Selective Listening: Control for Connected Autonomous Vehicles in Data-Rich Environments

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Raghvendra V. Cowlagi

Associate Professor
Aerospace Engineering Program

Alexander M. Wyglinski

Professor
Dept. Electrical & Computer Engineering

Worcester Polytechnic Institute, Worcester, MA, USA.
rvcowlagi, alexw@wpi.edu

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Background & Motivation

- $\gg$10M miles driven autonomously[1]
  - $\sim$1B miles with Tesla Autopilot[2]
- "Corner cases" remain an issue
- V2X comms. are non-line-of-sight information sources
  - 300m range
  - NHTSA estimate: V2V comms. could prevent $>$**600K** crashes every year

Peder Hulthin, a Tesla Model S 70D owner from Norway, told *Electrek* (after first sharing the story on the **Teslanytt** facebook group) that he was driving his electric car on Autopilot on the highway between Oslo and Drammen when a car swerved in and out of his lane.

As the vehicle exited his lane, there was red van stuck in the middle of the highway and neither Hulthin or Autopilot could react in time to avoid the crash.

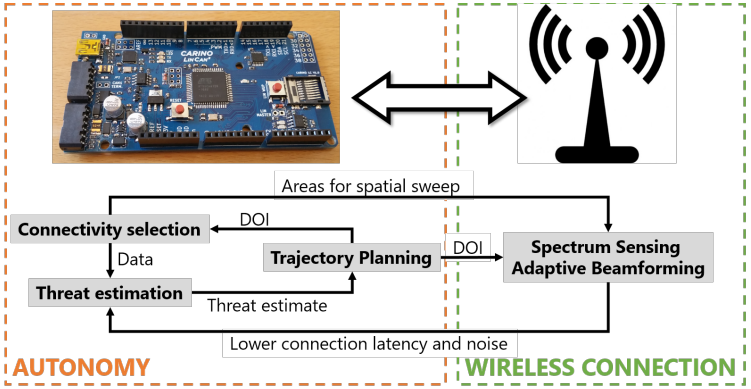
The Model S hit the vehicle head-on at about 85 to 90 km/h, according to the driver.

Hulthin shared pictures of the aftermath with *Electrek* — showing just how strong of an impact the Model S had to absorb:

[1] Waymo Safety Report 2019: On the Road to Fully Self Driving. `https://waymo.com/safety/`

[2] Tesla Vehicle Safety Report. `https://www.tesla.com/VehicleSafetyReport`

Research Questions



We study bidirectional interactions between V2V comms. and autonomy and control.

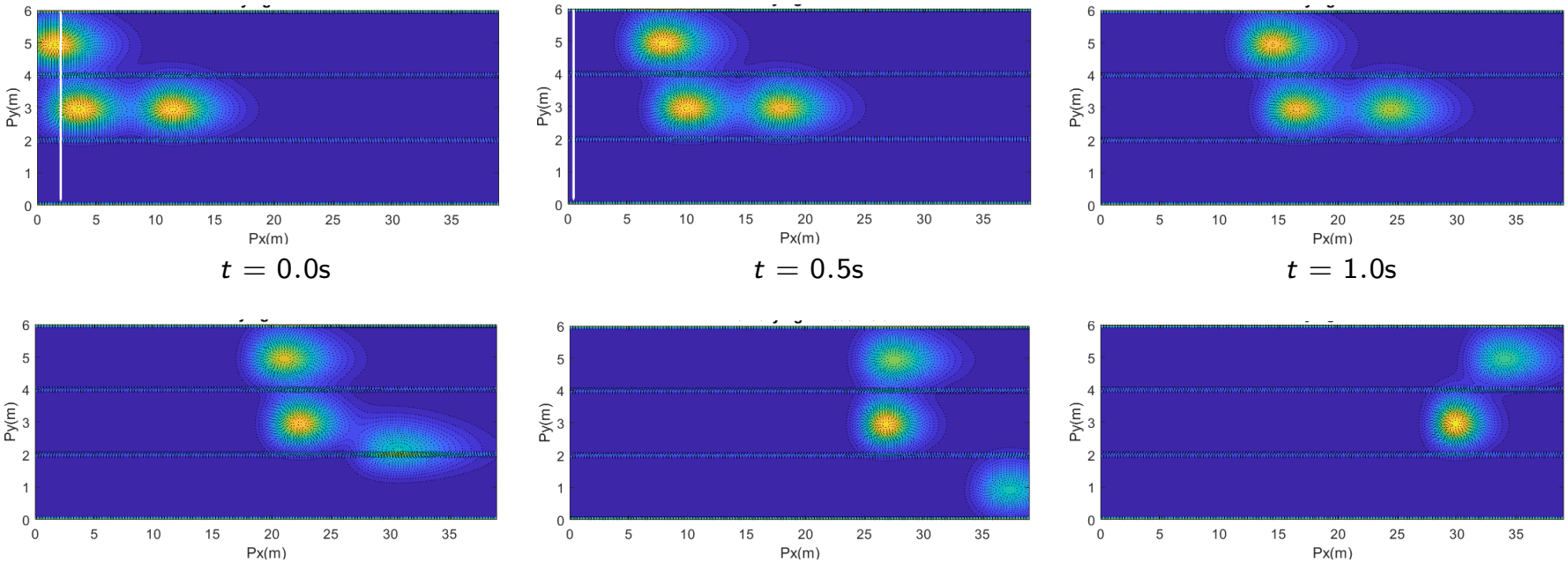
- How to assimilate data from onboard sensors and V2V comms.?
- In congested traffic, which V2V links are the most important?
- Can control/estimation techniques improve V2V link quality?

