Measuring Radar and Communication Congruence at Millimeter Wave Frequencies

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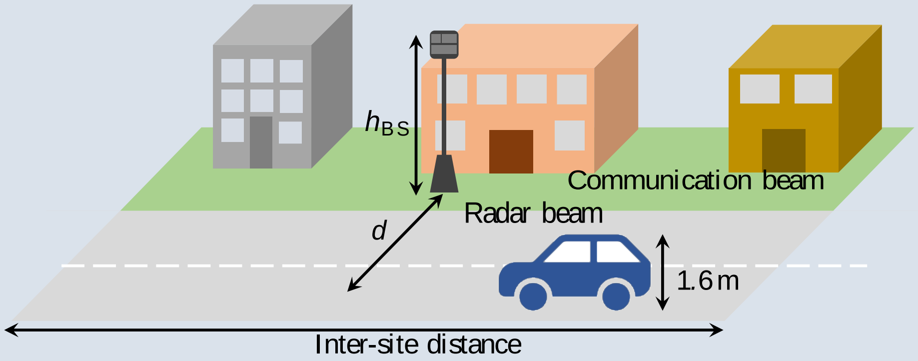
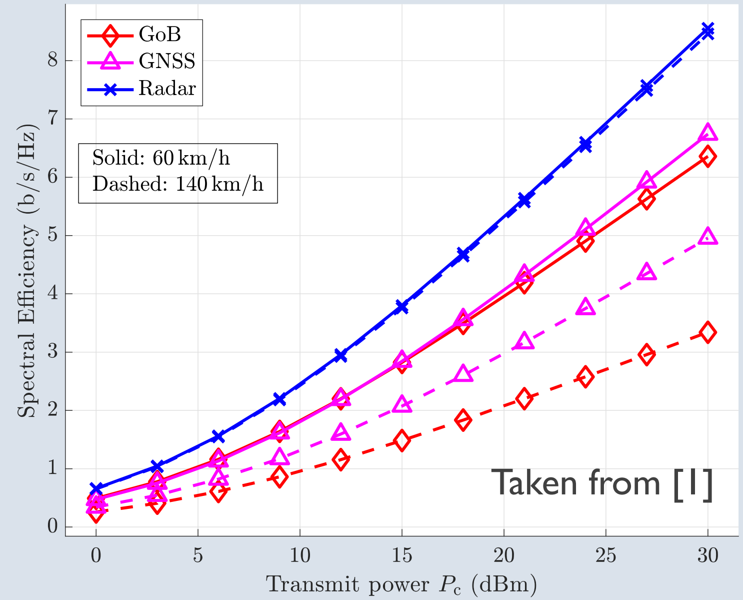
TEXAS
The University of Texas at Austin

BS mounted radar for aided mmWave beam search



Higher spectral efficiency due to reduced training overhead



25% overhead reduction using GNSS

Potential reductions as high as 97% for radar from the CRLB analysis [1]

How can we evaluate this using real-world data?

[1] Anum Ali, Nuria González-Prelcic, and Amitava Ghosh, "Millimeter wave V2I beam-training using base-station mounted radar", IEEE Radar Conference, 2019

Goals

Using real-world measurements

1. Verify that BS mounted radar based positioning is better than GPS [1]
2. Establish the level of congruence between the radar and communication signals
3. Evaluate the performance of radar-assisted and GPS-assisted beam training

[1] Anum Ali, Nuria González-Prelcic, and Amitava Ghosh, "Millimeter wave V2I beam-training using base-station mounted radar", IEEE Radar Conference, 2019

