Università degli Studi di Padova

Connectivity Evolution of Vehicular Nodes Operating at mmWave

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Dipartimento di Ingegneria dell'Informazione

OVERVIEW

- Next-generation V2X applications require data rates in the order of terabytes per driving hour.
  - Limit of traditional technologies (e.g., DSRC, LTE).
  - **Millimeter waves**: huge rates but unstable propagation.
- Use of **beamforming**, to balance for the increased pathloss.
- Need for fine and durable **alignment** of the beam pair.
- Need to TRACK and MONITOR the channel quality.

SYSTEM MODEL

- Multi-lane **highway** section.
- BSs (either **LOS** or **NLOS**) form a 1D PPP.
- Consider a measurement-based urban **pathloss** model.
- Model **interference** from surrounding BSs.
- Model multi-antenna arrays for **directionality**.

PERFORMANCE ANALYSIS

GOAL: Stochastic model for characterizing the beam **coverage** and **connectivity** probabilities in mmWave V2X systems.

- CONNECTIVITY: probability of the vehicle not to disconnect from its serving BS during a slot of duration T_S.

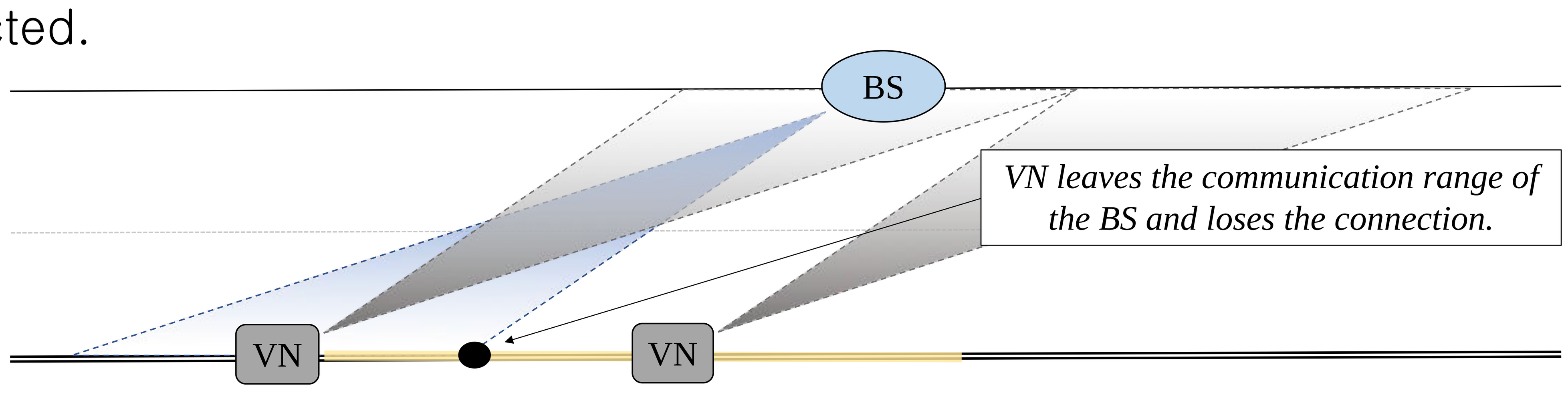
$$P_{\mathrm{NL}}^{(s)} = \mathbb{P}[T_L > T_S] = \mathbb{P}\left[r > \frac{VT_S}{\sin(\psi/2)}\left(\frac{R}{r}\sin(\eta) + \sqrt{1-\left(\frac{R}{r}\right)^2}\cos(\eta)\right)\right]$$

- COVERAGE: probability of finding a base station with sufficiently good channel quality: P[SINR(r) > $\mathbf{\Gamma}$].

