# Overcoming GNSS Degradation by Cooperative Networked Localization of Autonomous Vehicles

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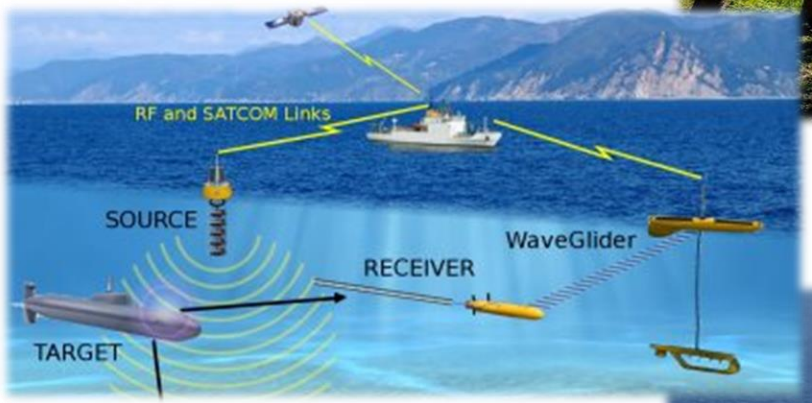
SET-275 Symposium on Cooperative Navigation in GNSS Degraded and Denied Environments
29-30 September 2021, Split, Croatia

# Context

## Where do we currently find sensor networks?

- Internet of things
  - indoor
  - outdoor
- Mobility
- Surveillance
  - indoor
  - outdoor
- Military/Defence

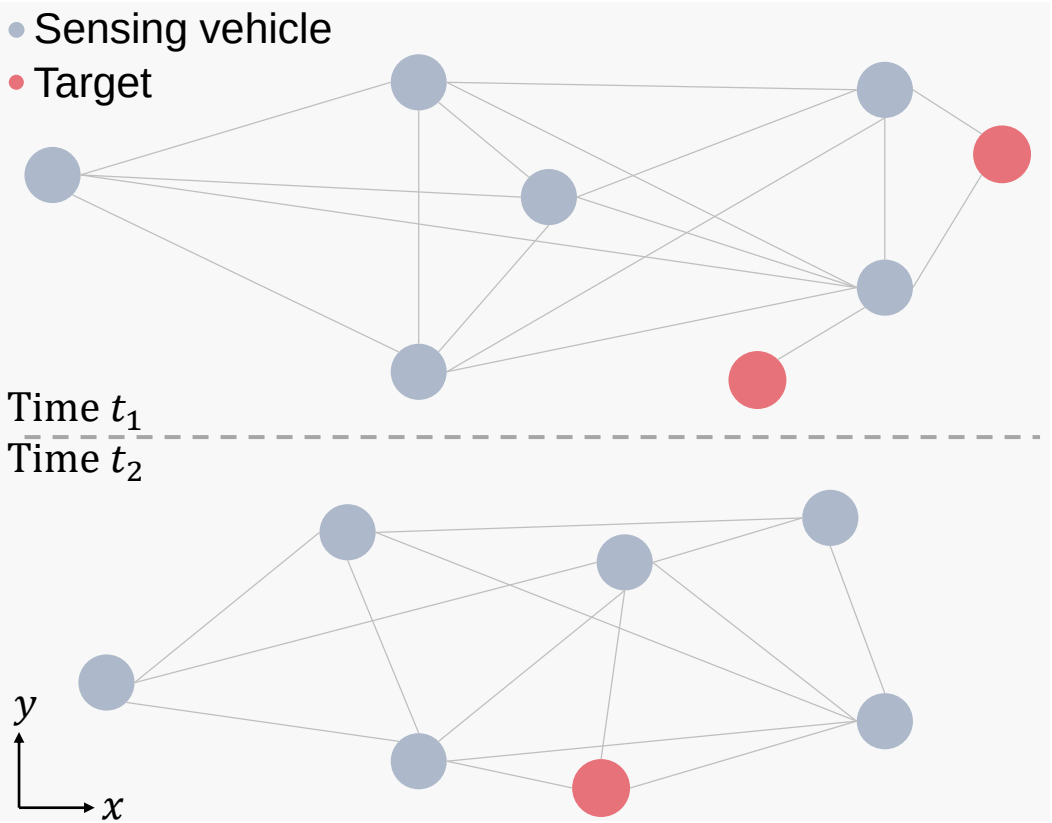




## What has to be detected?

- intruders (e.g., surveillance systems)
- objects/humans close to streets (or in the middle of the lane…)
- submarines or intruding ships

In brief: non-cooperative entities that do not deliberately share information.