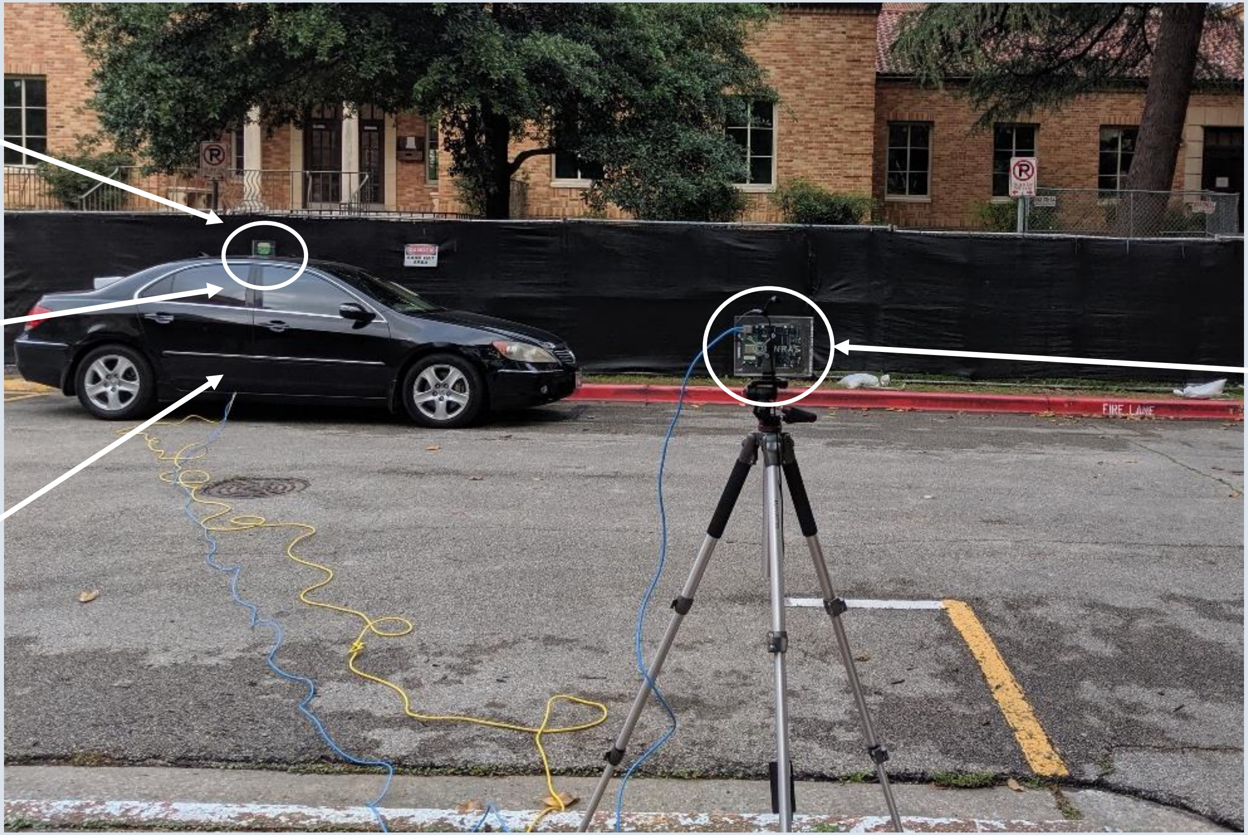
Measurements

Measurement set-up

Receiver

Cellular GPS

Target car



Transmitter / Radar

Example of radar and communication set-up

Number of measurements

20 locations





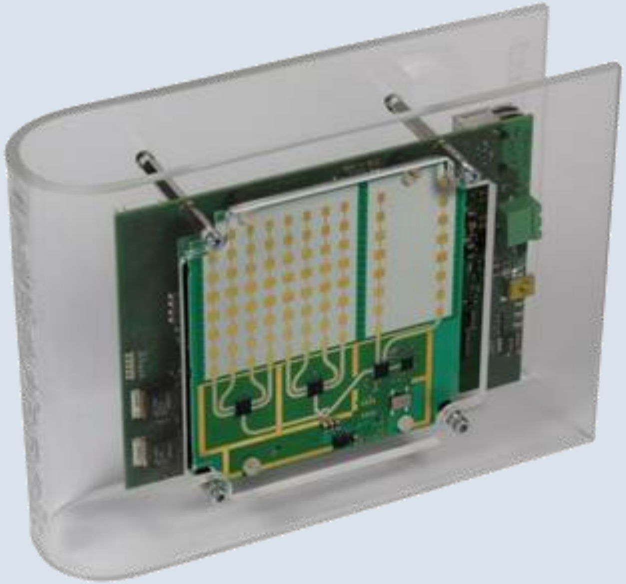



4-5 measurements at each location




A total of 82 set of measurements were collected

Radar



