Vehicular Antenna Deployments for Downlink Positioning

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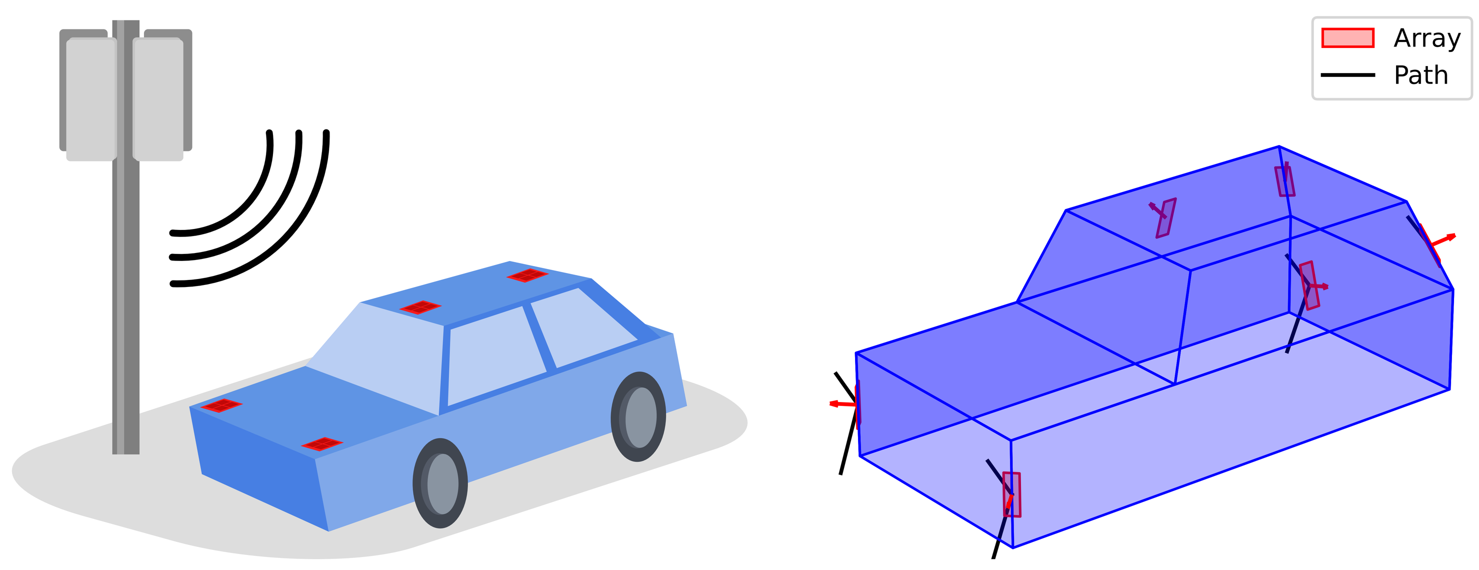
Motivation & Research Goals

In future advanced driver assistance systems (ADAS) in vehicles, vehicular positioning techniques are expected to fulfill sub-meter accuracy requirements [1], [2]. To accomplish this, we need alternatives to contemporary solutions such as stand-alone global navigation satellite systems (GNSS). Motivated by the emergence of vehicle-to-anything communications (V2X) equipment [3], this work [4] investigates the feasibility of distributed vehicle-side deployments of communications equipment for positioning.

System Model



A vehicle equipped with K planar antenna arrays receives a reference signal transmitted by a nearby base station. The environment is simple; the vehicle is situated on flat ground and no obstacles are in its vicinity.

- Using the received reference signal at each antenna array, the vehicle is tasked with **positioning itself relative to the base station**.
- Two different system modes of operation: (i), **phase-coherence** among antenna arrays and, (ii), no phase-coherence.
- **Our goal** is to find the **optimal array deployment** $\mathcal{A}$ in terms of (snapshot) positioning performance.

