BMW Summer School 2015: Connected Cars Driving on Digital Roads

Cooperative Data Fusion for GPS-aided Positioning in IEEE 802.11p VANETs

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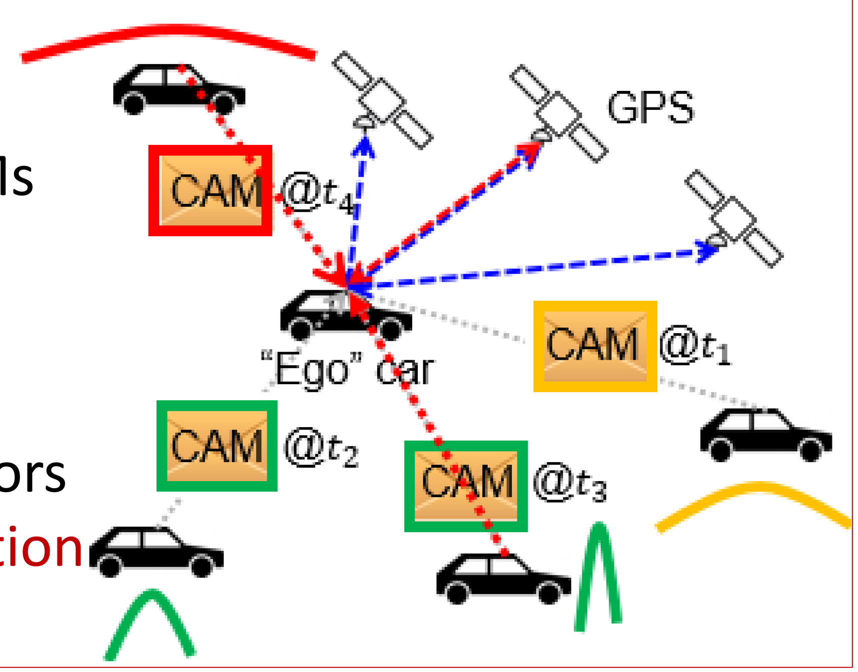
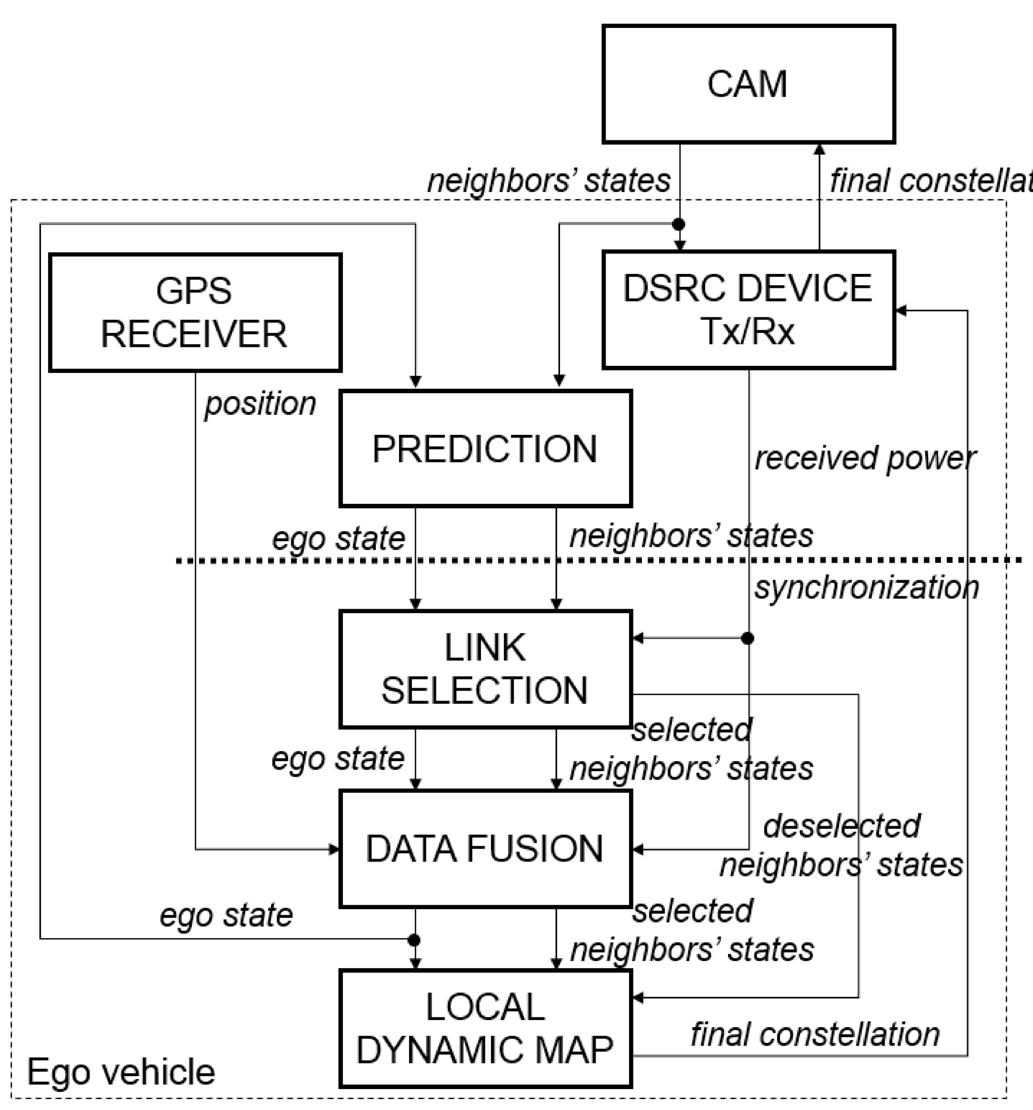
Abstract: A framework is proposed to improve car navigation through cooperative data fusion. We consider incorporating information from GPS-enabled neighboring cars and Received Signal Strength Indication (RSSI) out of IEEE 802.11p messages. The solution includes prediction-based data resynchronization, links selection mechanisms using RSSI measurements pre-validation or a Cramér-Rao Lower Bound (CLRB) indicator eliminating non-informative data, and finally a Bayesian tracking filter. First simulations show benefits from selective cooperation in terms of navigation continuity under harsh GPS conditions.