$$P_{cov}^{(s)}(\Gamma) = \sum_{i\in\{L,N\}} \int_R^\infty \exp\left(\frac{-\mu\sigma^2\Gamma r^{\alpha_i}}{\Delta_1 C_i}\right) \mathcal{L}_{I_i^L}^{(s)}\left(\frac{\mu\Gamma r^{\alpha_i}}{\Delta_1 C_i}\right) \mathcal{L}_{I_i^N}^{(s)}\left(\frac{\mu\Gamma r^{\alpha_i}}{\Delta_1 C_i}\right) \bar{f}_i^{(s)}(r)\mathrm{d}r$$

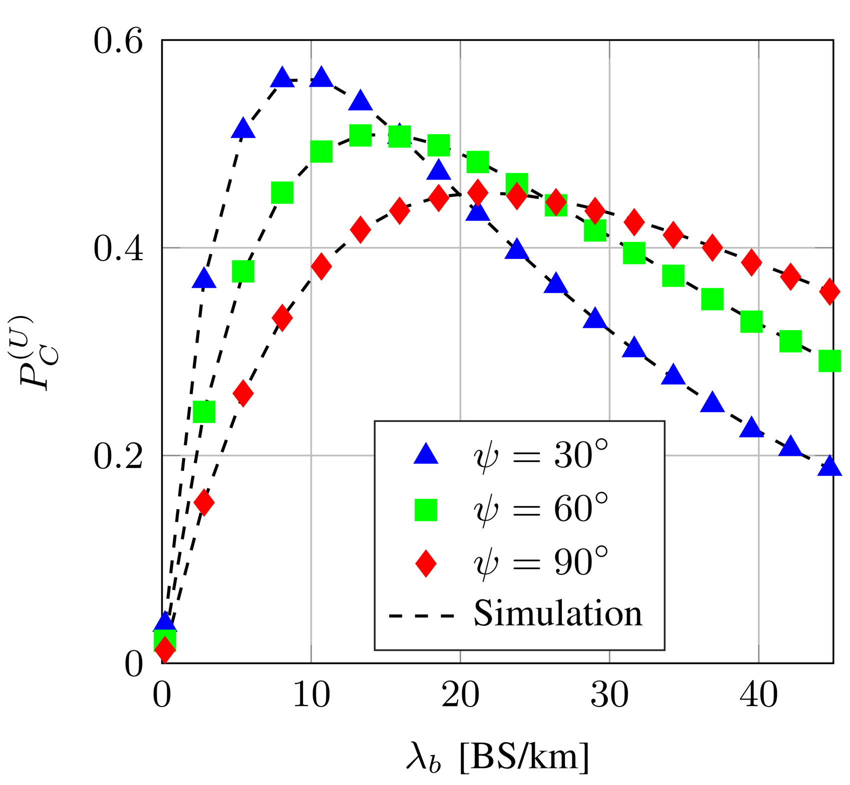
- **Measurement reports** are periodically exchanged among the nodes so that, at the beginning of every slot, vehicles and base stations identify the optimal directions for their respective beams.
- Starting from a *connected* state, the vehicular node (VN) can either maintain connectivity to the serving BS for the whole slot duration, or lose the beam alignment and get disconnected.