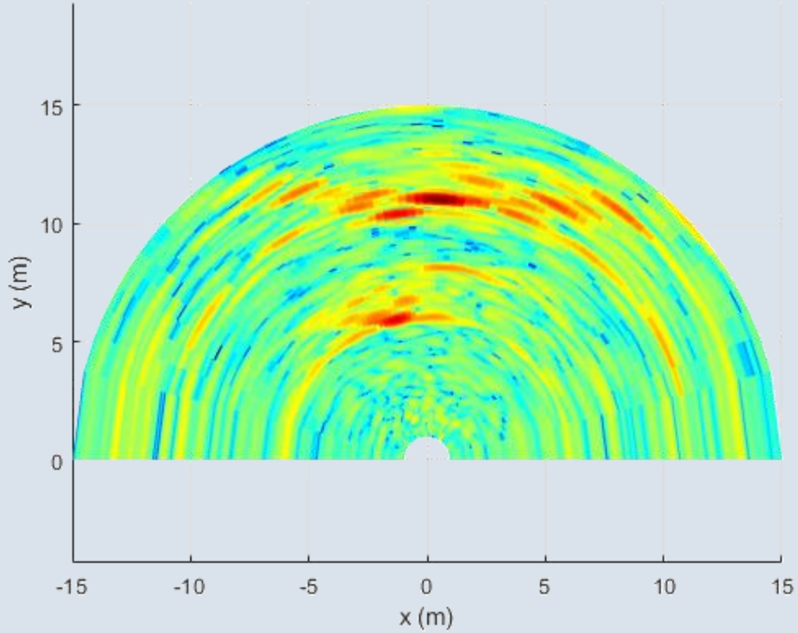
INRAS Radarbook

Parameter	Value
Center Frequency	77 GHz
Bandwidth	1 GHz
# of TX antennas	4
# of RX antennas	8
# of virtual antennas	29
Sampling frequency	10 MHz
Ramp up time	256 µs
Max Range	192 m
Range resolution	15 cm
Azimuth resolution	~4°

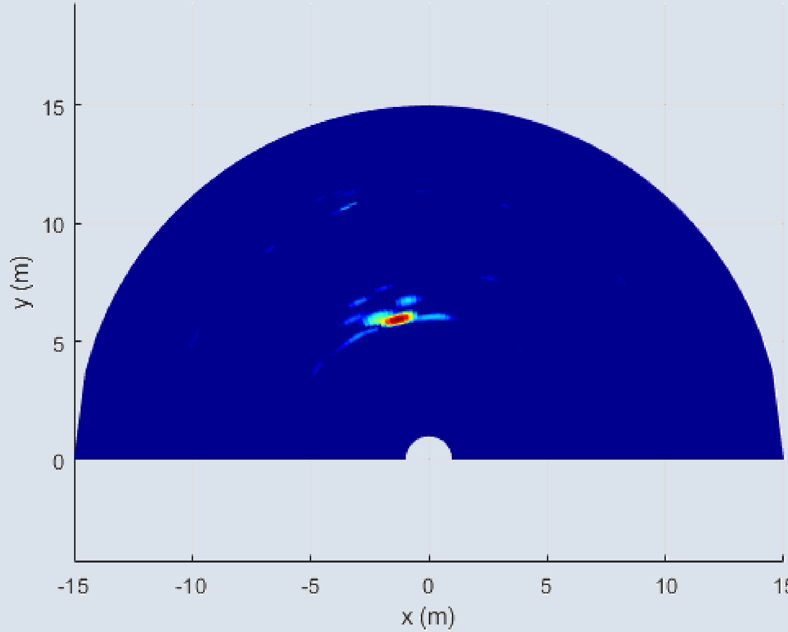
Software-defined so we can modify the processing chain

