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XXXVI Cycle

Advanced Bayesian solutions applied to GNSS cooperative positioning

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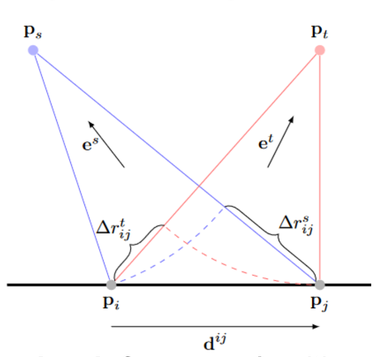
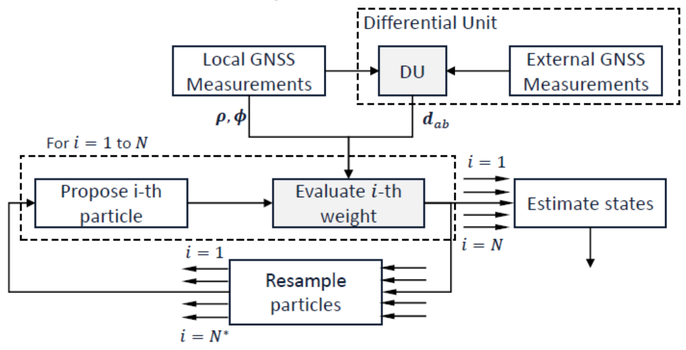
Research context and motivation

- Research interest has grown towards an increased complexity of fusing proprioceptive and exteroceptive sensors with Global Navigation Satellite System (GNSS).
- In spite of the growing availability of such sensors, GNSS receivers are still exploited for their capability of estimating **absolute timing and position**.
- However, harsh conditions in urban environment (e.g., multipath, fading, occlusions) impair the quality of the positioning solution.
- In this context, **Cooperative Positioning** (CP) techniques, such as double difference ranging, have been proposed to improve the positioning capabilities of GNSS receivers by enabling the **exchange of raw measurements** between agents of in a network.



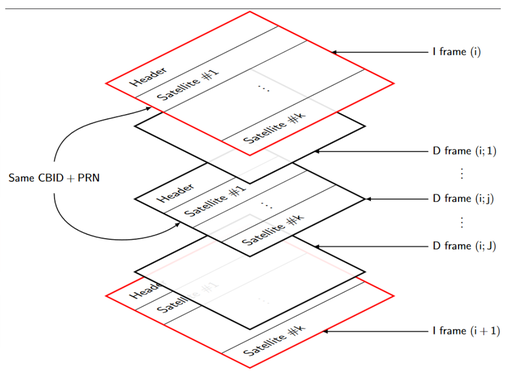


- **Bayesian inference** algorithms are at the basis of current Positioning, Navigation and Timing (PNT).
- The integration of external information from additional sensors or cooperative measurements has led to the development of **more complex navigation filters**.

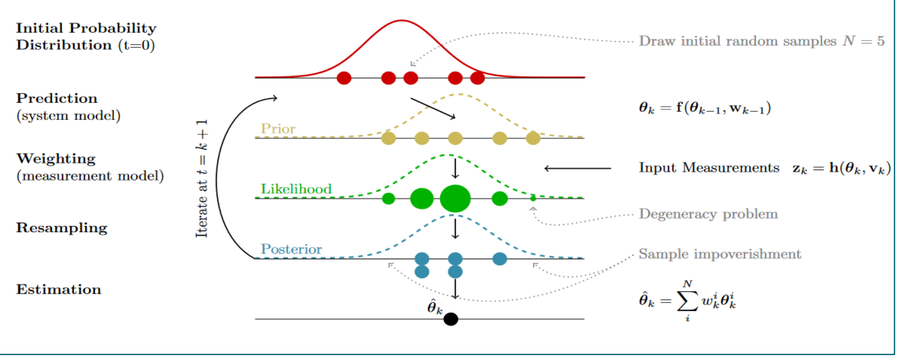
Addressed research questions/problems

- Intelligent Transport Systems (ITS) pose strict safety requirements. In urban environments, the **accuracy and realiability** of standalone GNSS might not be sufficient. To solve this problem, CP techniques have been proposed to improve the quality of GNSS solutions.
- In many of these works, the transmission of relevant data between agents in a vehicular network is given for granted and the **network impact** of this transmission is neglected. To prove the feasibility of cooperative solutions among agents, a network protocol to transmit raw GNSS observables was definied and tested to verify its impact on the network load as the density of agents increases.