# Vehicular mobile network




- A network of vehicles with sensing and communication capabilities
  - Localization
  - Cooperation

Network tasks:

- CSL
- MTT

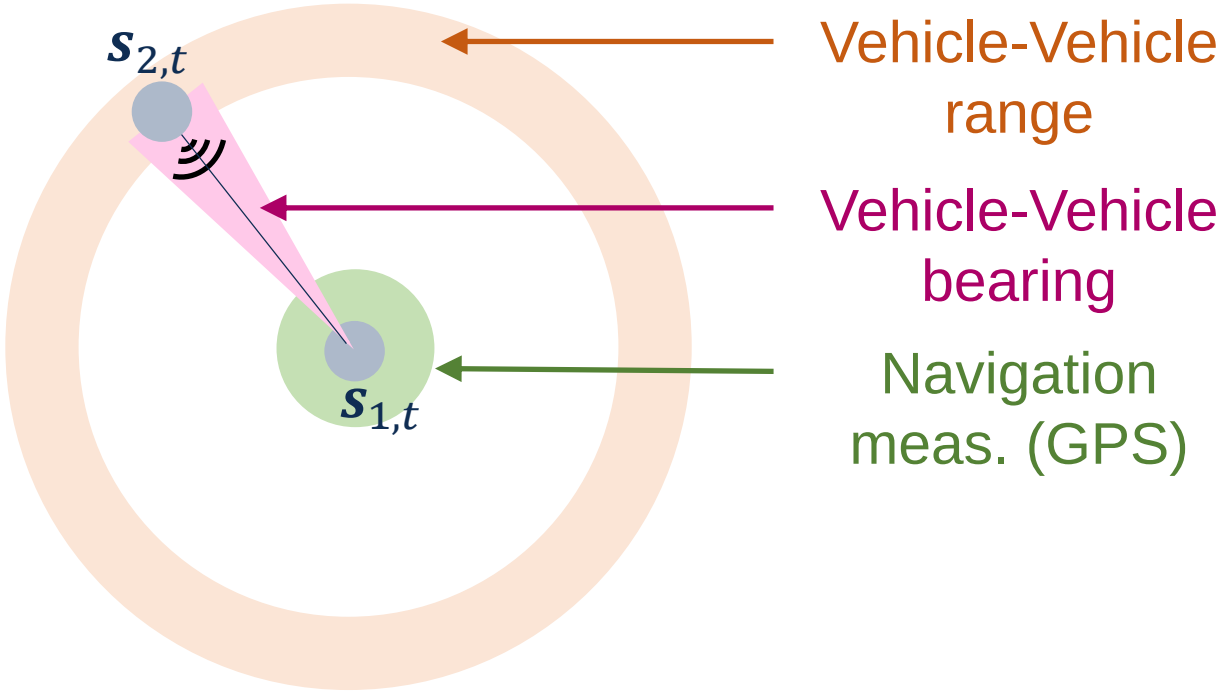
- Mobile
- Time variant
- Unknown position
- Variable connectivity