Cooperative Positioning (CP) in VANETs

- **Motivations**
  - Poor/lost GPS → Needs for improved navigation continuity
  - CP involves mobile-to-mobile measurements (e.g., RSSI)
  - Pure VANET context → No real known anchors (only GPS-aided neighbors)
  - Existing Cooperative Awareness Message (CAM) traffic (e.g., 802.11p) → Support to both RSSI and cooperative data fusion
- **Problem statement**
  - Asynchronous/missing CAMs → Re-align in time
  - Poor CAM-based RSSI measurements → Reject
  - Coarsely positioned neighbors → Perform selective cooperation

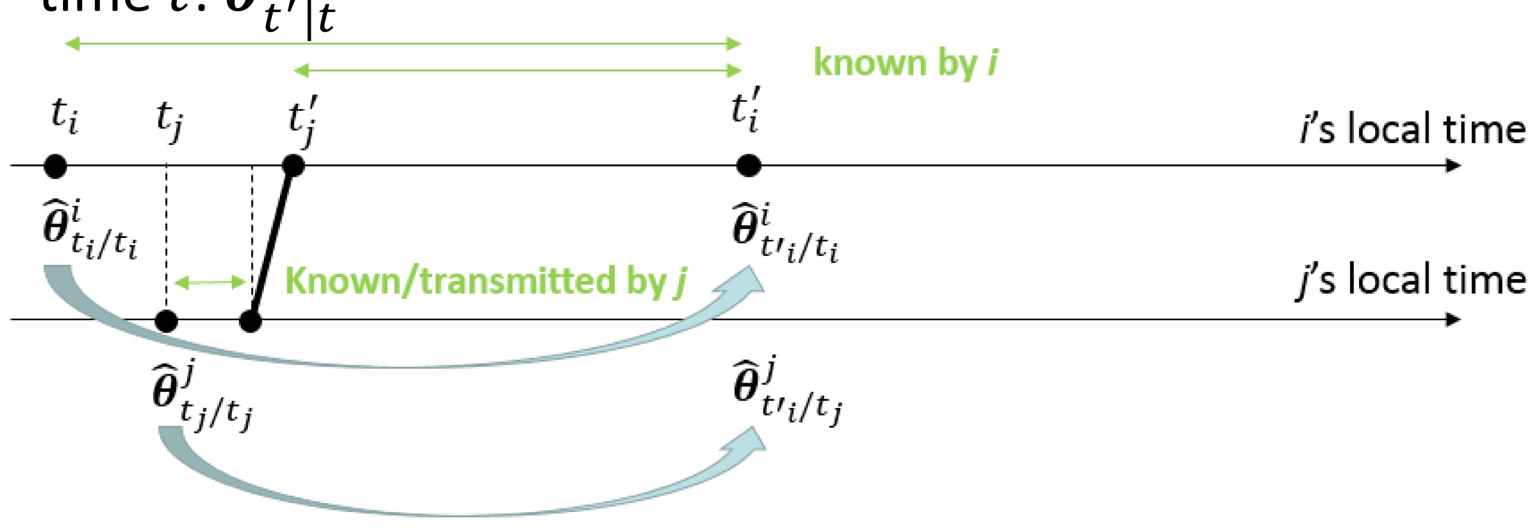


Overall Fusion Synopsis and Data Flow



Data Resynchronization

- Stochastic linear (Kalman-like) prediction
  - True state of vehicle i at time t: $\boldsymbol{\theta}_t^i = \left[(x, y, \dot{x}, \dot{y})_t^i\right]^T$
  - Estimated aligned state of vehicle i at time t' given state at time t: $\widehat{\boldsymbol{\theta}}_{t'|t}^i$