NMEA 0183	Proprietary	No Raw GNSS Observables	Real-Time
RTCM	Proprietary	Raw GNSS Observables	Real-Time
IGS International GNSS Service	Open	Raw GNSS Observables	No Real-Time
CAM2CEM	Open	Raw GNSS Observables	Real-Time

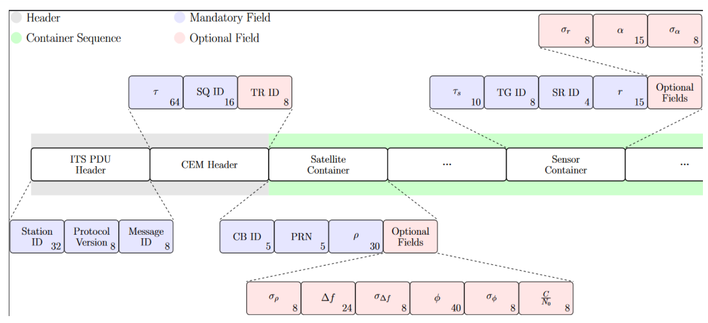


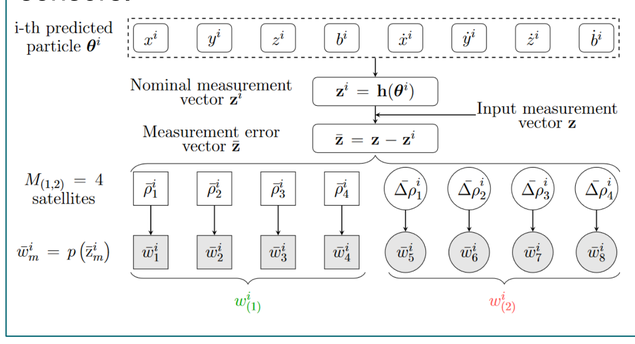
- In the context of GNSS, Kalman Filter based solutions offer optimal estimation under a set of highly **restrictive constraints**, such as linear measurement models and Gaussian error Probability Density Functions (PDFs), which are often not encountered in real scenarios.
- To cope with these limitations, Particle Filters (PF) algorithm have been proposed, thanks to their ability to natively handle **non-linear models and arbitrary PDFs**.
- The disadvangage of PFs is their **increased computational cost**, especially for estimation problems with a large cardinality of the state space.



Novel contributions

Development and extension of a **real-time, open-source protocol** and message, namely Cooperative Enhancement Message (CEM), for the transmission of raw GNSS observables in vehicular networks and measurements from other on-board sensors.