CSL: Cooperative Self Localization

MTT: Multi Target Tracking

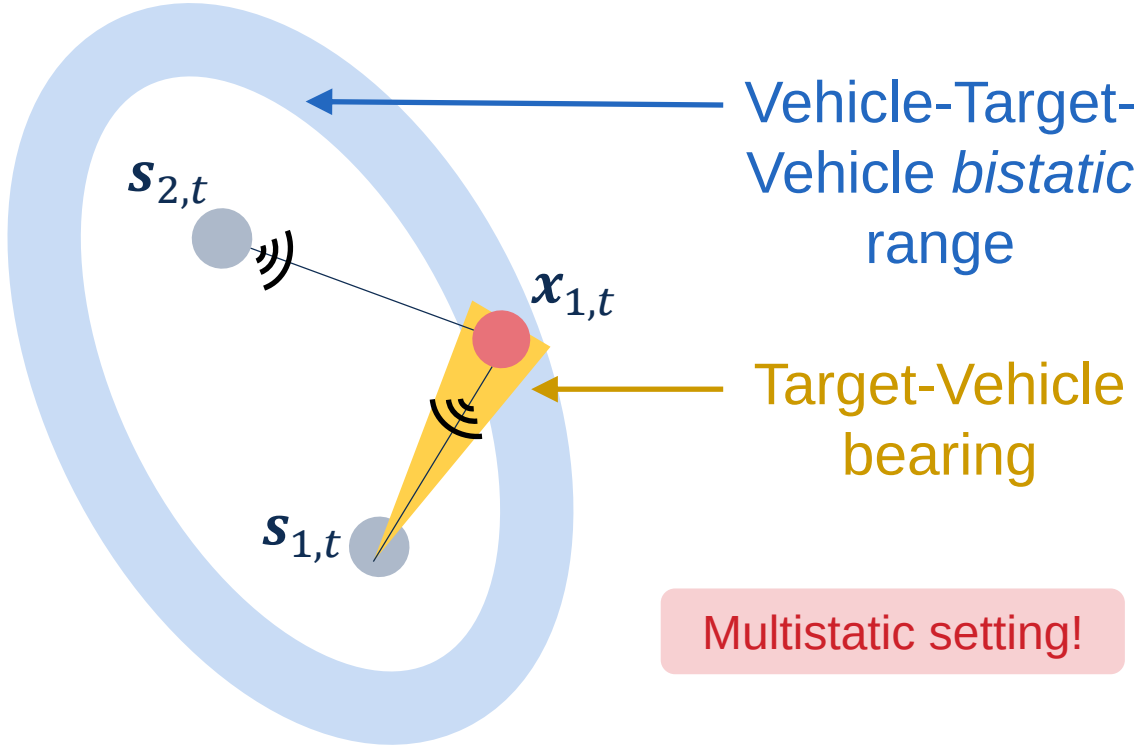
# Measurements

## Cooperative Self Localization (CSL)




No Data Association needed

## Multi Target Tracking (MTT)




Data Association needed

Data Association: it is unknown which target or agent has generated an MTT measurements

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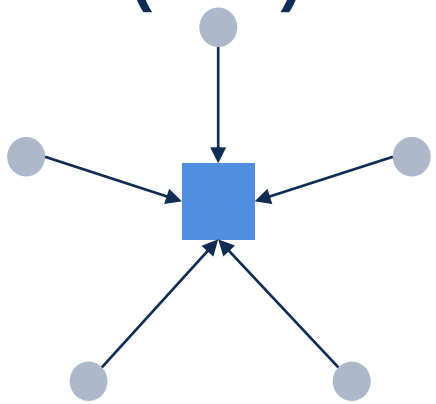
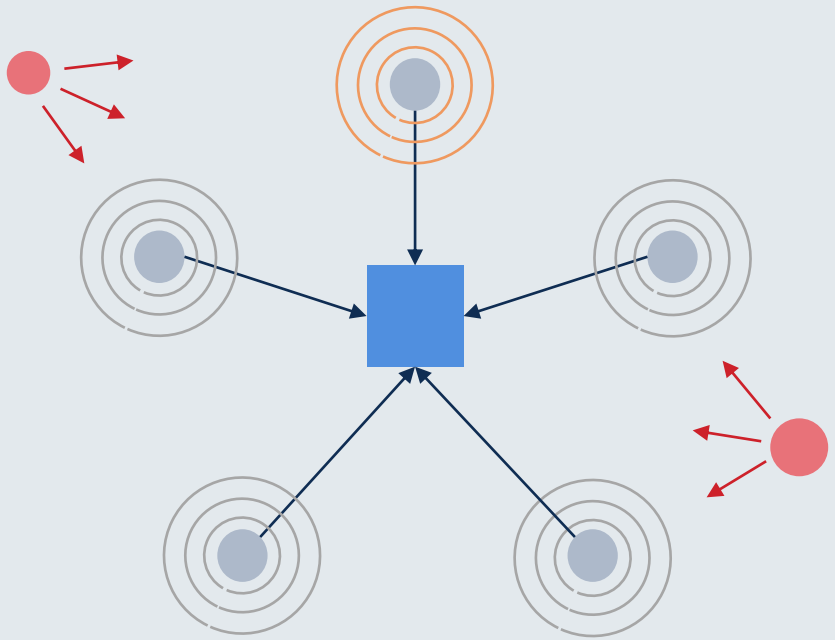
# Paper contribution

## Cooperative Self Localization (CSL)

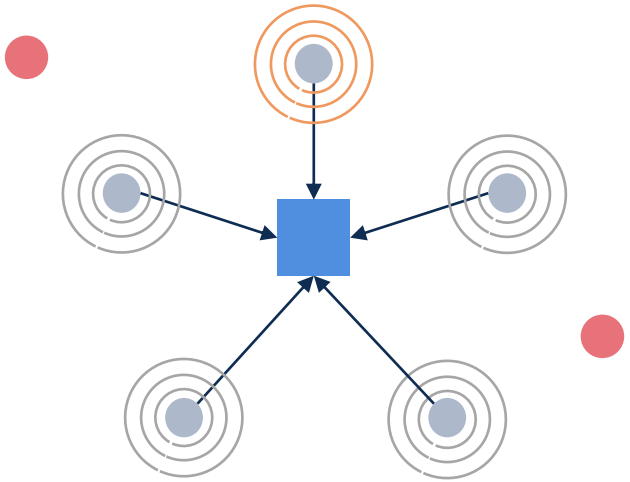


Centralized architecture:
all vehicles send measurements to a single control center

## CSL + MTT



## Multi Target Tracking (MTT)



Target beliefs contribute in refining vehicle beliefs

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# MTT addressed issues

**Missed detection**

Targets are hypothesized to be detected from the reception of reflected known signals. If a target exists it can be NOT detected.

**Clutter**

An MTT measurement can be NOT originated from a target.

**Birth/death/survivability**

Targets can exist / not exist, survive or die.