Radar Processing

Range Angle Reflectivity Map

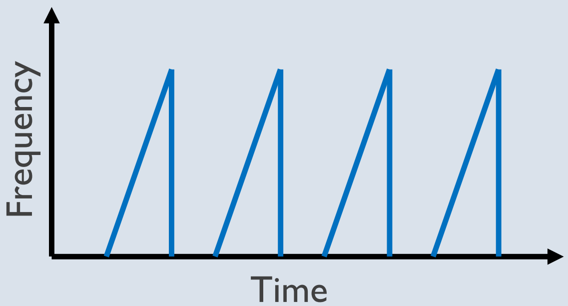


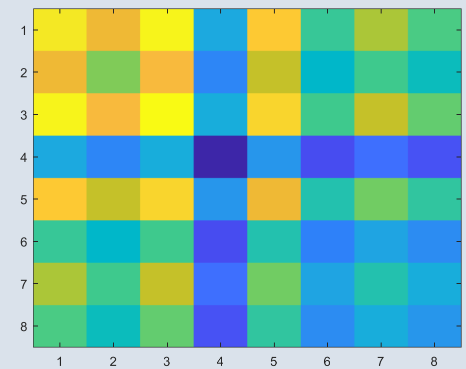
After Background Cancellation

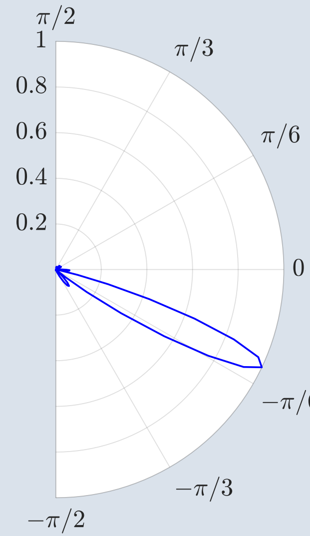


Used peak power after cancellation to locate the vehicle

Communication Channel





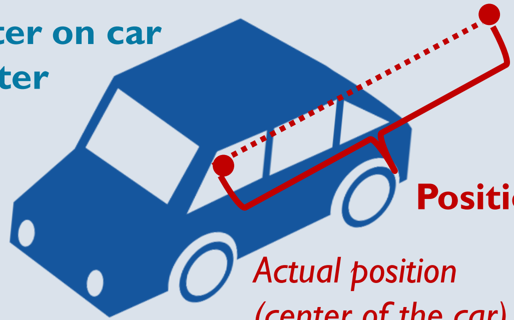


FMCW Pulses → Channel Covariance → Angular Power Spectrum / Comm Channels

Modified Radarbook processing chain

Positioning

Positioning using BS mounted radar



Average GPS error 7.36 m

Average radar error 2.96 m

GPS performance very good in open areas

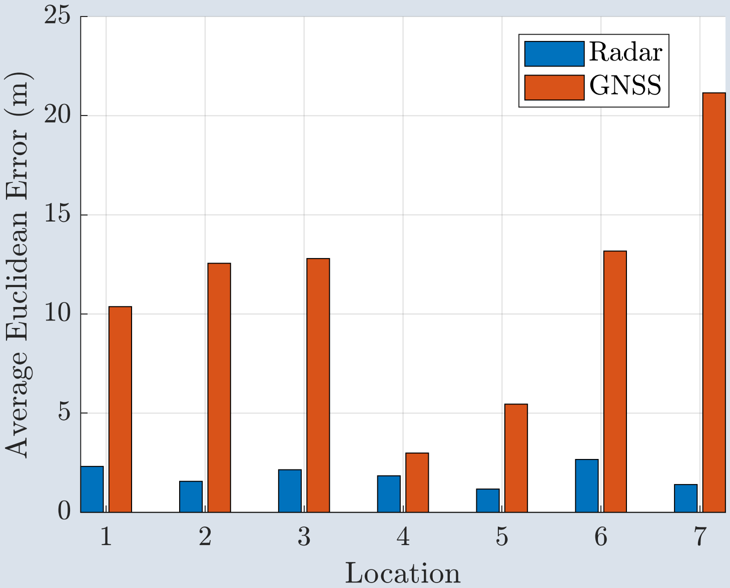
With high rise buildings average GPS error **over 11.3 m**

Radar performance consistent in high rise and open areas

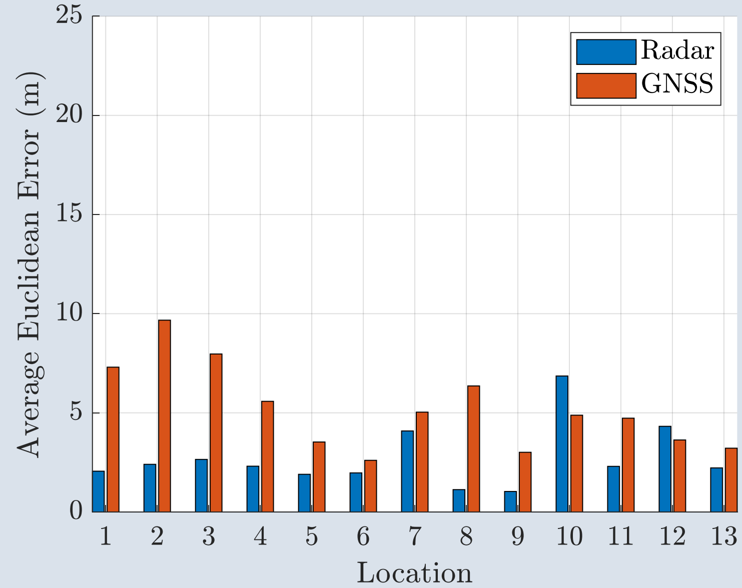
Radar performs much better than GPS in dense urban scenarios