Threat Field Model

- Map indicating possibility of colliding with other vehicles
- E.g.,

$$c(x,y,t) = \sum_{n=1}^{N} \frac{\lambda_1 e^{(\lambda_2+\lambda_3\delta V_n(t))\delta r_n(t)x}}{(1+e^{(\lambda_2+\lambda_3\delta V_n(t))\delta r_n(t)x})^2} \frac{1}{\lambda_4 \delta x_n(t)\delta y_n(t)} e^{\frac{1}{2}(\delta x_n^2(t)+\delta y_n^2(t))}$$

Highlighted terms depend on relative position and velocity of nth nearby vehicle



$t = 0.0$s $t = 0.5$s $t = 1.0$s

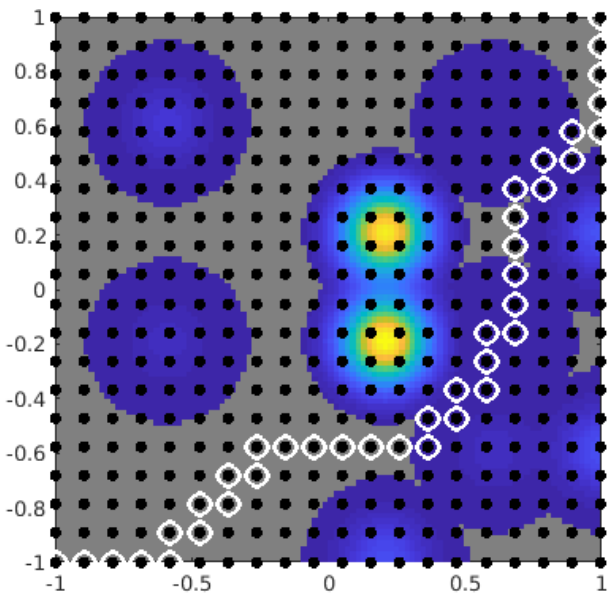
$t = 1.5$s $t = 2.0$s $t = 2.5$s

Path- or Trajectory Planning

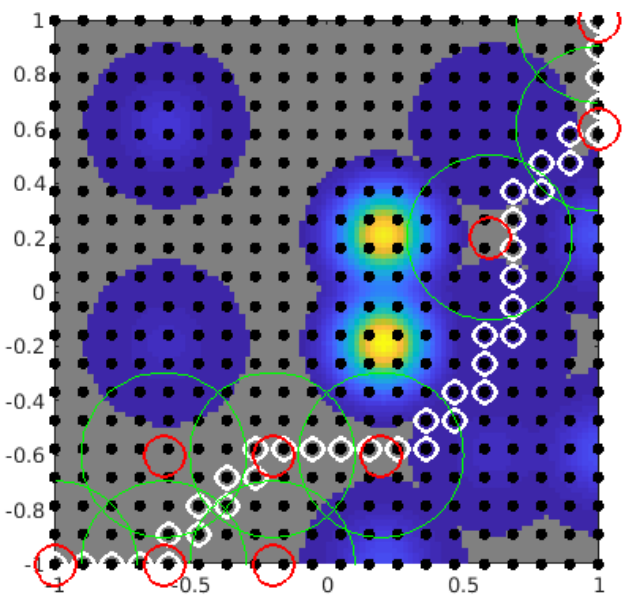
- Threat field to be estimated from onboard sensors and V2V comms.
- Onboard sensors emulated by ray-tracing

Coupled Planning and Sensing

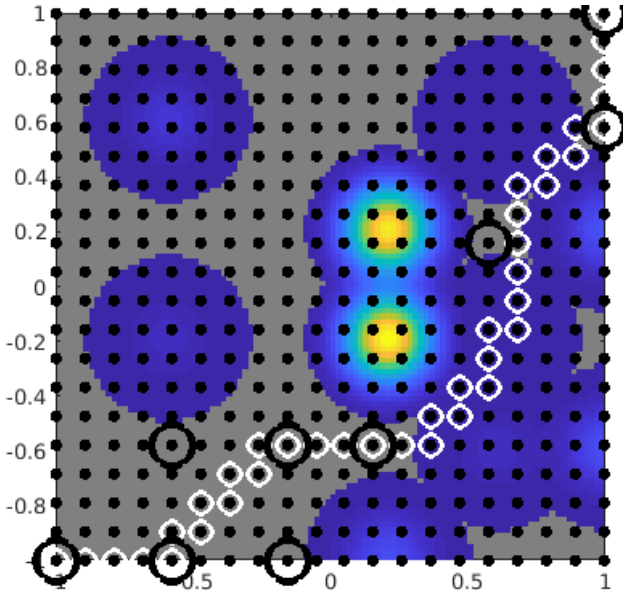
- Obtain candidate optimal path from current knowledge of field.
- Identify bases relevant to the candidate path:
  - path coverage, xcorr of path/environment, uncertain regions,...
- Determine a subdomain of interest, and place sensors.
- Repeat until path cost variance is sufficiently reduced.



Current optimal path.