**Data association**

An MTT measurement is of unknown origin,
Clutter? A vehicle? A target? Which vehicle? Which target?

» Potential Target (PT)[A]

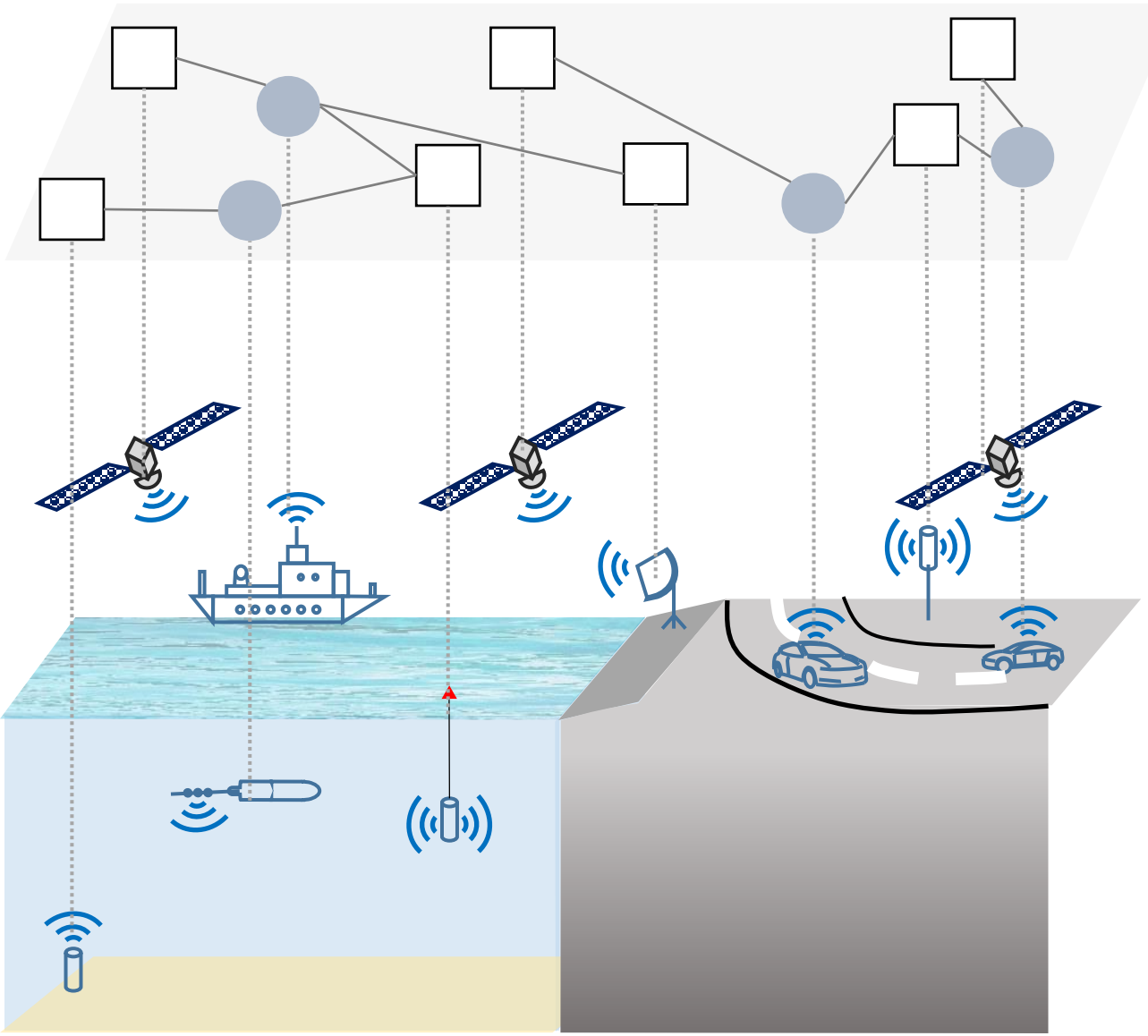
$$\boldsymbol{y}_{k,t} = [\boldsymbol{x}_{k,t} \quad r_{k,t}]$$

↳ Existence probability

- Legacy PT: a target that has already been detected — $\underline{\boldsymbol{y}}_{l,t}$
- New PT: a target that is detected for the first time — $\overline{\boldsymbol{y}}_{m,t}$

[A] Meyer, F., Kropfreiter, T., Williams, J. L., Lau, R., Hlawatsch, F., Braca, P., & Win, M. Z. (2018). Message passing algorithms for scalable multitarget tracking. *IEEE Proc.*, *106*(2), 221-259.

