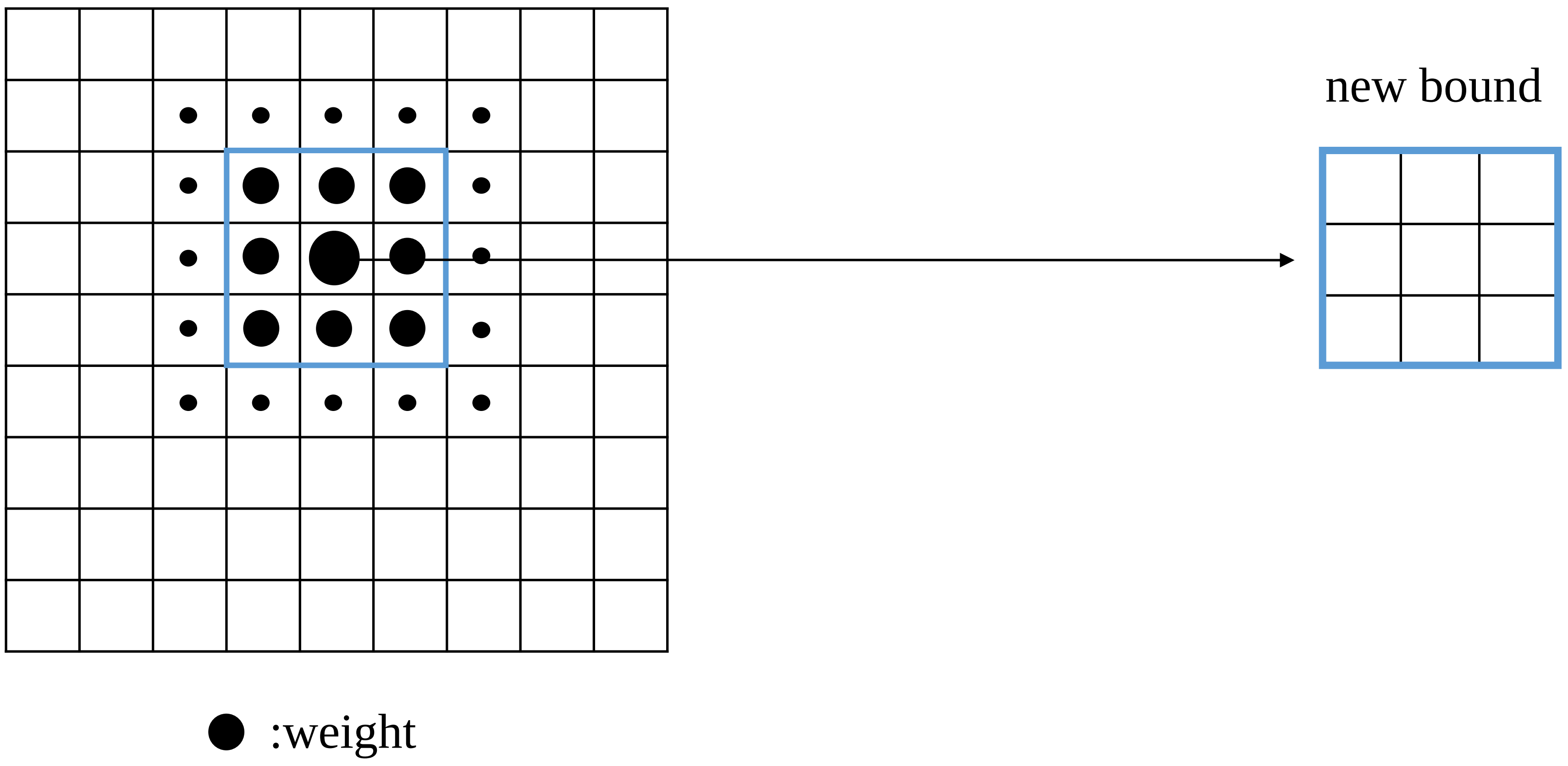
3. Bound Contraction

Weight prediction and weight update

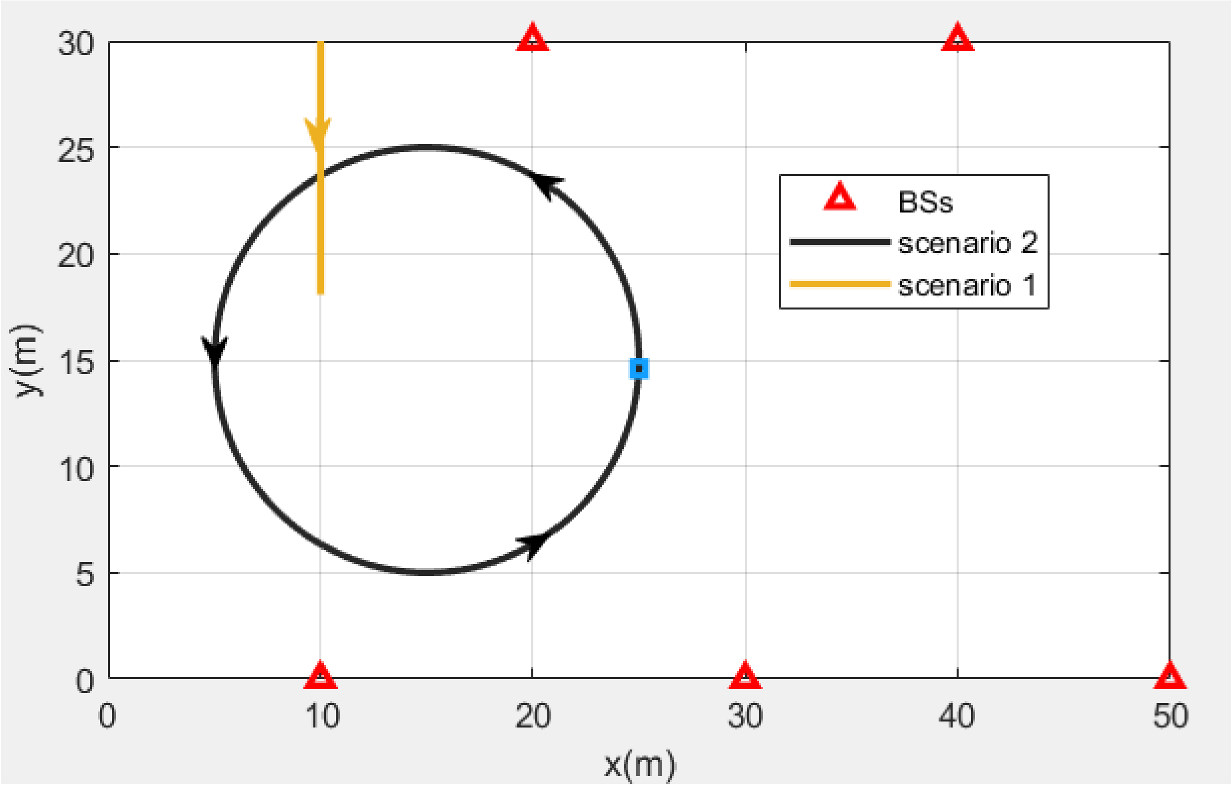
$$p(\mathbf{u}_k \mid \mathbf{r}_1, \cdots \mathbf{r}_k) = \sum_{j=1}^{N_k} \omega_k^j \delta(\mathbf{u}_k - \mathbf{u}_k^j)$$

