CAREER: Multi-Resolution Model and Context Aware Information Networking for Cooperative Vehicle Efficiency and Safety Systems

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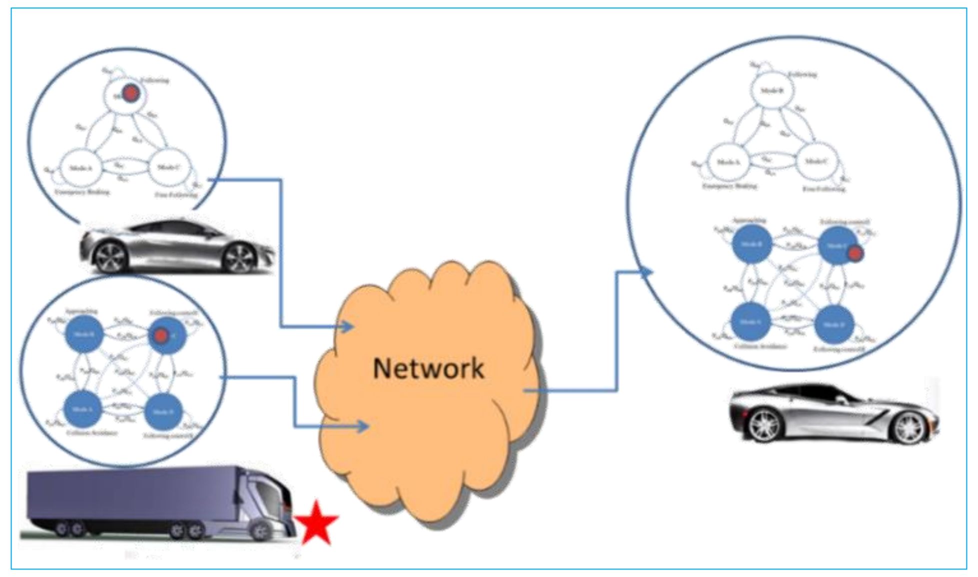
Motivation and Problem Statement

- Connected vehicles rely on V2V networks. Scalability is one of the main challenges, preventing rich collaboration and sensor information sharing.
- Proposed approach:
- replace: ***Data*** Communication and Networking
- with: ***Model*** Communication and Networking
- Model sharing prevents imposing huge load on the communication network in comparison with raw information beaconing methods.



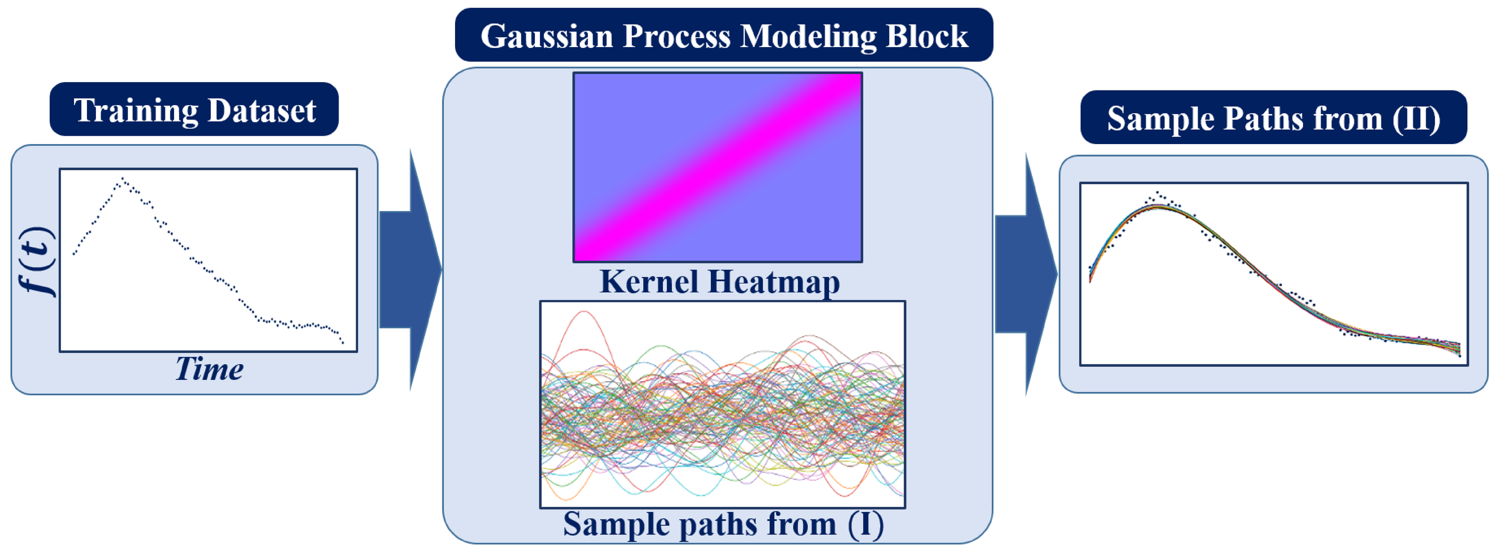
Background Theory of the Modeling Framework