Signal Model: The base station transmits an orthogonal frequency-division multiplex (OFDM) reference signal and observations are made over multiple subcarriers at each antenna element. For the k-th array, we have the observation matrix

$$\boldsymbol{Y}_k = \sum_{\ell \in \mathcal{L}_k} \alpha_{k,\ell} e^{j\phi_{k,\ell}} \sqrt{P_{\text{tx}}} \boldsymbol{a}_k(\theta^{\text{az}}_{k,\ell}, \theta^{\text{el}}_{k,\ell}) \left(\boldsymbol{b}(\tau_{k,\ell}) \odot \boldsymbol{x}\right)^T + \boldsymbol{Z}_k \,,$$

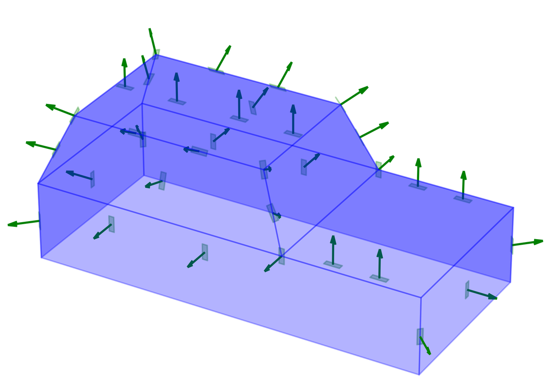
where ℓ is the incident path index, $\alpha_{k,\ell} e^{j\phi_{k,\ell}}$ is the complex channel coefficient, $\boldsymbol{a}_k$ and $\boldsymbol{b}$ are the spatial- and frequency domain steering vectors, respectively, $\boldsymbol{x}$ are the transmitted OFDM symbols and $\mathrm{vec}\boldsymbol{Z}_k \sim \mathcal{CN}(\boldsymbol{0}, \sigma^2\mathbb{I})$.

Assessing Performance & Optimizing Deployments

We define a performance metric based on the **Cramér-Rao lower bound** of a position estimator, called the position-error bound $\mathrm{PEB}(\boldsymbol{r}, \varphi; \mathcal{A})$. The metric is

$$\rho\colon \Pr\big(\mathrm{PEB}(\boldsymbol{r}, \varphi; \mathcal{A}) < \rho\big) = 1 - \varepsilon \,,$$

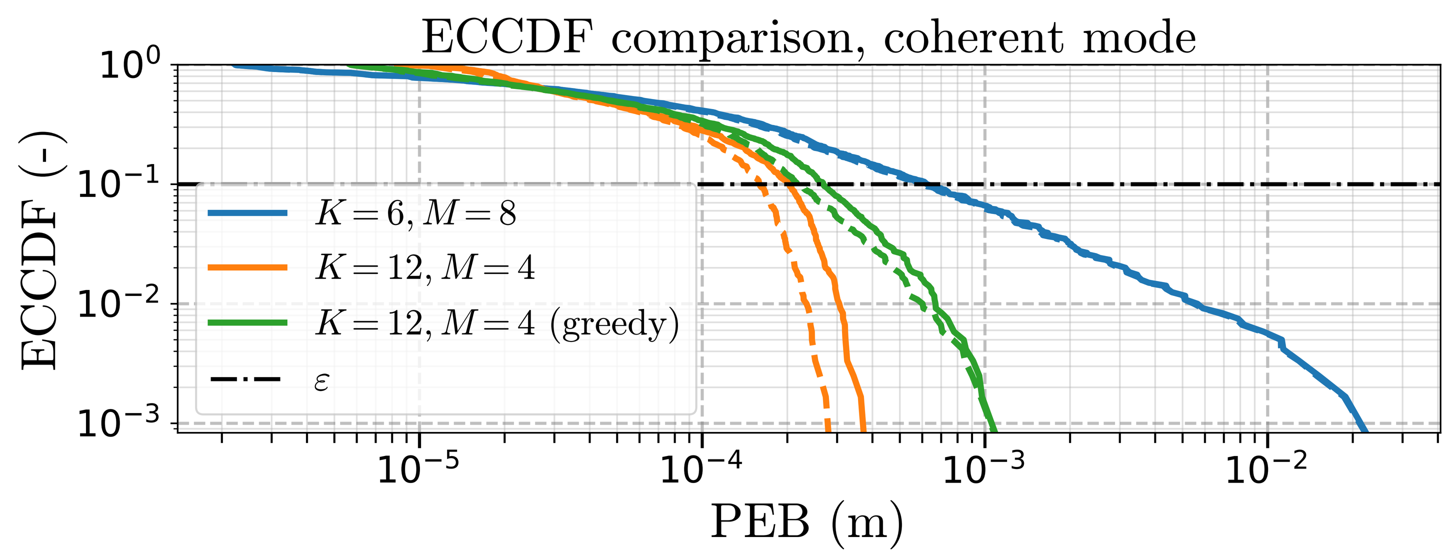
and is evaluated numerically.