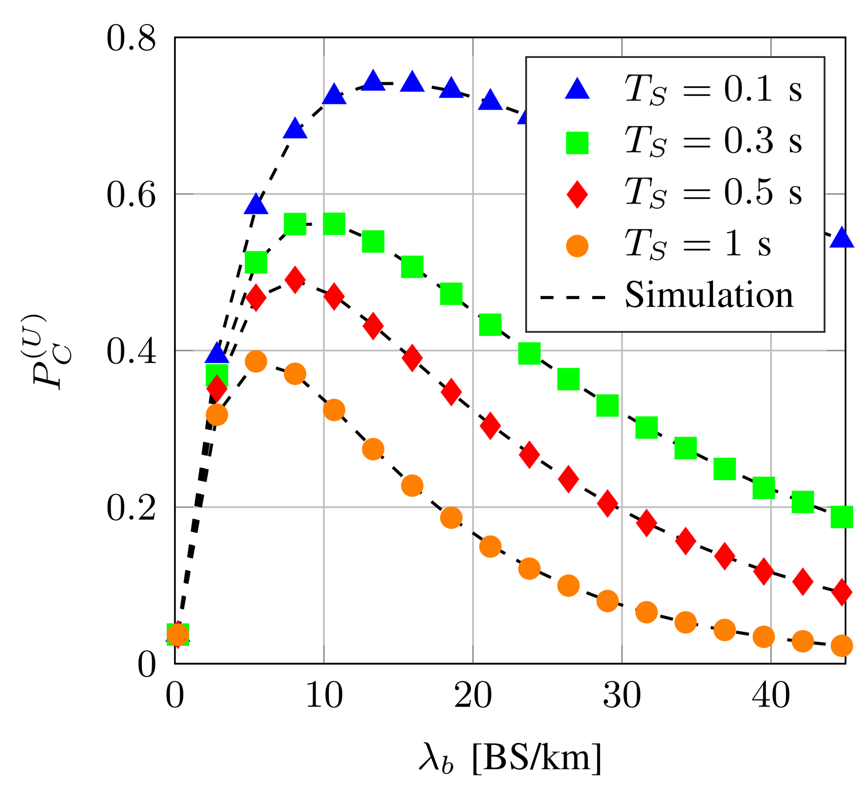
- Vehicles steer beams of width Φ.
- BSs steer beams of width Ψ.
- Vehicles move at speed *V*.
- Tracking periodicity T_S.