Gaussian Processes: A Bayesian Non-parametric Approach for Supervised Learning

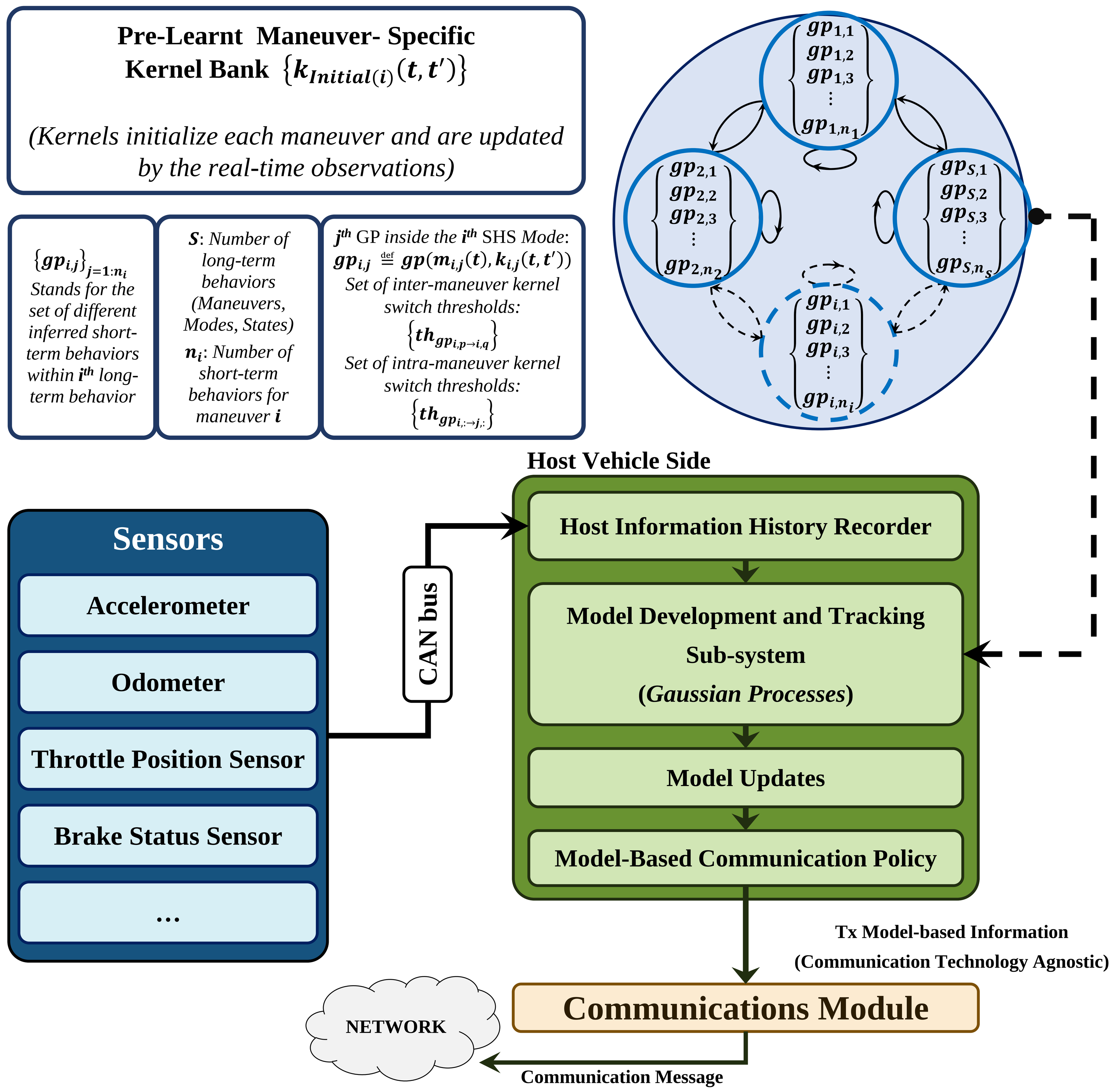
- Gaussian Process is defined as a stochastic process with each of its draws defines a continuous function over the (multi-dimensional) input space.
- The training (observation) set of $(\bar{x}, y)$s is treated as the marginalized distribution of the process and finite-length marginalized vector forms a *consistent* multivariate normal vector.
- GP puts the prior directly on the function space rather than parametrizing the function and putting the priors on the parameters space.
- Mean vector and covariance matrix of these marginalized distributions are defined as follows:

$$\bar{\mu} = m(\bar{x})$$
$$Cov(\bar{x}_i, \bar{x}_j) = K(\bar{x}_i, \bar{x}_j)$$

- $m(x)$ and $K(x_1, x_2)$ define the mean and the kernel functions, respectively.
- GP's non-parametric Bayesian inference fashion empower the model to discover and follow different patterns in the training set (using different kernel choices) in a fully data-driven manner.
- GPs discover the underlying function which has generated the target (observed) values and are proven to be a strong mechanism for both *regression* (reconstructing the missed observations) and *forecasting* (at possible unobserved future inputs) purposes.
- Model complexity is automatically adapted with respect to the observed training data set.
- Some of the most investigated kernels are Squared Exponential (a.k.a RBF), Linear, Periodic, Spectral Mixture, etc.
- Linear kernel was the best choice for our targeted problem due to the relative physical system's response time (system inertia) with respect to the time interval of the successive observation records of our data sets.

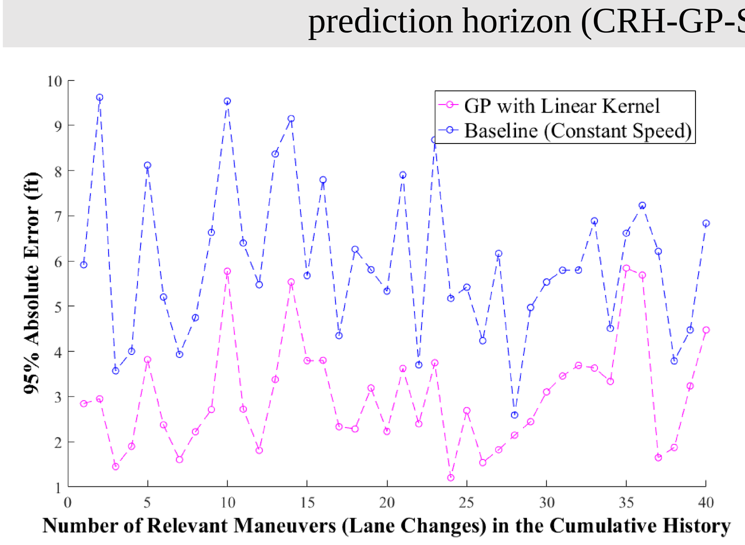


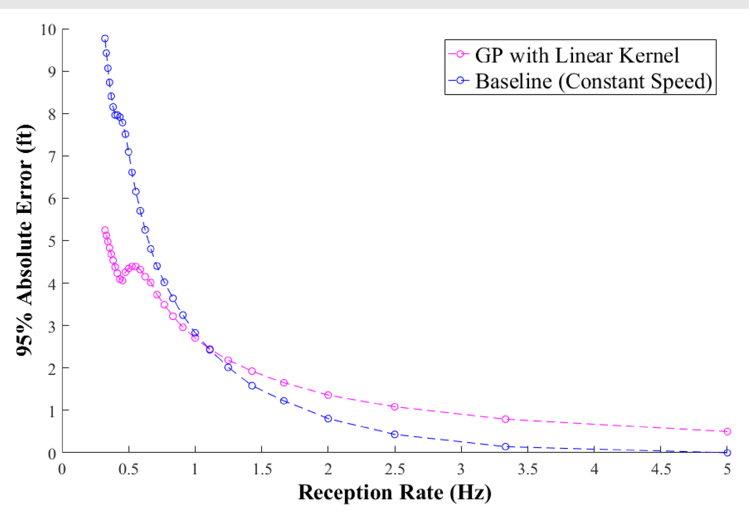
System-Level Architecture With the Proposed GP-SHS Framework



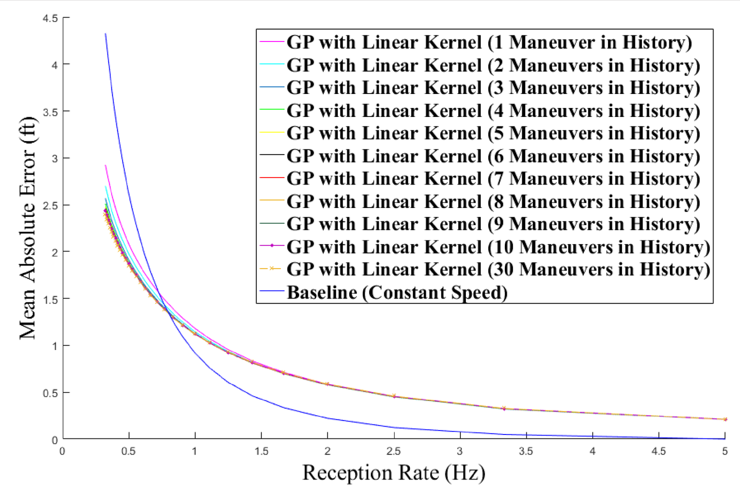
Gaussian Processes Inference Results

Lateral displacement forecasting accuracy for a complete Lane-change maneuver over 0-3.0 seconds ahead prediction horizon (CRH-GP-SHS) - Calculated over 40 maneuvers