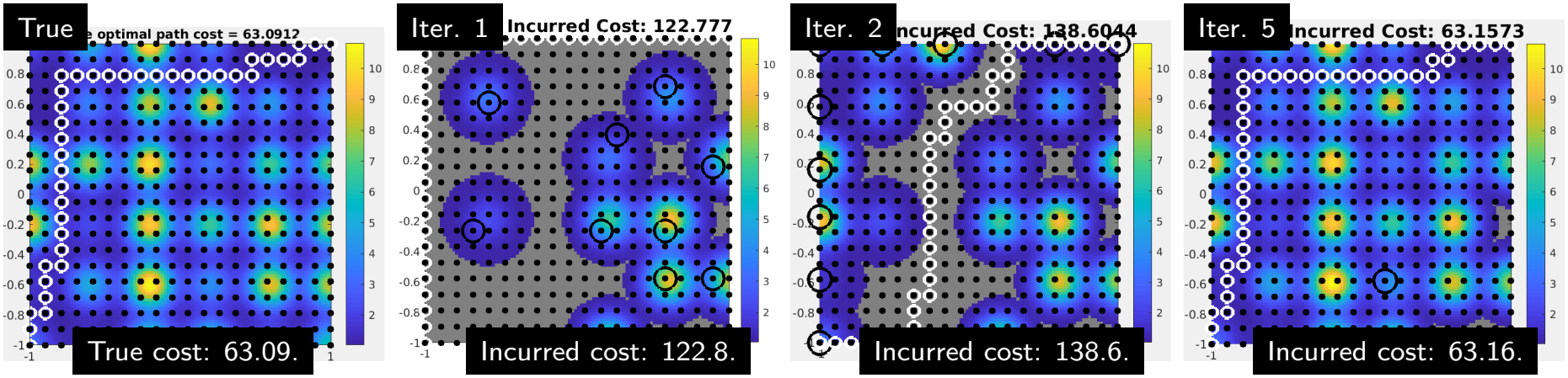


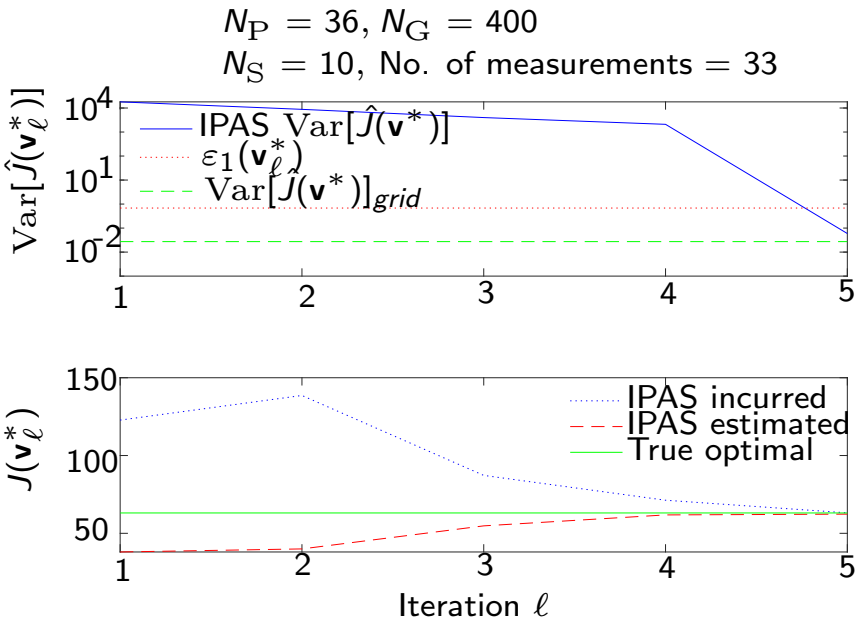
Identify basis relevant to path.



Place sensors within subdomain.

Iteration Example





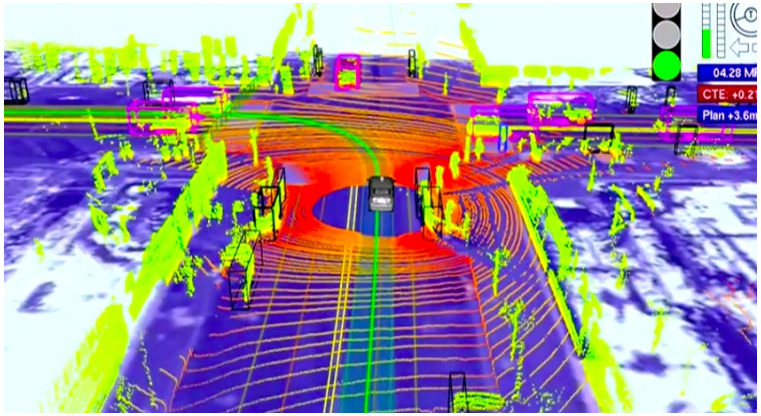
StopCondition

- Terminate when Path Cost Variance, $\mathrm{Var}[\hat{J}(\mathbf{v}_\ell^*)]$, below tolerance $\varepsilon_1(\mathbf{v}_\ell^*)$.
- $\varepsilon_1(\mathbf{v}_\ell^*) := \lambda_1^2 \sum_{i=0}^{P} \Phi^{\mathrm{T}}(\mathrm{x}_{v_i}) P_{\mathrm{grid}} \Phi(\mathrm{x}_{v_i})$, where $P_{\mathrm{grid}} := (H_{\mathrm{grid}}^{\mathrm{T}} R^{-1} H_{\mathrm{grid}})^{-1}$.

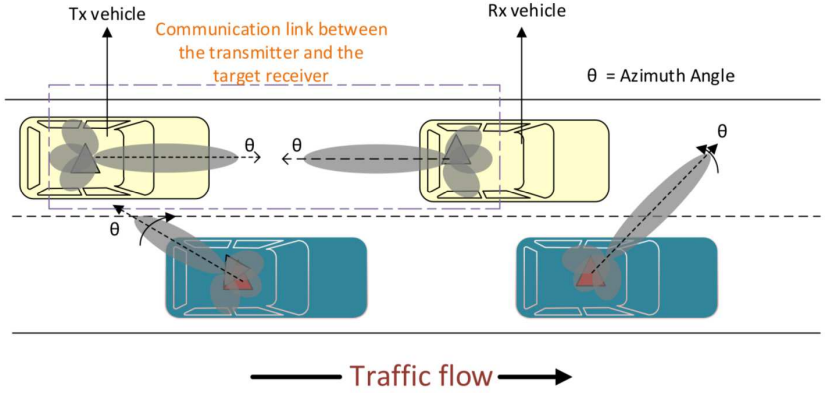
Ongoing Work

- Apply coupled sensing and planning technique to identify "most informative" sensor locations
- V2V comms. as "sensors" of threat field
- Finite parametrization and evolution model for threat field
- Head-to-head short-term trajectory planning performance comparison