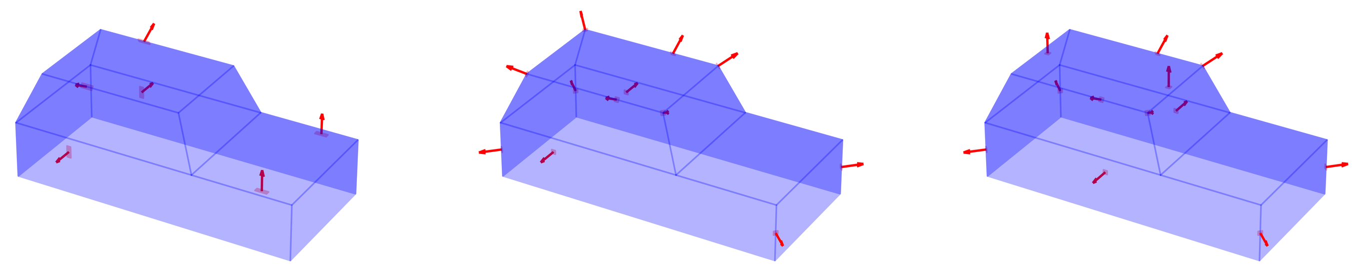


- Array placements are constrained to **finite number of candidate sites**.
- Number of feasible deployments $\mathcal{A}$ become finite.
- **Exhaustive search** minimizing $\rho(\mathcal{A})$.