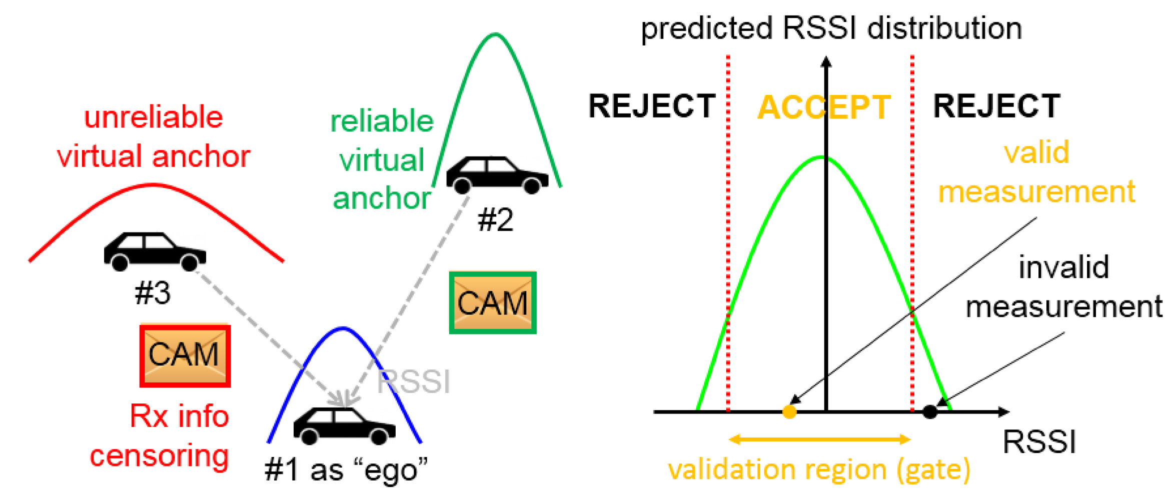


Measurements

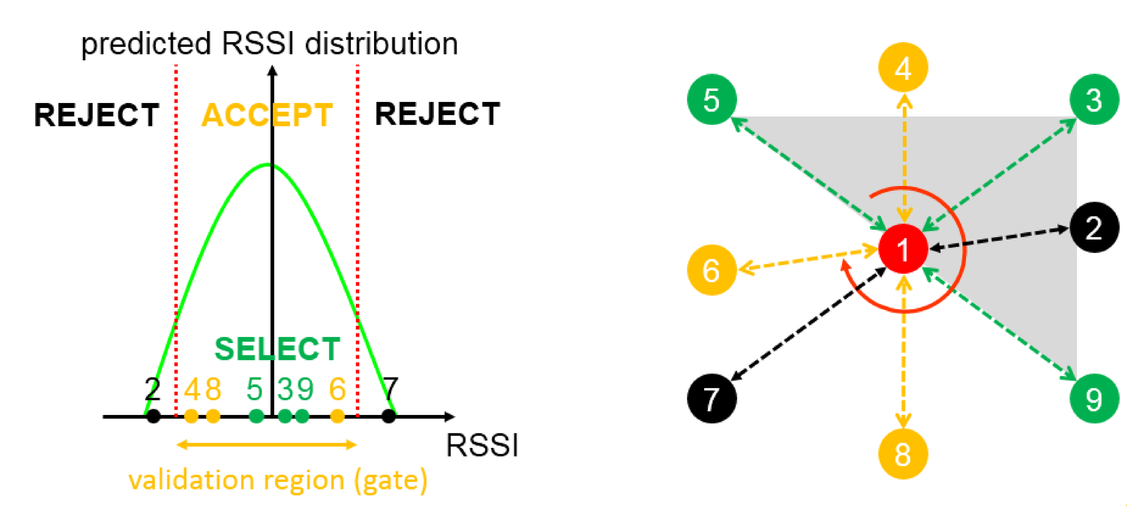
- 2D coordinates estimated by GPS receiver affected by Gaussian centered measurement noises (i.i.d)
- V2V RSSI measurements w.r.t. neighbors affected by Gaussian shadowing (i.i.d)
- Overall observation vector
  - Non-cooperative: "Ego" GPS position estimate
  - Cooperative: Neighboring GPS position estimates, V2V RSSI measurements

Links Selection

- **Pre-validation step:** Innovation monitoring rejecting non-reliable neighboring info & poor RSSIs