Onboard sensors only

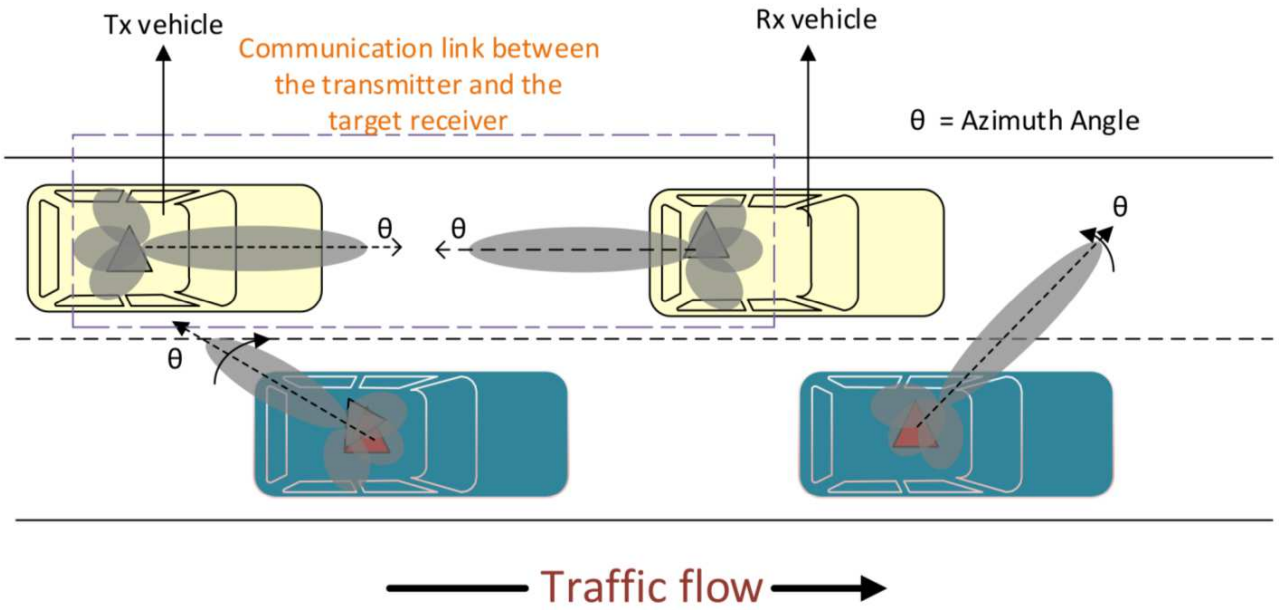


Onboard sensors + V2V comms.

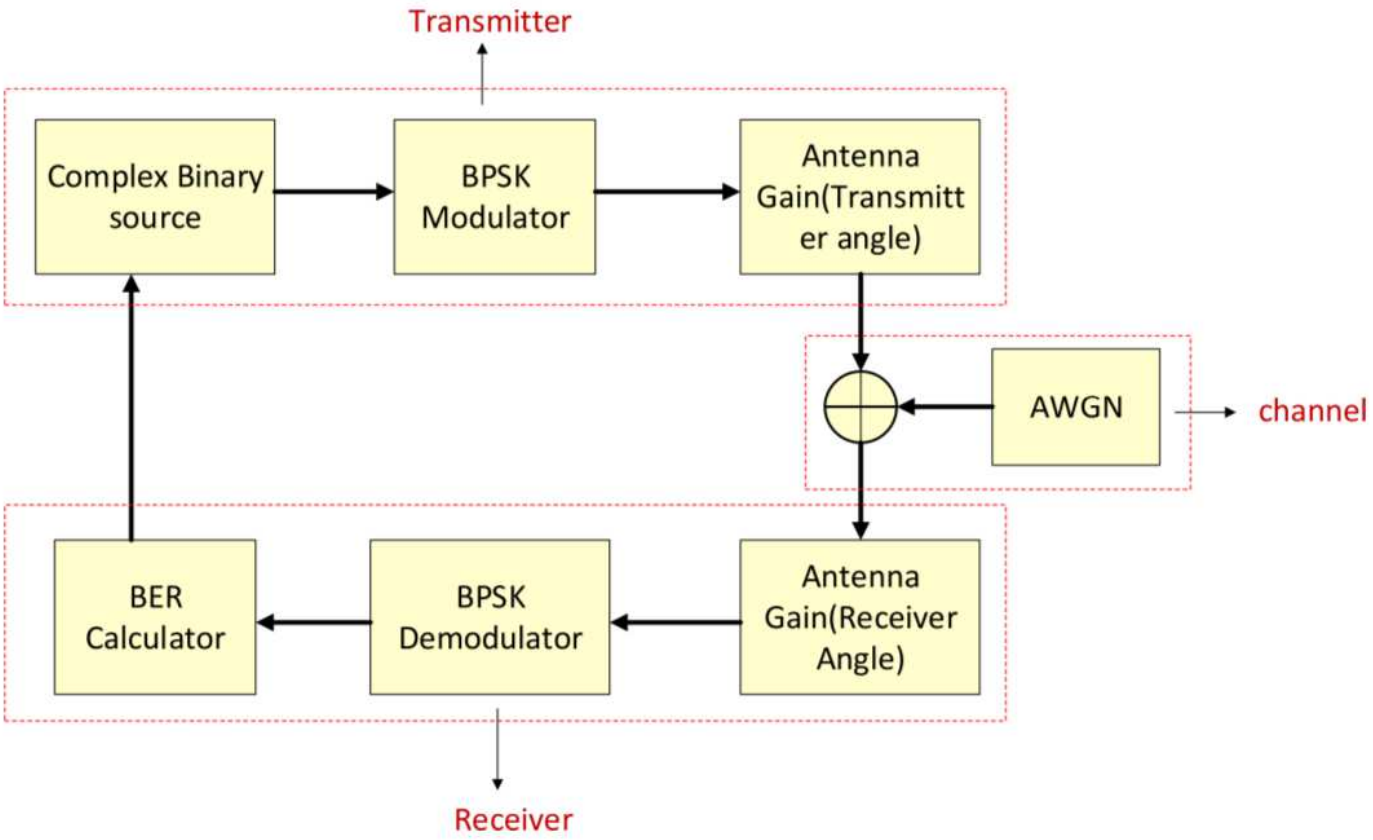


Beamforming for V2V Communications

- A dual beamforming architecture for V2V networks where one vehicle acts as the transmitter whose location is assumed to be precise and the other vehicle acts as the receiver.
- An analysis of the positioning errors due to GPS and overhead channel updates on the system performance of a V2V network employing dual beamforming.