# Problem formulation



- Goal: CSL&MTT to estimate vehicle and target positions

Nav., direct, indirect meas.

$$\hat{\boldsymbol{s}}_{a,t}^{\mathrm{MMSE}} \triangleq \int \boldsymbol{s}_{a,t}\, f(\boldsymbol{s}_{a,t}|\boldsymbol{g}_{1:t}, \boldsymbol{\rho}_{1:t}, \boldsymbol{z}_{1:t})\, \mathrm{d}\boldsymbol{s}_{a,t}$$

$$\hat{\boldsymbol{x}}_{k,t}^{\mathrm{MMSE}} \triangleq \int \boldsymbol{x}_{k,t}\, \frac{f(\boldsymbol{x}_{k,t}, r_{k,t}=1|\boldsymbol{g}_{1:t}, \boldsymbol{\rho}_{1:t}, \boldsymbol{z}_{1:t})}{f(r_{k,t}=1|\boldsymbol{g}_{1:t}, \boldsymbol{\rho}_{1:t}, \boldsymbol{z}_{1:t})}\, \mathrm{d}\boldsymbol{x}_{k,t}$$

- Time-variant graph with continuous and discrete variables. Flexible and intuitive representation of a mobile network with nodes (variables) and links among them (factors).

- Bayesian inference through direct marginalization of variables by message passing algorithm (instead of solving their -USUALLY INTRACTABLE- joint posterior distribution). [see next slide]

# Joint posterior pdf

DA

$$f\left(\boldsymbol{y}_{0:t}, \boldsymbol{s}_{0:t}, \boldsymbol{\alpha}_{1:t}, \boldsymbol{\beta}_{1:t} \middle| \boldsymbol{g}_{1:t}, \boldsymbol{\rho}_{1:t}, \boldsymbol{z}_{1:t}\right)$$

Nav.

Direct

$$\propto f(\boldsymbol{y}_0) f(\boldsymbol{s}_0) \prod_{t'=1}^{t} \underbrace{\left( \prod_{a \in \mathcal{V}} \tau\left(\boldsymbol{s}_{a,t'} \middle| \boldsymbol{s}_{a,t'-1}\right) \right)}_{\text{VEHICLE PREDICTION}} \underbrace{\left( \prod_{a \in \mathcal{V}_{t'}^{\boldsymbol{g}}} \mathfrak{g}_a\left(\boldsymbol{g}_{a,t'} \middle| \boldsymbol{s}_{a,t'}\right) \right) \left( \prod_{a \in \mathcal{R}} \prod_{a' \in \mathcal{T}_{t'}^{(a)}} \mathfrak{d}\left(\boldsymbol{\rho}_{t'}^{(a,a')} \middle| \boldsymbol{s}_{a,t'}, \boldsymbol{s}_{a',t'}\right) \right)}_{\text{CSL}}$$

$$\times \underbrace{\left( \prod_{\ell \in \mathcal{L}_{t'}^{(1)}} f\left(\boldsymbol{y}_{\ell,t'}^{(1)} \middle| \boldsymbol{y}_{\ell,t'-1}\right) \right)}_{\text{PT PREDICTION}} \prod_{j=1}^{J} \underbrace{\left( \prod_{\ell \in \mathcal{L}_{t'}^{(j)}} q\left(\boldsymbol{y}_{\ell,t'}^{(j)}, \alpha_{\ell,t'}^{(j)}, \boldsymbol{s}_{j_1,t'}, \boldsymbol{s}_{j_2,t'}; \boldsymbol{z}_{t'}^{(j)}\right) \prod_{m \in \mathcal{M}_{t'}^{(j)}} \psi\left(\alpha_{\ell,t'}^{(j)}, \beta_{m,t'}^{(j)}\right) \right)}_{\text{MTT WITH DA}}$$

LEGACY PTs

$$\times \underbrace{\left( \prod_{a \in \mathcal{V}} h\left(\boldsymbol{s}_{a,t'}, \alpha_{L+a,t'}^{(j)}, \boldsymbol{s}_{j_1,t'}, \boldsymbol{s}_{j_2,t'}; \boldsymbol{z}_{t'}^{(j)}\right) \prod_{m \in \mathcal{M}_{t'}^{(j)}} \psi\left(\alpha_{L+a,t'}^{(j)}, \beta_{m,t'}^{(j)}\right) \right) \prod_{m \in \mathcal{M}_{t'}^{(j)}} \upsilon\left(\bar{\boldsymbol{y}}_{m,t'}^{(j)}, \beta_{m,t'}^{(j)}, \boldsymbol{s}_{j_1,t'}, \boldsymbol{s}_{j_2,t'}; \boldsymbol{z}_{m,t'}^{(j)}\right)}_{\text{MTT WITH DA}}$$