Positioning using BS mounted radar

Urban scenarios



Open scenarios



Radar performs much better than GPS in dense urban scenarios

Congruence

Proposed similarity metric

Azimuth power spectrum; diagonal of the DFT of the covariance matrix of the channel

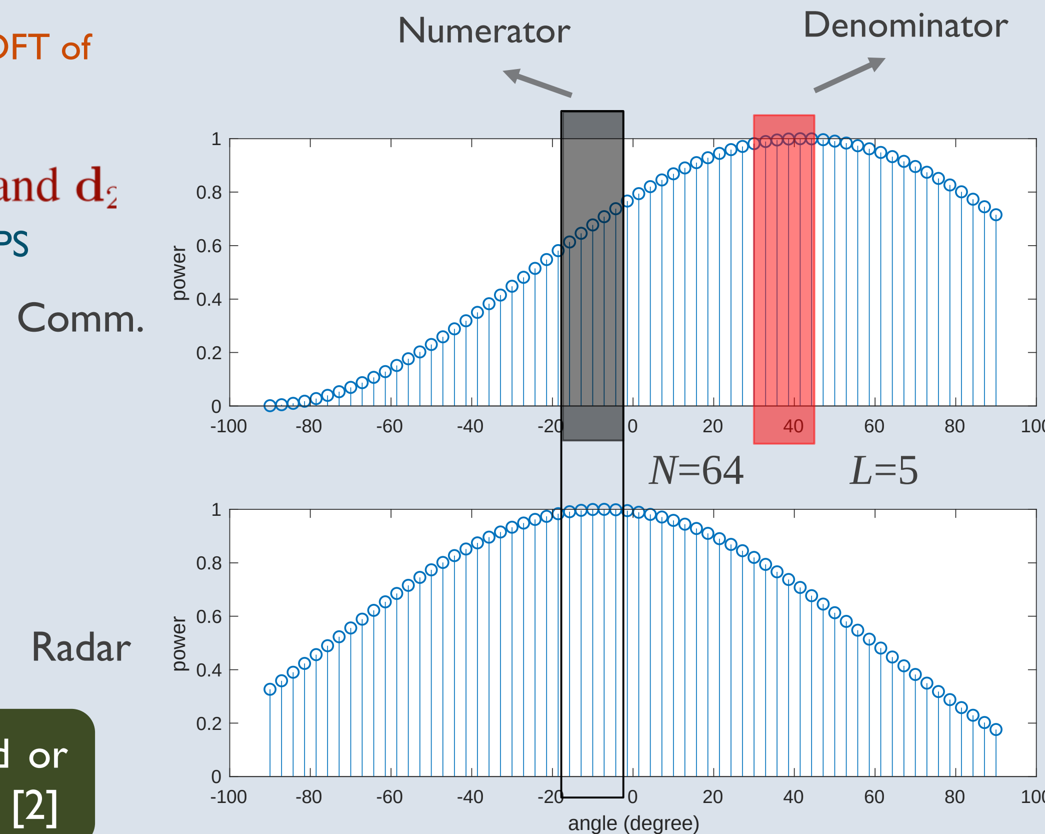
Similarity of two N point APS $\mathbf{d}_1$ and $\mathbf{d}_2$

# of largest entries considered in the APS

# of points in the APS

$$S_{1\to 2}(L, N) = \frac{\sum_{i\in\mathcal{I}_1} \mathbf{d}_2[i]}{\sum_{i\in\mathcal{I}_2} \mathbf{d}_2[i]} \quad [1]$$

index set of cardinality N



S same as RPE when AoA fall on grid or infinite antennas, RPE related with rate [2]

Ratio of sum of L spectral components (strongest as suggested / strongest in truth)