V2V Architecture Model



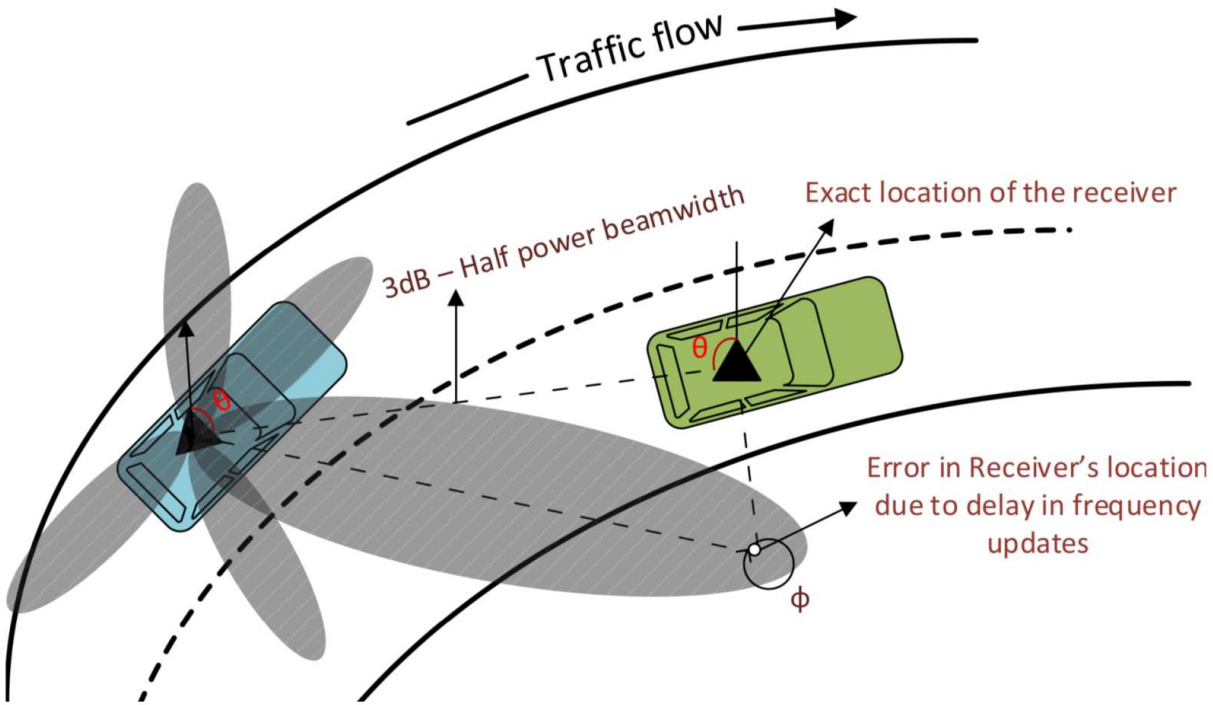
Block diagram of simulation environment through AWGN using BPSK.

Positioning Error Models for Beamforming V2V

- GPS horizontal position measurement error standard deviation[3]:

$$E_{n-e,\mathrm{rms}} = \mathrm{HDOP} \cdot \mathrm{UERE}_{\mathrm{rms}} = (1.3)(5.1) = 6.6m,$$

where HDOP is the horizontal dilution of precision,
UERE is user-equivalent range error



[3] P. Misra & P. Enge. *Global Positioning System.* Ganga-Jamuna Press, Lincoln MA, 2012.

Beamforming Implementation

- For isotropic sources, the array factor AF is given by the expression:

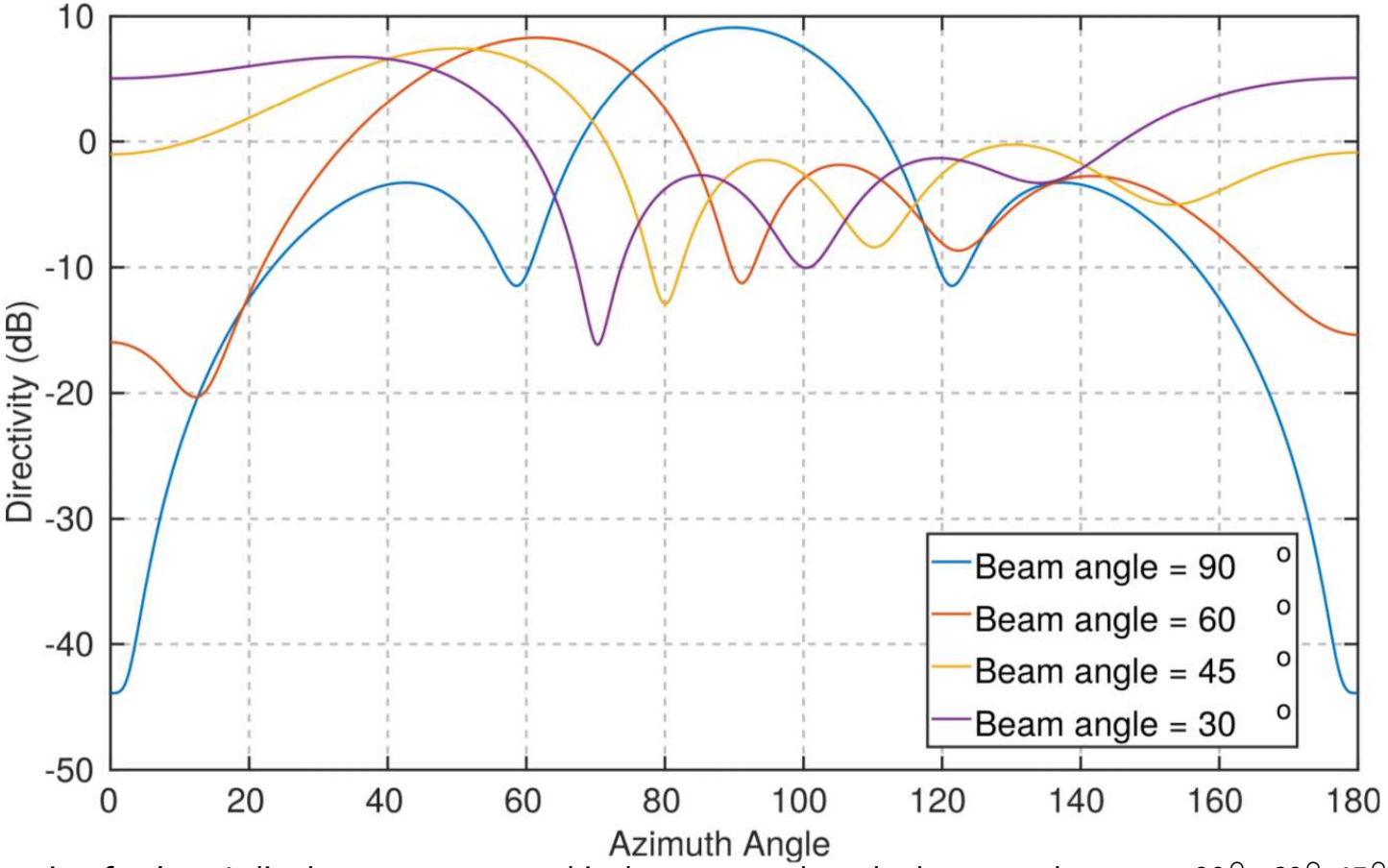
$$AF(\theta, \gamma) = \frac{1}{L}\left(\frac{\sin(\frac{L}{2}\chi)}{\sin(\frac{1}{2}\chi)}\right) \tag{1}$$