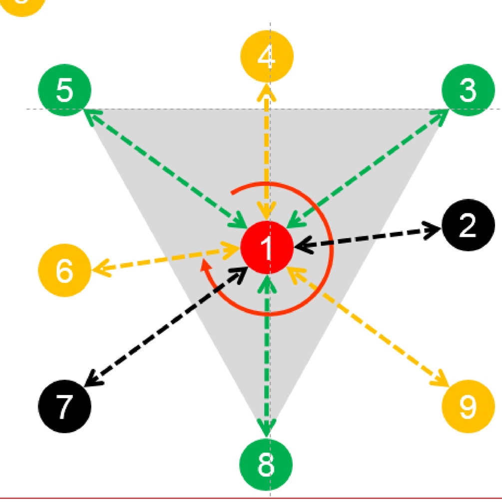


- **Links selection step:** Choosing an "optimized" shorter list among pre-validated links
  - *Nearest Neighbor (NN):*



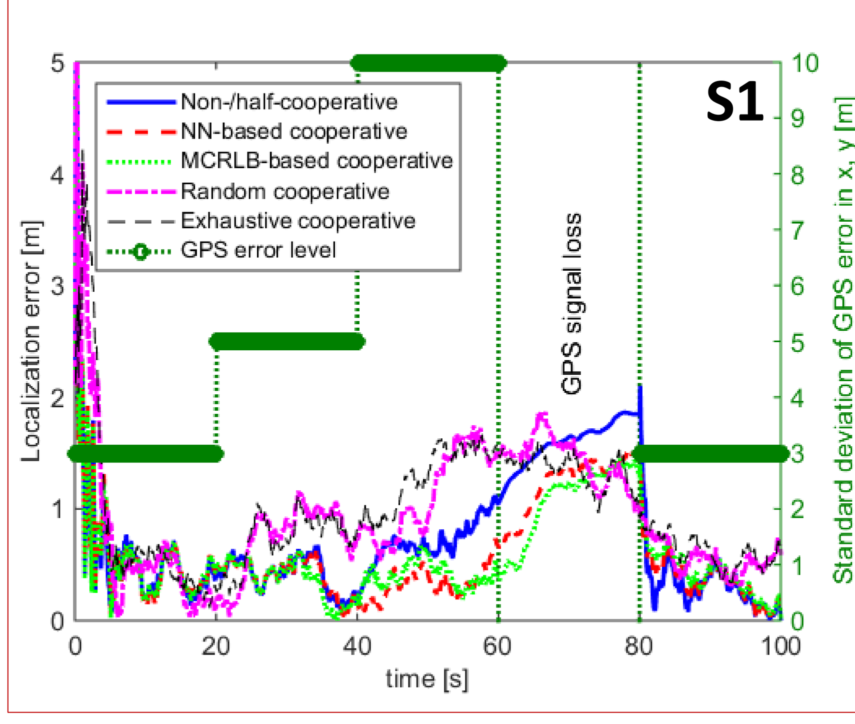
  - *Modified CLRB (MCRLB)-based scheme:*

$\mathrm{CRLB}_1(8, 5, 3, 1) < \mathrm{CRLB}_1(9, 5, 3, 1) < \mathrm{CRLB}_1(6, 5, 3, 1) < \mathrm{CRLB}_1(4, 5, 3, 1)$



Performance Evaluation

- **Simulation settings**
  - 3-lane highway, 9 vehicles, Gauss Markov mobility model
  - Gaussian GPS error model, log-distance path loss model
  - Coop. data fusion at "ego" car, filtered GPS at neighbors
- **Evaluation scenario 1 (S1):** Time-variant GPS level (20 % of loss) at the "ego" car with 1 trial/run
- **Evaluation scenario 2 (S2):** Time-invariant GPS level with 1000 Monte Carlo simulations



Algorithm	Whole trajectory				Poor GPS	
	S1		S2		S2	
	$\mu_{1/2}$	WC	$\mu_{1/2}$	WC	$\mu_{1/2}$	WC
Raw GPS	5.90	12.2	N/A	N/A	N/A	N/A
Non/half-CP	0.53	1.11	0.57	1.78	1.10	1.85
NN-CP	0.49	1.02	0.46	1.43	0.67	1.47
MCRLB-CP	0.48	1.01	0.46	1.37	0.53	1.39
Ran. Sel. CP	0.50	1.18	0.82	1.74	1.41	1.72
Exhaust. CP	0.51	1.28	0.87	1.61	1.39	1.60

Conclusions

- Practical low-complexity solutions for data synchronization and links/measurements selection before fusion
- Exhaustive cooperation not systematically helpful
- Better resilience through selective cooperation, mostly in harsh/host GPS conditions → Context-aware cooperation

Acknowledgment

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