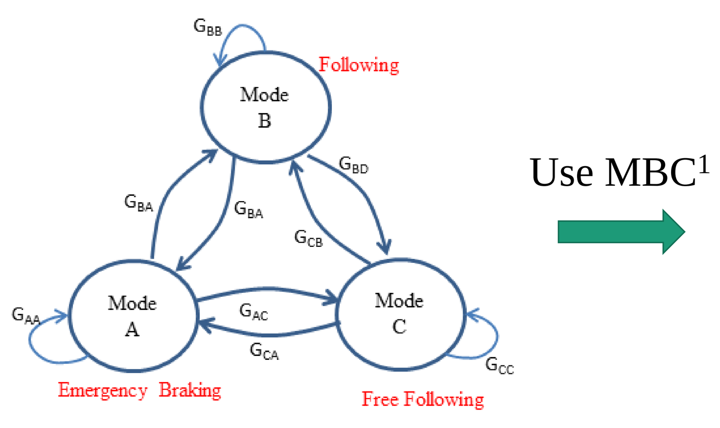




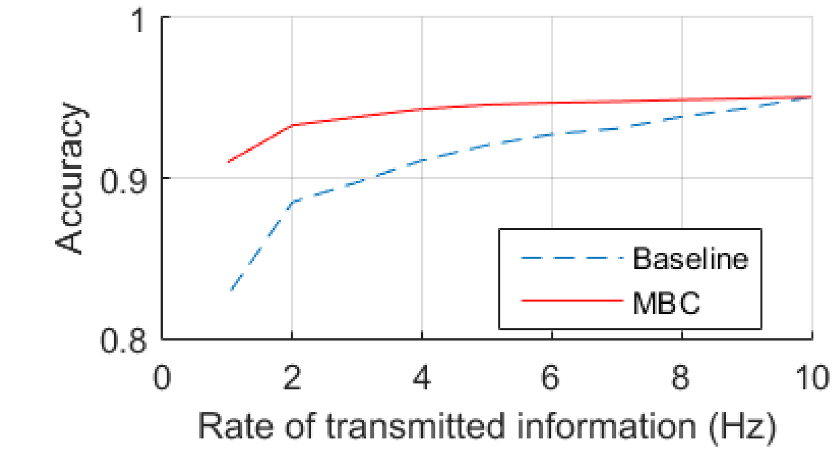
Mean absolute error vs. reception rate for a complete Lane-change maneuver (FRH-GP-SHS) (Calculated over 500 maneuvers)