$\mathbf{u}_k^j$: position of the j_{th} grid at time k

ω_k^j : weight of the j_{th} grid at time k



Simulation Results



Scenarios in consideration

measurement noise:

zero-mean t-distributed noise with DOF $\lambda = 3$

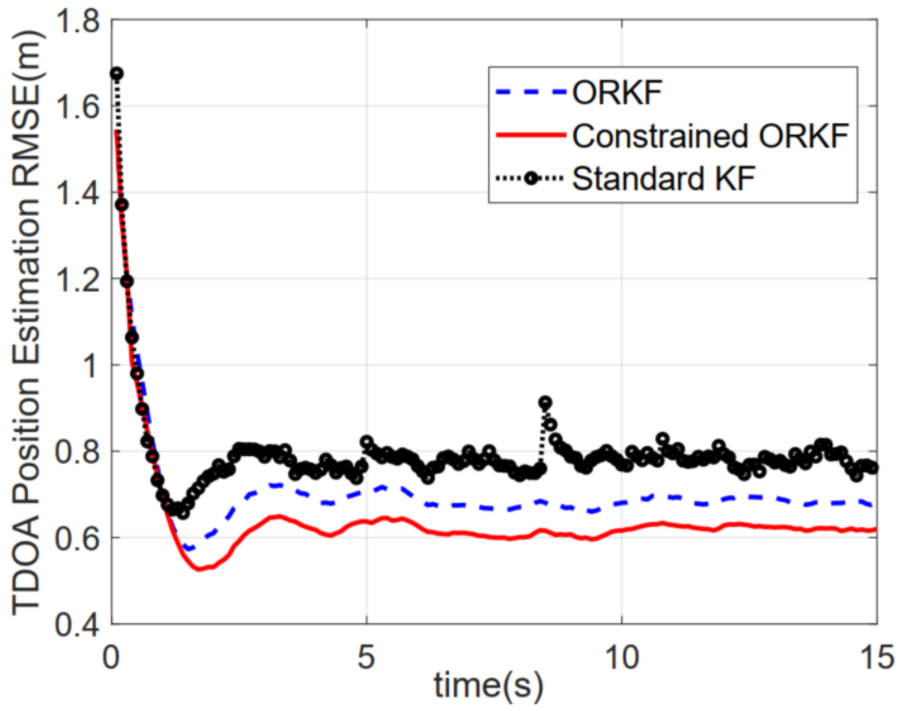
covariance: $\frac{\lambda}{\lambda-2}\mathbf{R}$