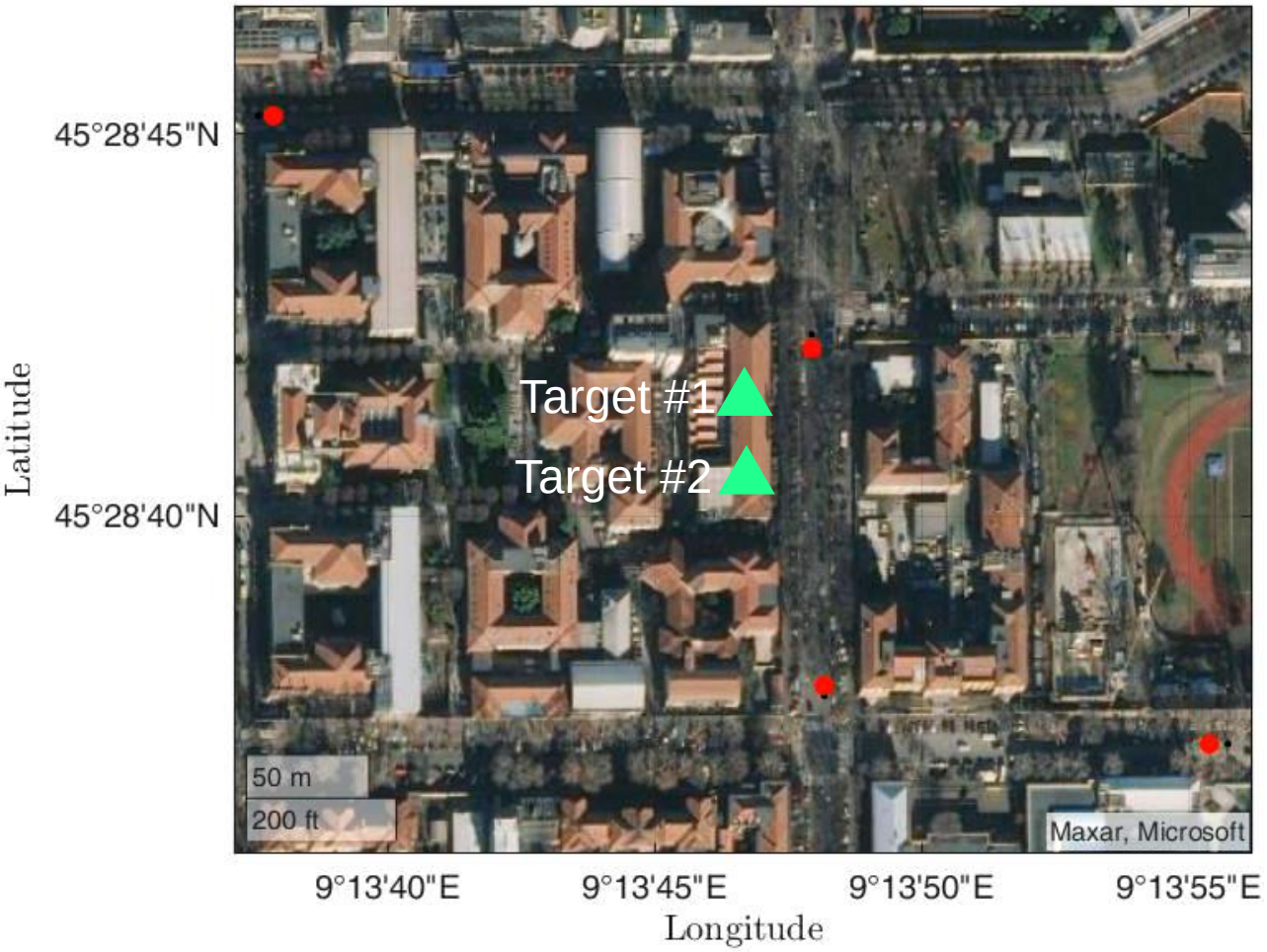
NEW PTs

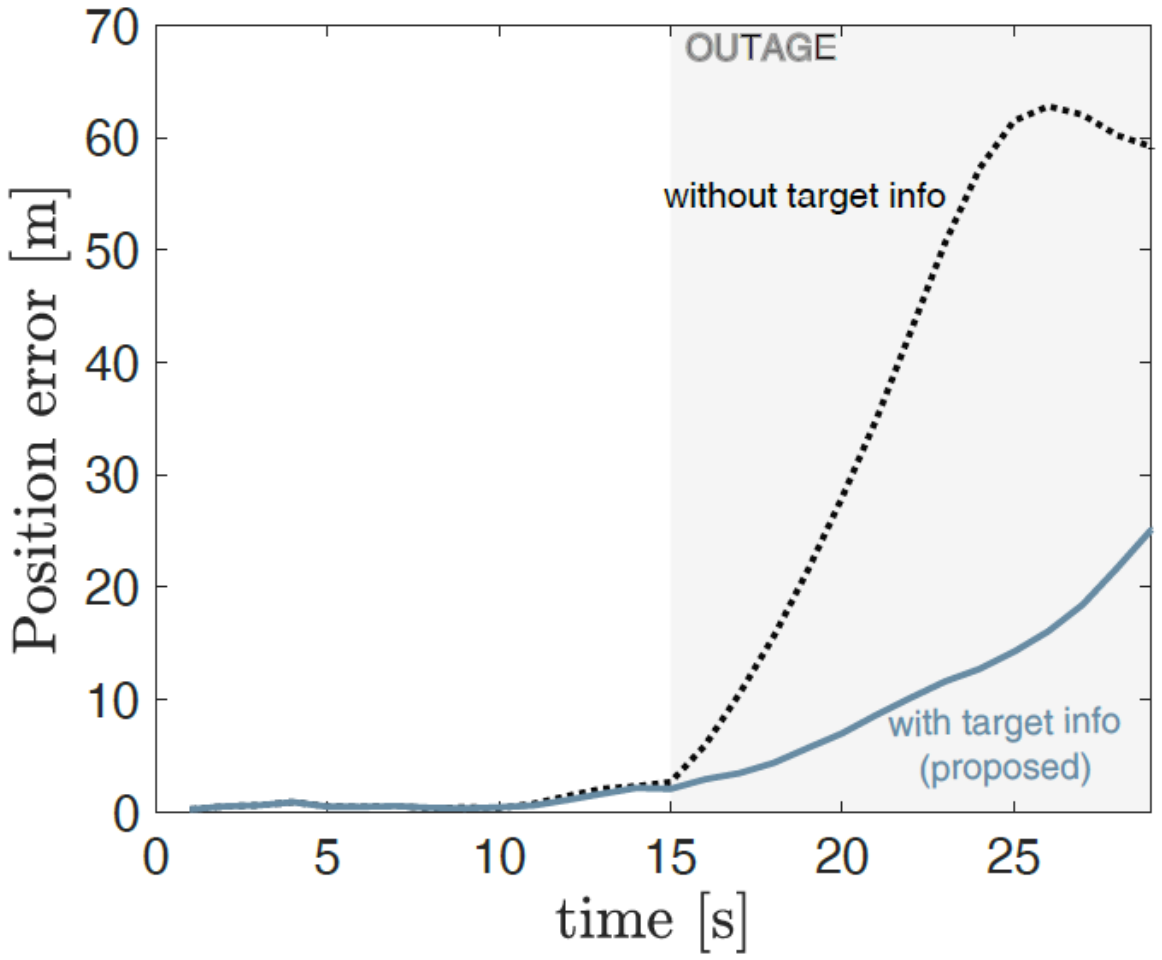
Its direct marginalization to compute the marginal posterior pdfs of vehicles and targets is unfeasible

→ approximated by sum-product algorithm

# Simulated urban scenario

Focus of the analysis: what happens in case of GNSS outage?




Meas. accuracy: GPS 5 m; Vehicle-Vehicle 3m (range), 1deg (bearing); Vehicle-Target-Vehicle 3m (range), 1deg (bearing)