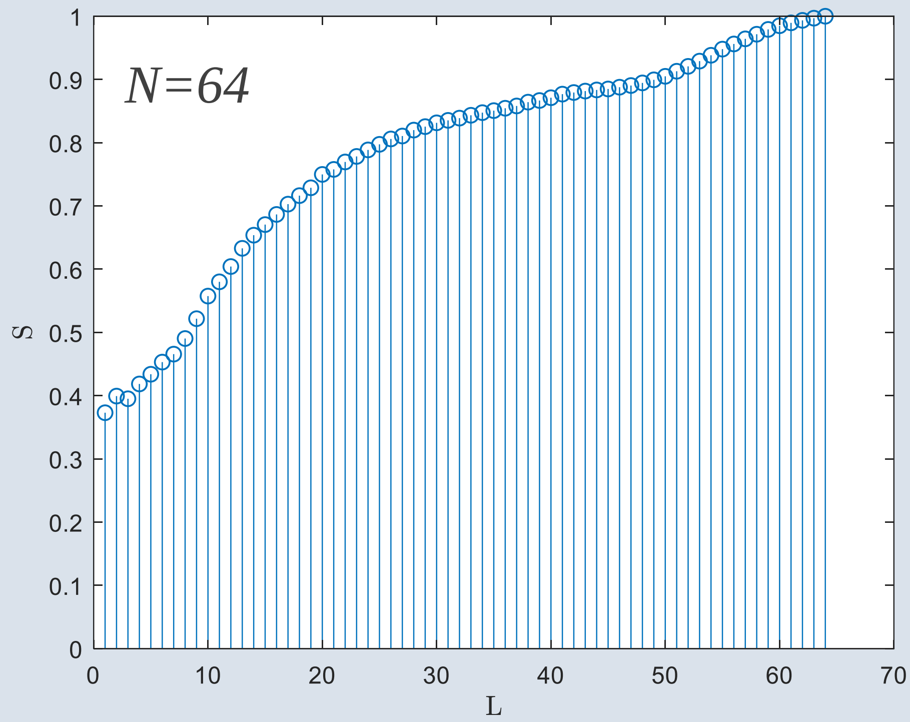
[1] A. Ali, N. González-Prelcic, A. Ghosh, "Passive Radar at the Roadside Unit to Configure Millimeter Wave Vehicle-to-Infrastructure Links", arXiv preprint arXiv:1910.10817, 2019
[2] S. Park et. al., ``Spatial Channel Covariance Estimation for Hybrid Architectures Based on Tensor Decompositions", submitted to IEEE TWC.

Radar/Communication Congruence

Average congruence in 82 measurements as a function of L

$$S_{1\to 2}(L,N) = \frac{\sum_{i\in\mathcal{I}_1} \mathbf{d}_2[i]}{\sum_{i\in\mathcal{I}_2} \mathbf{d}_2[i]}$$

Similarity increases with L as expected [1]