- The received power is calculated as:

$$\begin{aligned}\Gamma_r(d) = \Gamma_t dBm + 10\log_{10}(g_t) + 10\log_{10}(g_r) + \\ 20\log_{10}(\lambda) - 20\log_{10}(4\pi d) - 10log_{10}(L).\end{aligned} \tag{2}$$

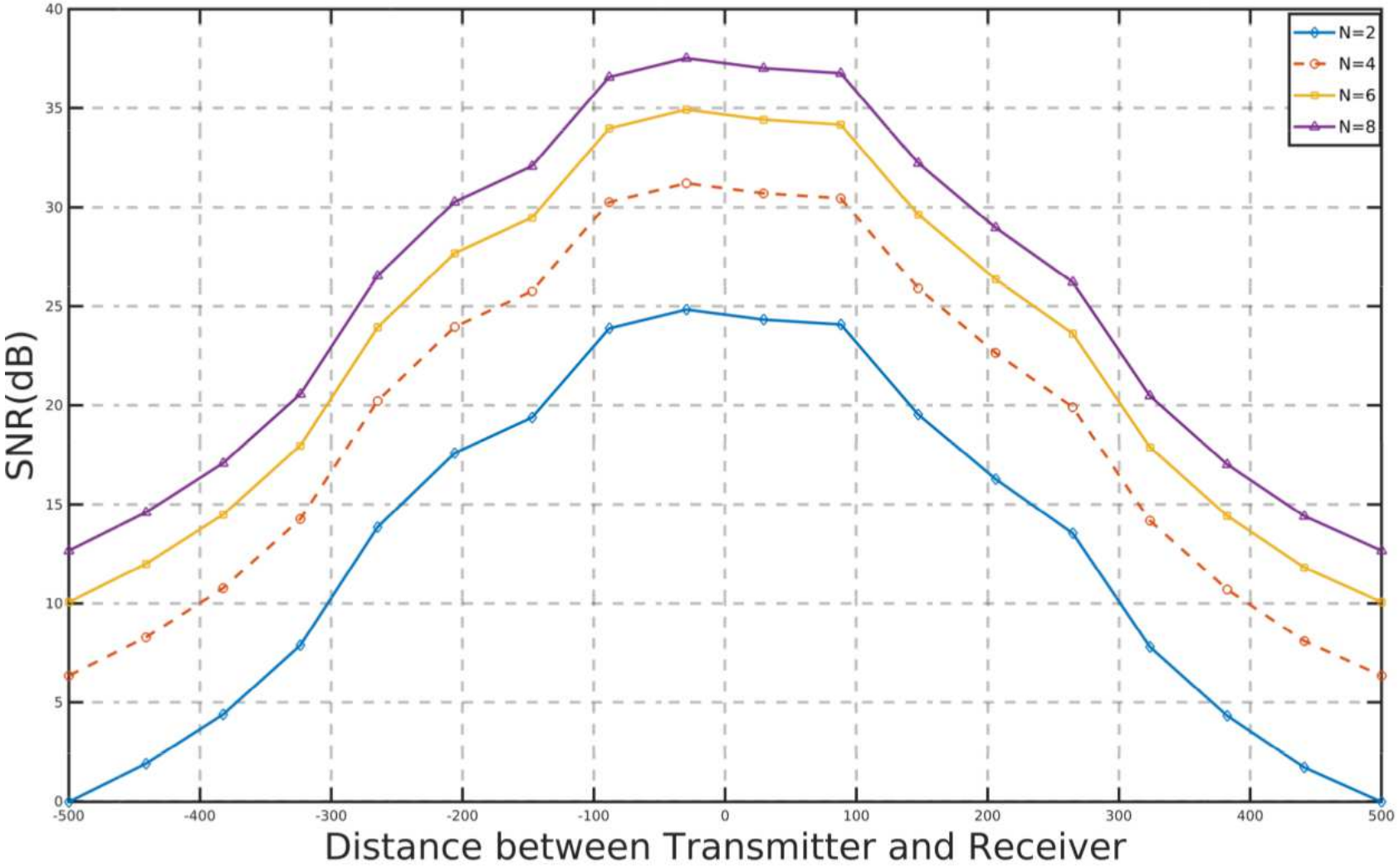
- The path loss is predicted using Friis Free Space Propagation Model for this paper.