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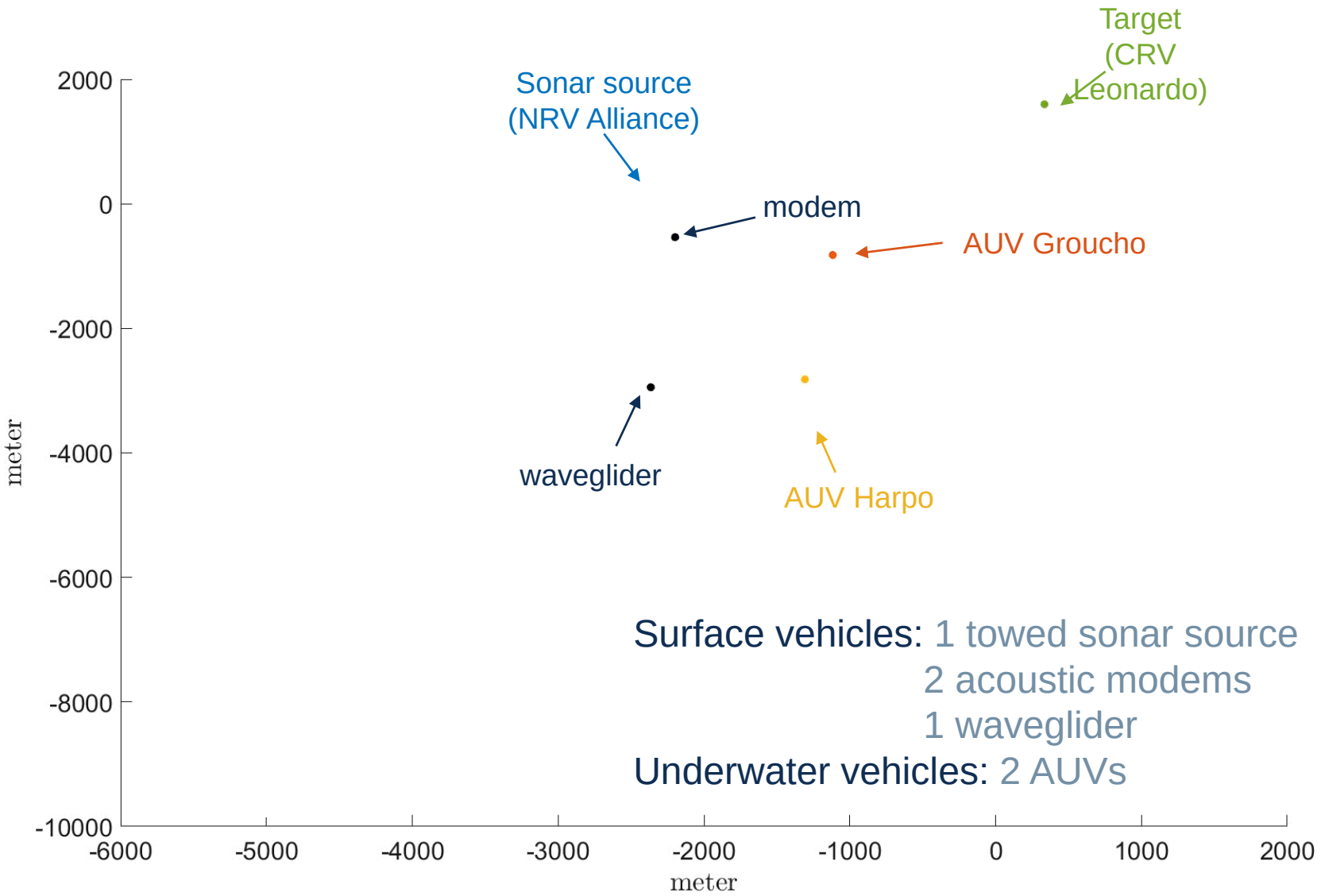
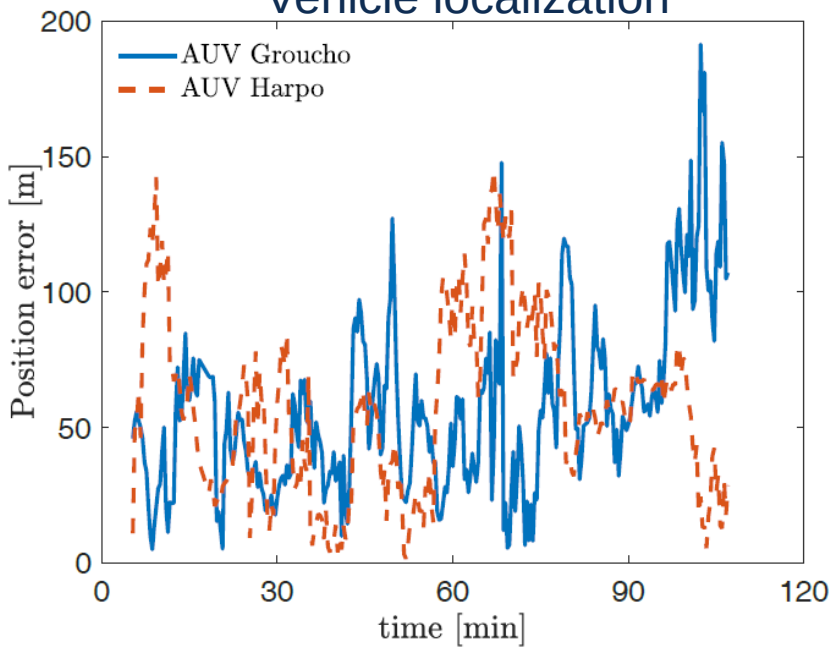
# Real maritime experiment




Surface vehicles: 1 towed sonar source
2 acoustic modems
1 waveglider

Underwater vehicles: 2 AUVs

## Vehicle localization




## Target localization

Meas. accuracy: GPS 5 m; Vehicle-Vehicle 70m (range), 7deg (bearing); Vehicle-Target-Vehicle 70m (range), 7deg (bearing)

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# Conclusions

- Development of a generic framework for cooperative self localization (CSL) and multitarget tracking (MTT) in a multistatic scenario with mobile sensing vehicles
- Unification of CSL and MTT via belief propagation such that target beliefs are conveniently used as a mean to improve vehicle localization
- Versatile algorithm for multiple scenarios to fit specific needs

## Main references


- F. Meyer, T. Kropfreiter, J. L. Williams, R. Lau, F. Hlawatsch, P. Braca, and M. Z. Win, “Message passing algorithms for scalable multitarget tracking," Proc. IEEE, vol. 106, pp. 221{259, Feb. 2018.
- M. Brambilla, D. Gaglione, G. Soldi, R. Mendrzik, G. Ferri, K. D. LePage, M. Nicoli, P. Willett, P. Braca, and M. Z. Win, “Cooperative localization and multitarget tracking in agent networks with the sum-product algorithm," 2021. https://arxiv.org/abs/2108.02573.