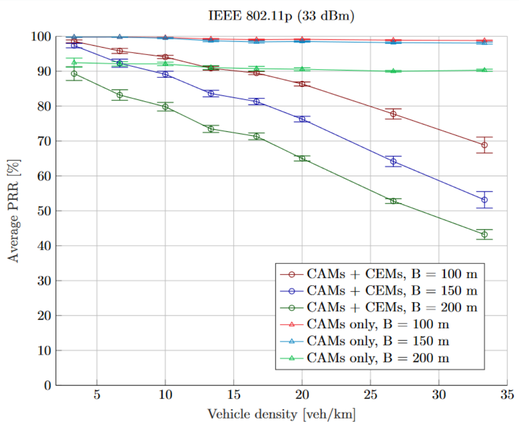


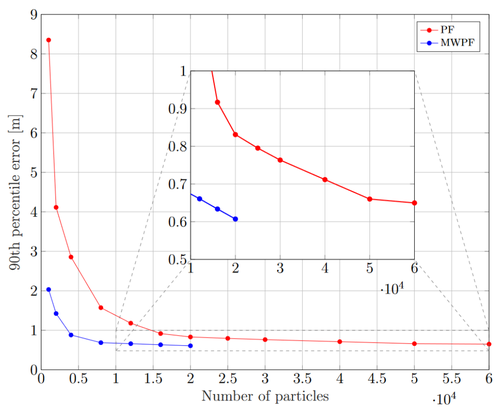


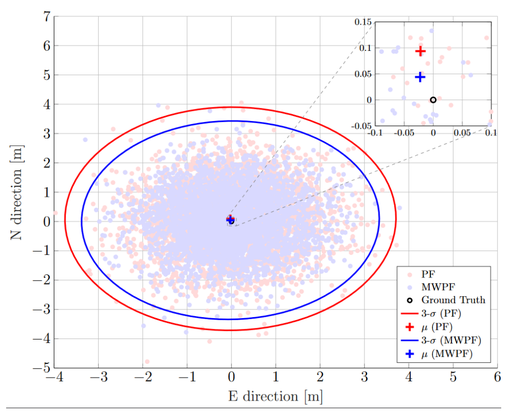
Definition of a **Multi-Weighting** (MW) techinque for Particle Filters (PF) which accounts for mutual information of different sets of input measurements to perform a **more efficient sampling** of the state space and obtain improved accuracy at a lower computation cost.

Adopted methodologies

The performance of the proposed CEM method has been simulated and tested using the ms-van3t framework on both CV2X and IEEE 802.11p access technologies and with varying parameters of interest.
Results show that even for relatively high vehicle densities, the CEM protocol performs well in terms of latency and packet reception ratio.







- A mathematical proof has been derived to prove the advantages of the novel MW-PF.
- Its performance has been tested against legacy PF. Results show that the proposed method provides an improvement in accuracy which becomes **more significant as the number of particles decreases**, both in static and dynamic scenarios.

Future work

- Exploitation of Soft Information concepts in advanced Bayesian estimation with Particle Filters. Soft Information generalizes the concept of Single Value Estimates (SVEs) to a set of possible values each with different probabilities and different error PDFs. This multi-modal representation of probability densities can better model the statistical knowledge about a system and therefore lead to increased estimation performance.
- Factor Graphs optimizations as a generalization of Kalman Filter family of estimators with increased flexibility for more complex problem formulations.

Submitted and published works

- S. Zocca, Y. Guo, A. Minetto, F. Dovis, “Improved weighting in particle filters applied to precise state estimation in GNSS”, Frontiers in robotics and AI, vol. 9
- F. Raviglione, S. Zocca, A. Minetto, M. Malinverno, C. Casetti, CF Chiasserini, F. Dovis, “From collaborative awareness to collaborative information enhancement in vehicular networks”, Vehicular Communications, vol. 36
- O. Vouch, Y. Guo, S. Zocca, A. Minetto, F. Dovis, “Improved Outdoor Target Tracking via EKF-based GNSS/UWB Tight Integration with Online Time Synchronisation”, ION GNSS+ 2022
- O. Vouch, Y. Guo, S. Zocca, A. Minetto, F. Dovis “Enhanced EKF-based Time Calibration for GNSS/UWB Tight Integration”, TechRxiv (submitted to IEEE Sensors)

List of attended classes

- 02SFURV – Programmazione scientifica avanzata in matlab
- 01QRPRV – Satellite Navigation signal exploitation for atmospheric and environmental monitoring
- 01DMCRW – Bayesian inference: examples in civil and environmental engineering
- 01SHMRV - Entrepreneurial Finance
- 01UNYRV - Personal branding
- 01SYBRV - Research integrity
- 01SWQRV - Responsible research and innovation, the impact on social challenges

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