Angular Displacement



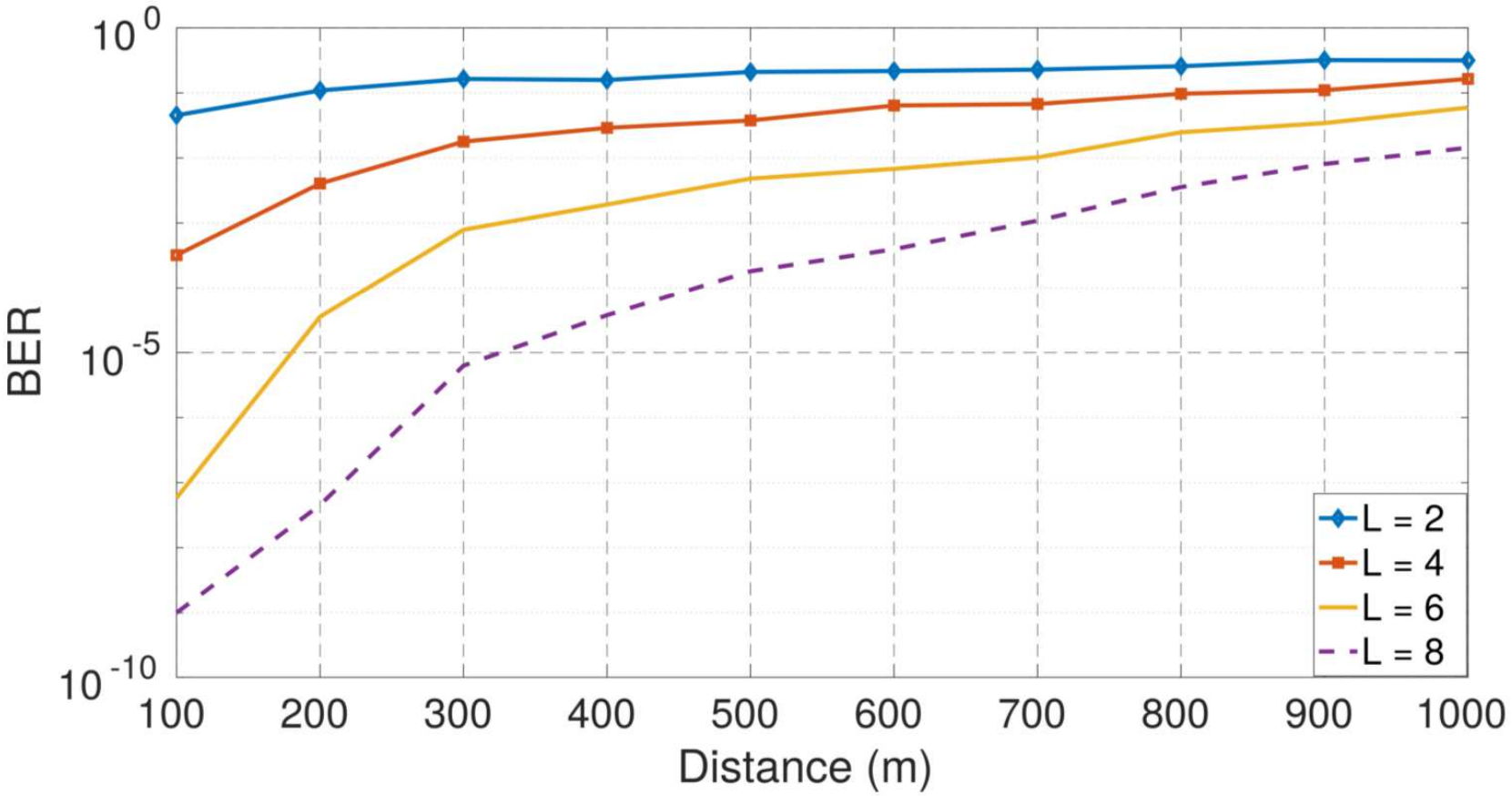
Beam orientation for $L = 4$ dipole antenna on a vehicular system when the beam angles are at 90°, 60°,45°, and 30°, respectively.

Changing SNR



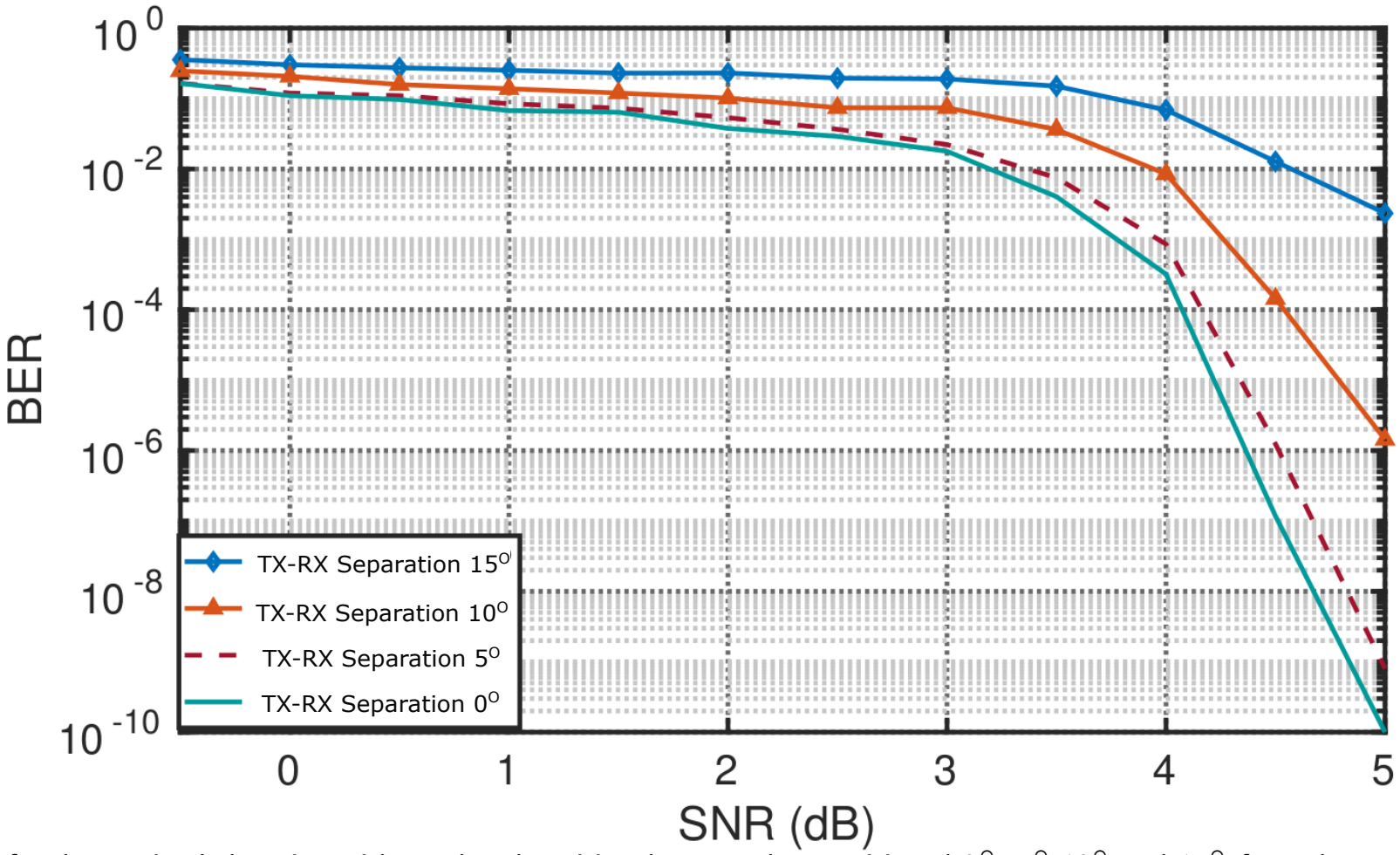
SNR for the varied number of antenna array elements and the vehicle's distance; d=100,200,300,...,1000 in meters and $L = 2, 4, 6, 8$.