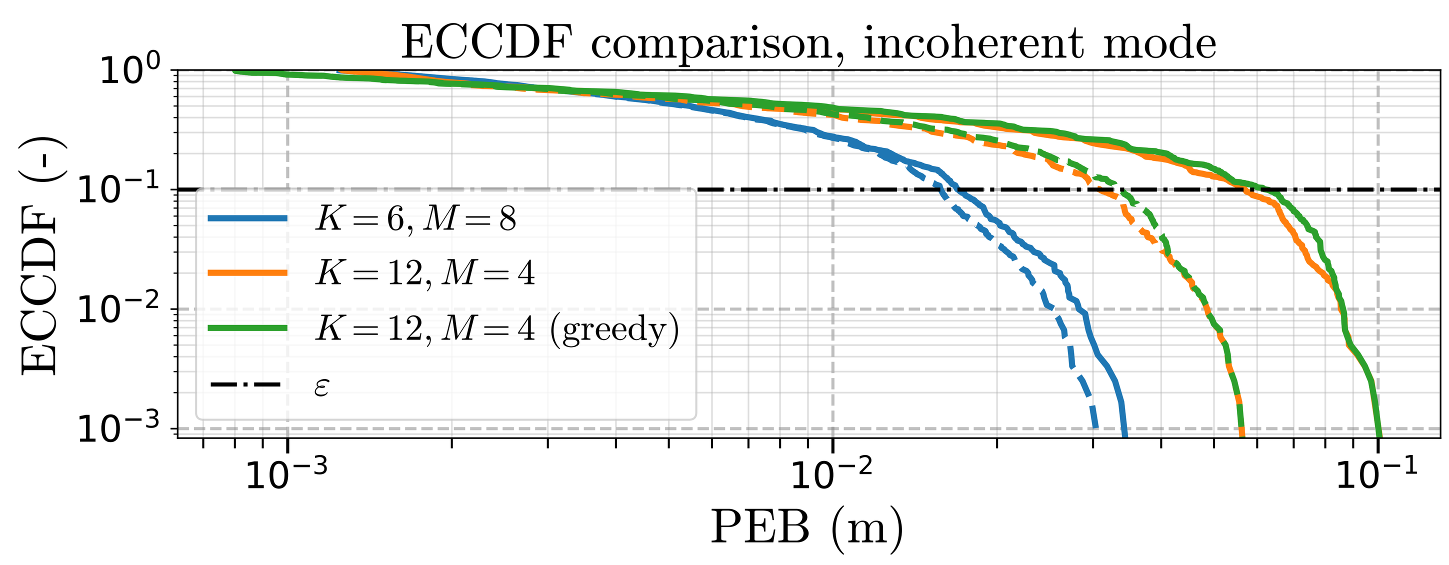
Selected Results

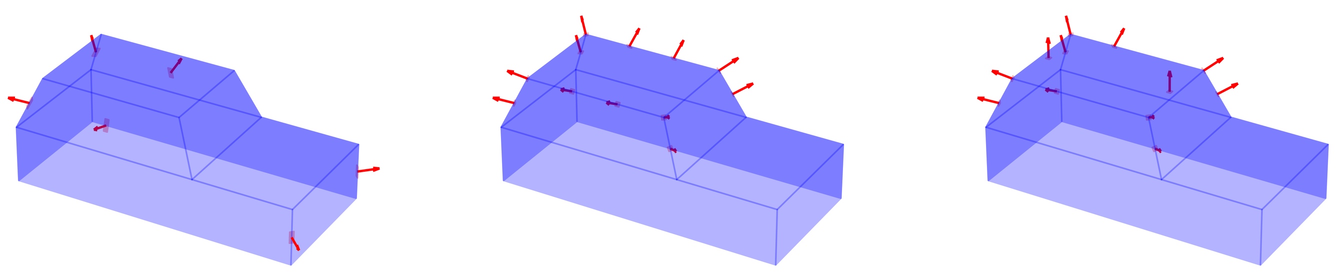
- Simulated **5GNR millimeter-wave** scenario using a 28 GHz carrier, 95 MHz bandwidth and individual array sizes M.
- Full lines indicate **multipath model** (ground reflections), dashed lines indicate no multipath.





$K=6, M=8$ $K=12, M=4$ $K=12, M=4$ (greedy)





$K=6, M=8$ $K=12, M=4$ $K=12, M=4$ (greedy)

Future Research: Simultaneous orientation and position estimation, mitigating coherent-phase induced ambiguities.

References

[1] J. A. del Peral-Rosado, G. Seco-Granados, S. Kim, and J. A. López-Salcedo, "Network design for accurate vehicle localization," *IEEE Transactions on Vehicular Technology*, 2019.

[2] S.-W. Ko, H. Chae, K. Han, S. Lee, D.-W. Seo, and K. Huang, "V2X-based vehicular positioning: Opportunities, challenges, and future directions," *IEEE Wireless Communications*, 2021.

[3] C. F. Mecklenbrauker, A. F. Molisch, J. Karedal, *et al.*, "Vehicular channel characterization and its implications for wireless system design and performance," *Proceedings of the IEEE*, 2011.

[4] V. Pettersson, M. F. Keskin, C. Marcus, and H. Wymeersch, "Optimized vehicular antenna placement for phase-coherent positioning," in *IEEE International Conference on Communications*, 2025 (Under Review).

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