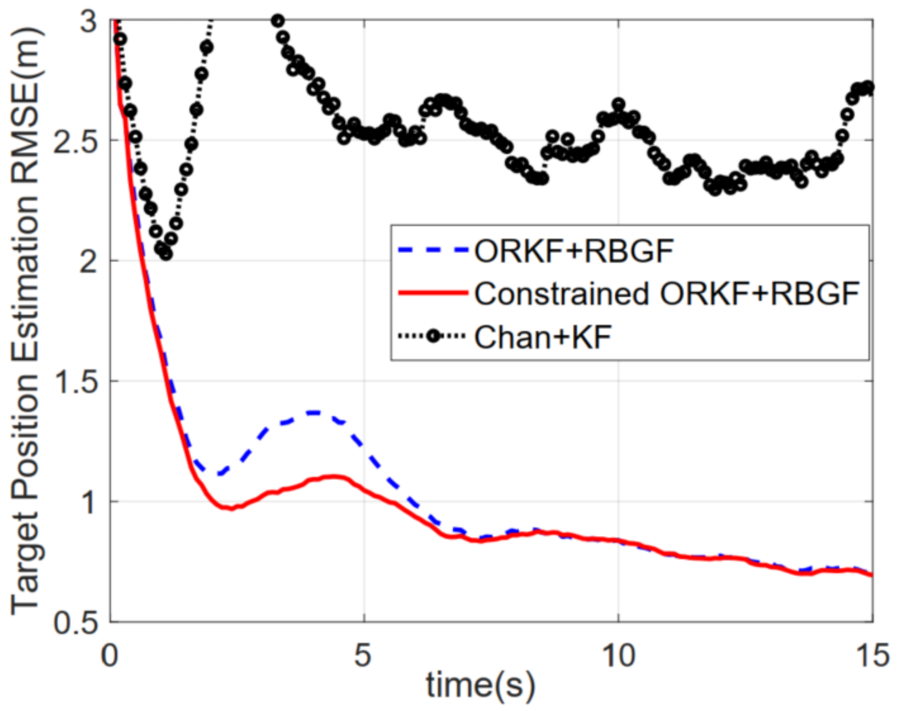
$\mathbf{R} = \sigma^2(\mathbf{I}_4 + \mathbf{1}_4\mathbf{1}_4^T)/2$

$\sigma = 1\mathrm{m}$

Simulation Results

Scenario1:





Better preprocessing performance,

Higher positioning accuracy.

Simulation Results

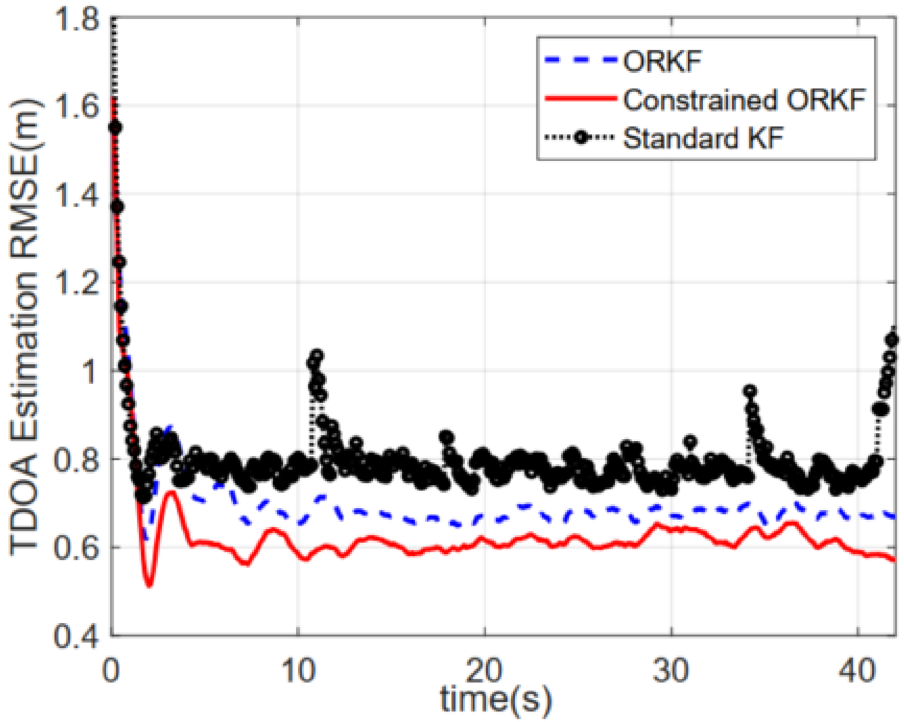
Scenario1:

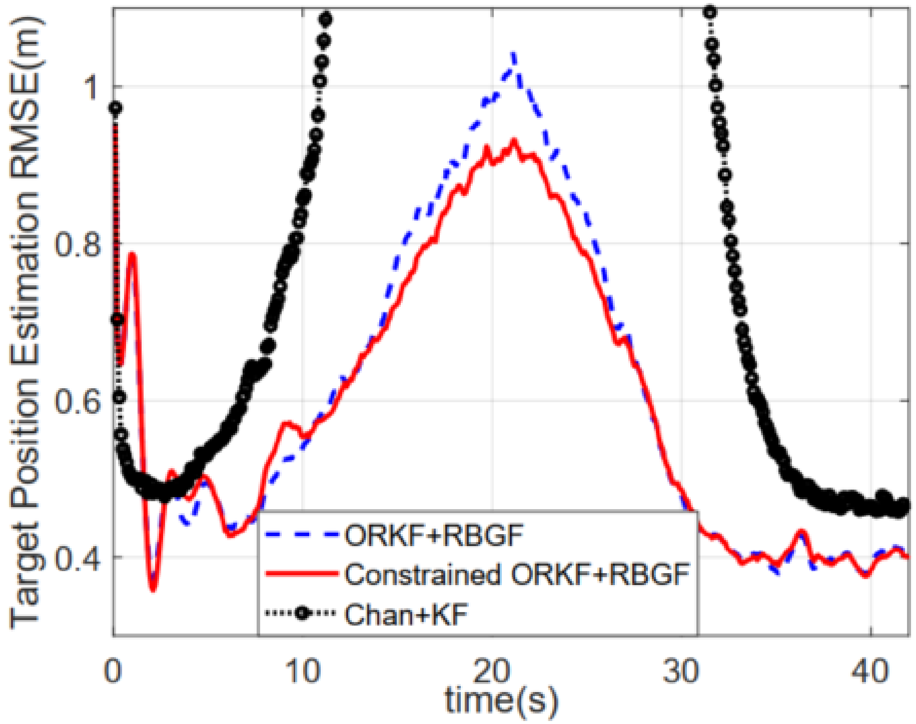
Comparison of positioning RMSE(m)

RMSE	$\sigma = 0.5$	$\sigma = 1.0$	$\sigma = 1.5$
Chan+KF	0.9701	2.5431	4.9495
ORKF+RBGF	0.5291	0.8325	1.5312
Constrained ORKF+RBGF	0.5151	0.7970	1.4637

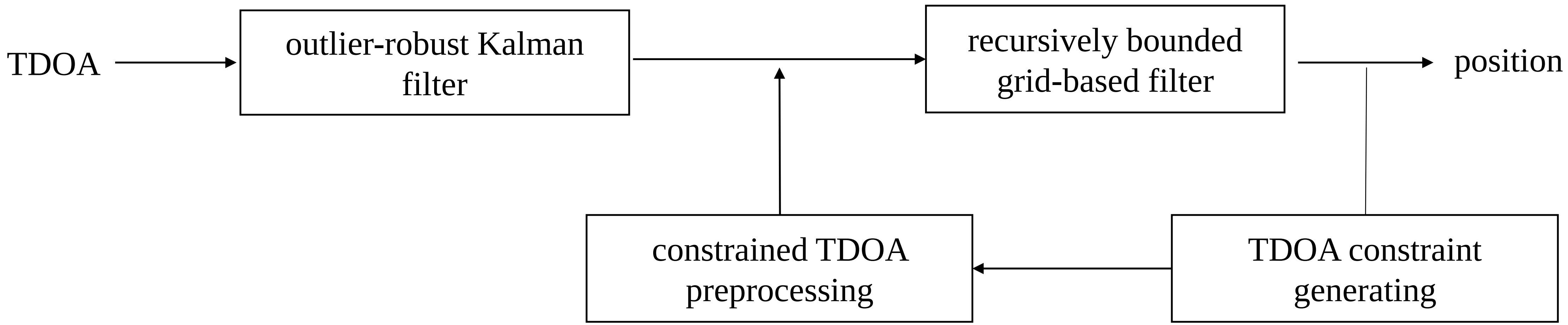
Simulation Results

Scenario2:





Conclusion



Future Work

- Velocity estimation
- Better constrained measurement filtering

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Thank you!

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