Changing BER



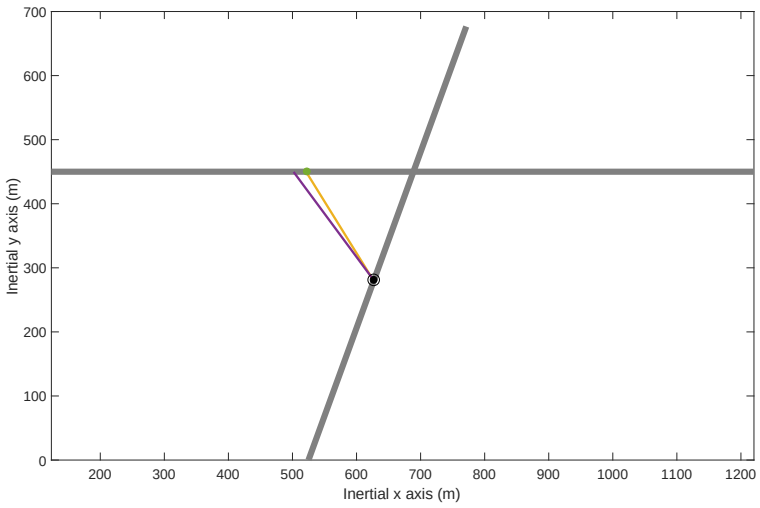
BER for the varied number of antenna array elements and the vehicle's distance; d=100,200,300,...,1000 and $L = 2, 4, 6, 8$.

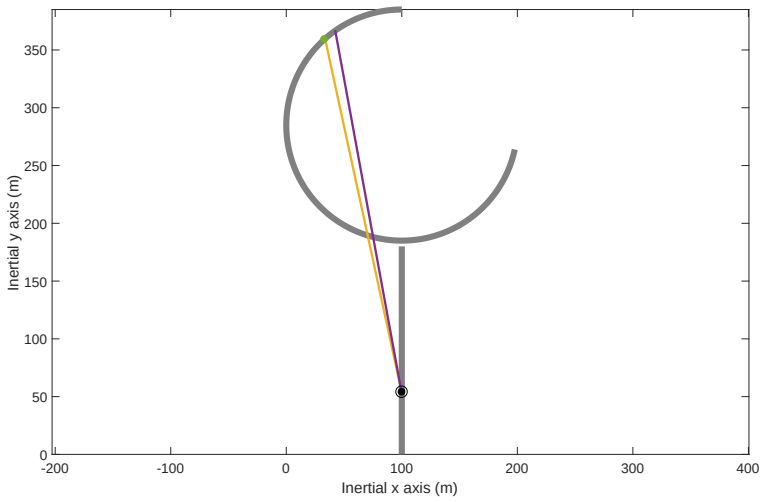
Receiver Location Error

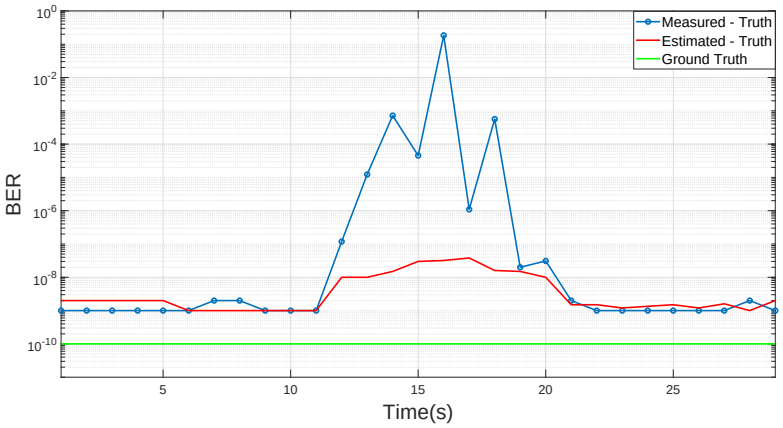


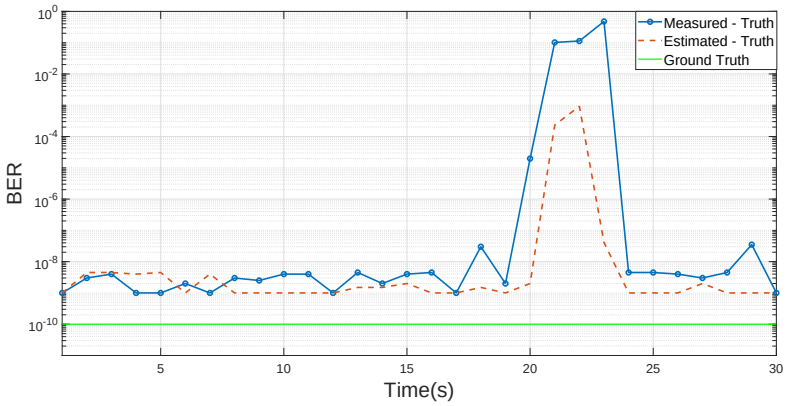
BER for the receiver's location with employed positional errors when positioned 0°, 5°,10° and 15° from the transmitter location.

Using Vehicle State Estimation to Mitigate BER Degradation

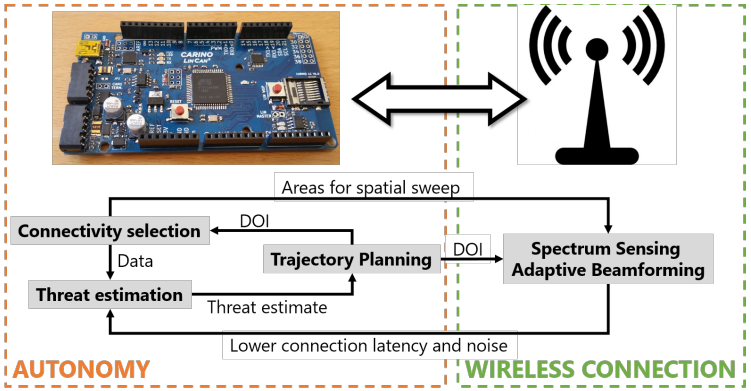








Summary



- Threat field model for onboard sensor data and V2V comms. data fusion; finite parametric representation for scalability
- Coupled sensing and planning to identify most informative V2V links
- Beamforming performance analysis under localization errors and interference (ongoing work)

rvcowlagi@wpi.edu alexw@wpi.edu