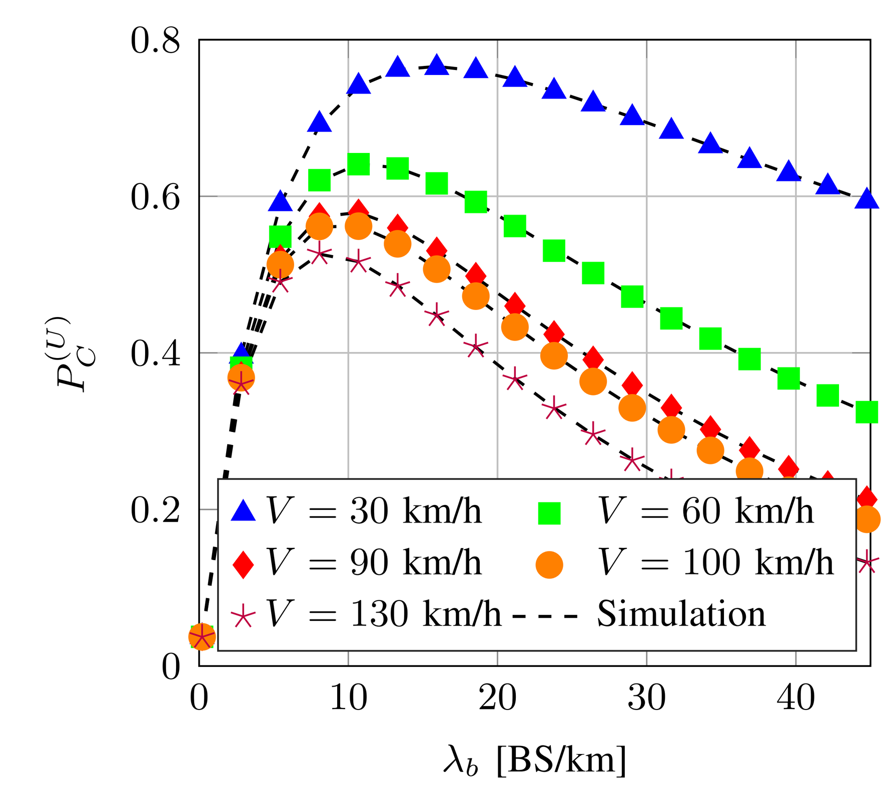


RESULTS

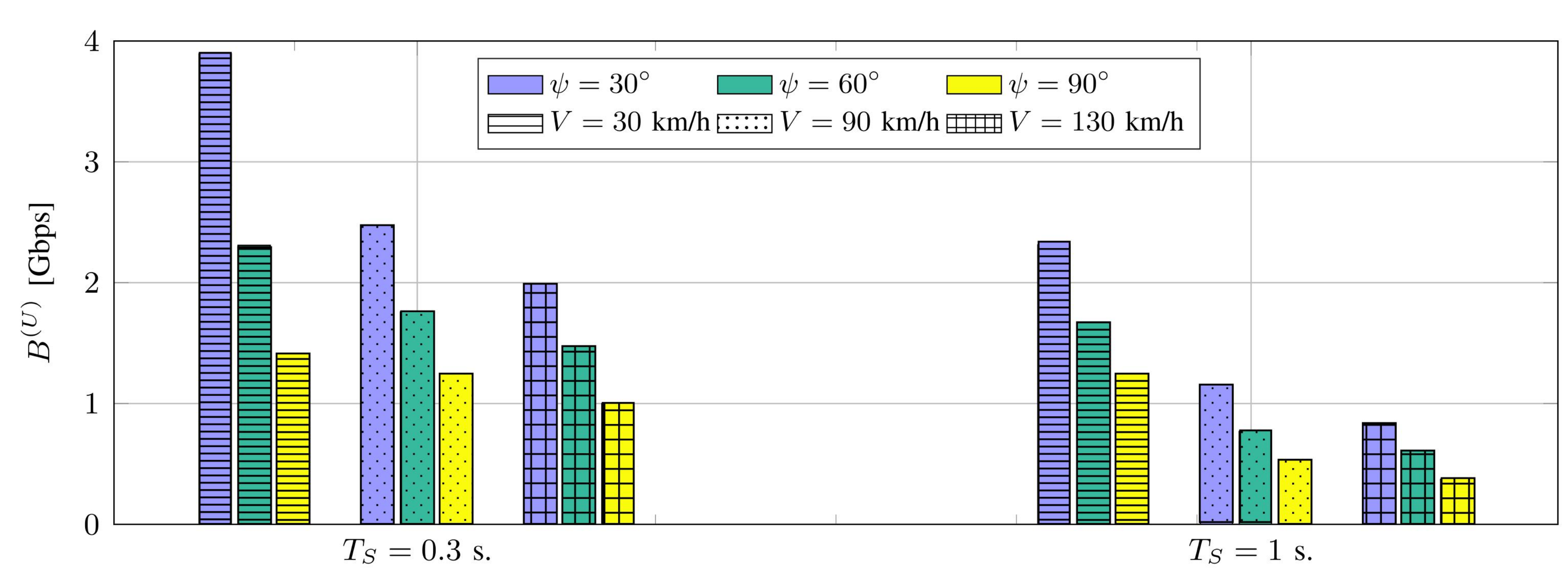
- GOAL: Validate the analytical framework through simulations.
- GOAL: Discuss the impact of several automotive-specific features in the V2X connectivity performance.







- Numerical and analytical curves match, thus validating the stochastic mathematical framework.
- The *connectivity probability* (P_C) requires alignment between the endnodes and sufficiently good signal quality.
  - P_C exhibits a **maximum** for a given **density** λ_b^* above which the deployment of more BSs results in a considerable increase of the system complexity while leading to worse communication performance.
  - For *sparse* networks, the connectivity is improved by considering **narrow beams**, due to the resulting higher gain achieved by beamforming.
  - For *dense* networks, **larger beams** should be steered to generate larger connectivity regions.
  - P_c can be increased by considering **slower** cars or **more periodic** tracking operations.
  - The considerations for the connectivity results are valid for the **throughput** analysis.



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[2]: M. Giordani, M Rebato, A. Zanella and M. Zorzi, "Poster: Connectivity Analysis of Millimeter Wave Vehicular Networks," accepted to *2017 IEEE Vehicular Networking Conference*, Turin, Italy, 2017.
[3]: M. Giordani, M. Rebato, A. Zanella, and M. Zorzi, "Coverage and Connectivity Analysis of Millimeter Wave Vehicular Networks: A Stochastic Geometry Approach," submitted to the *IEEE Transactions on Vehicular Technology*, 2017.