Other Examples and Applications



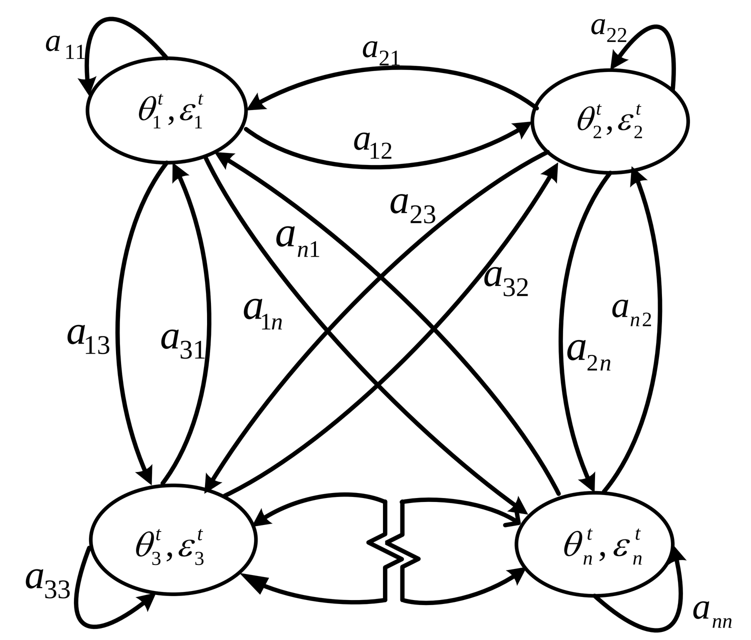
A simple vehicle movement model

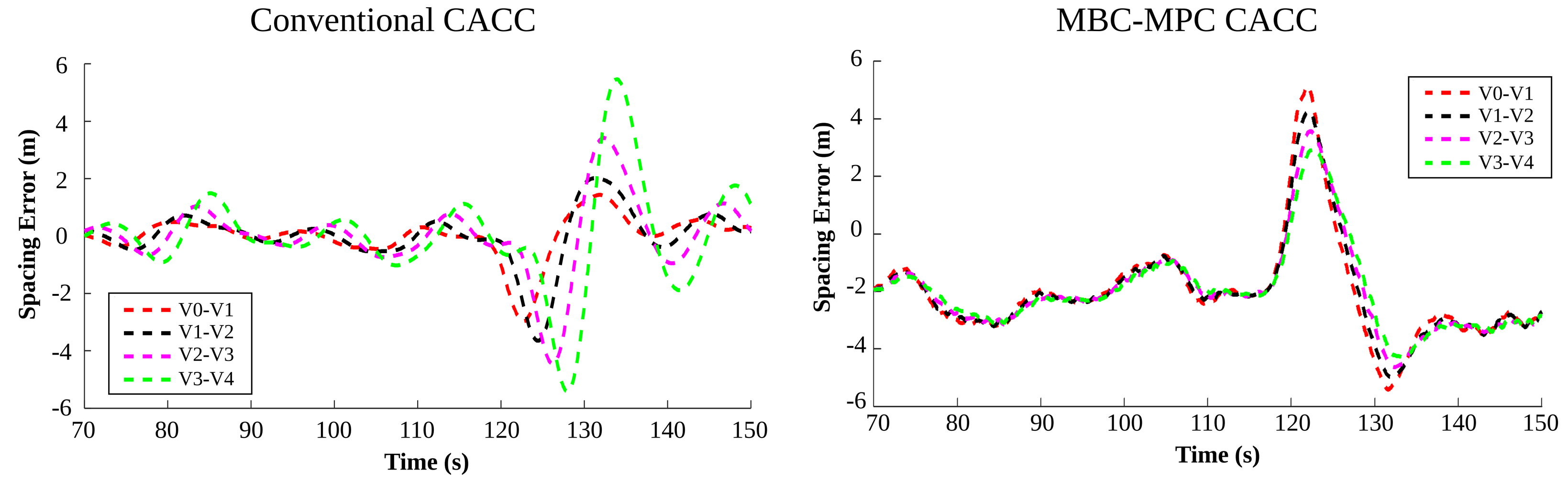


Accuracy vs Rate for Baseline and MBC methods, assuming PER =0

Example Application: Cooperative Adaptive Cruise Control

Learn and update model : Use a switched system structure such as HMM + ARX hybrid system.
Control: Use exchanged models in model-predictive CACC controllers.
Result is an order of magnitude improvement in spacing error in CACC[4].





5 vehicle platoon – CACC

Discussion & Future Work

Two main problems are now under investigation:

- Dividing a large-scale (full) maneuver into small-scale GP segments, each has its own semantics.
- Finding an appropriate latent-variables space representation of the GP models for different maneuvers.

References

[1] Y. P. Fallah, "A Model-based Communication Approach for Distributed and Connected Vehicle Safety Systems," *2016 Annual IEEE Systems Conference (SysCon)*, Orlando, FL, 2016, pp. 1-6.

[2] H Nourkhiz Mahjoub, B. Toghi, Y. P. Fallah, "A Driver Behavior Modeling Structure Based on Non-parametric Bayesian Stochastic Hybrid Architecture," *2018 IEEE Connected and Automated Vehicles Symposium (CAVS)*, Chicago, IL, Aug. 2018

[3] H Nourkhiz Mahjoub, B. Toghi, Y. P. Fallah, "A Stochastic Hybrid Framework for Driver Behavior Modeling Based on Hierarchical Dirichlet Process," *2018 IEEE Vehicular Technology Conference (VTC-Fall)*, Chicago, IL, Aug. 2018

[4] E. Moradi-Pari, H. N. Mahjoub, H. Kazemi, Y. P. Fallah and A. Tahmasbi-Sarvestani, "Utilizing Model-Based Communication and Control for Cooperative Automated Vehicle Applications," in *IEEE Transactions on Intelligent Vehicles*, vol. 2, no. 1, pp. 38-51, March 2017.

[5] Gaussian Processes for Machine Learning, Carl Edward Rasmussen and Christopher K. I. Williams The MIT Press, 2006. ISBN 0-262-18253-X.

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