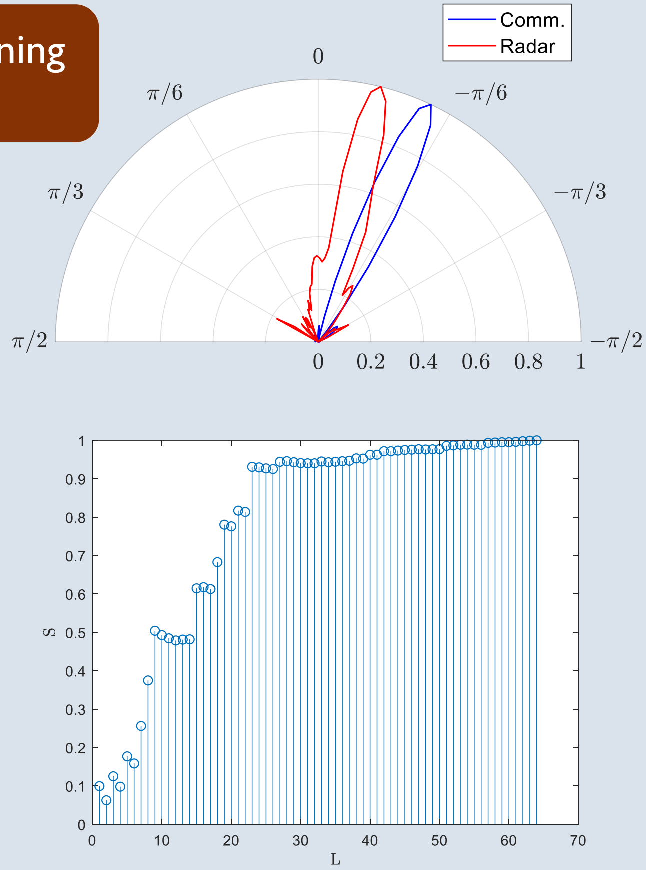


Intelligent strategies required to exploit the congruence between radar and comm

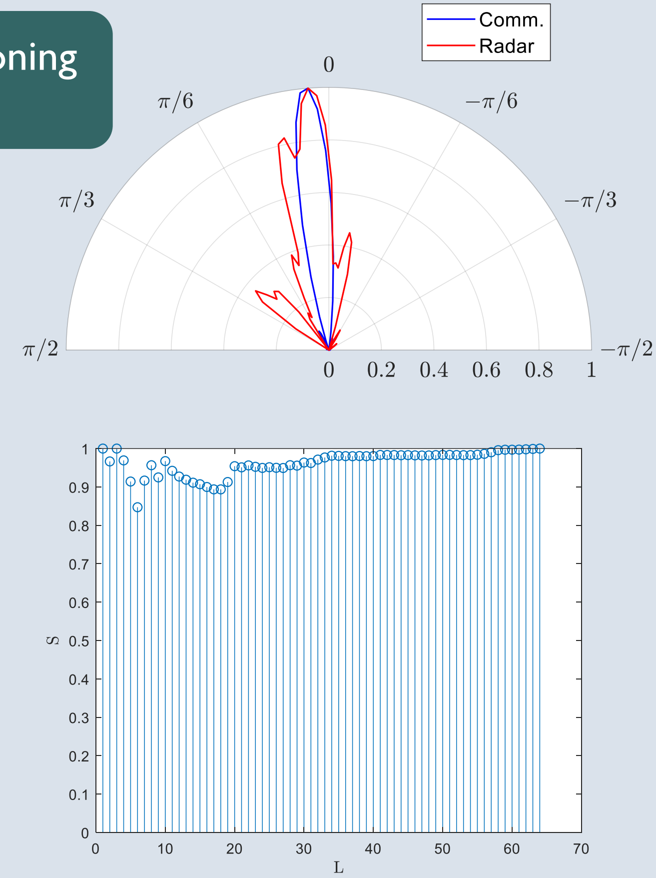
[1] A. Ali, N. González-Prelcic, A. Ghosh, "Passive Radar at the Roadside Unit to Configure Millimeter Wave Vehicle-to-Infrastructure Links", arXiv preprint arXiv:1910.10817, 2019

Radar/Communication Congruence

Large positioning error



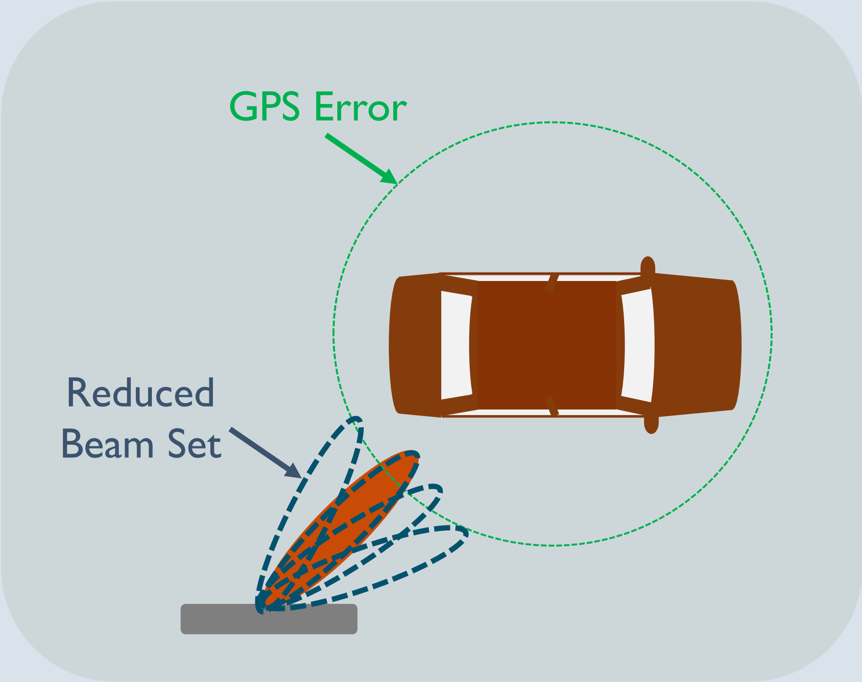
Small positioning error



Radar and comm. azimuth power spectra always fairly correlated

Beam Selection

Beam Selection



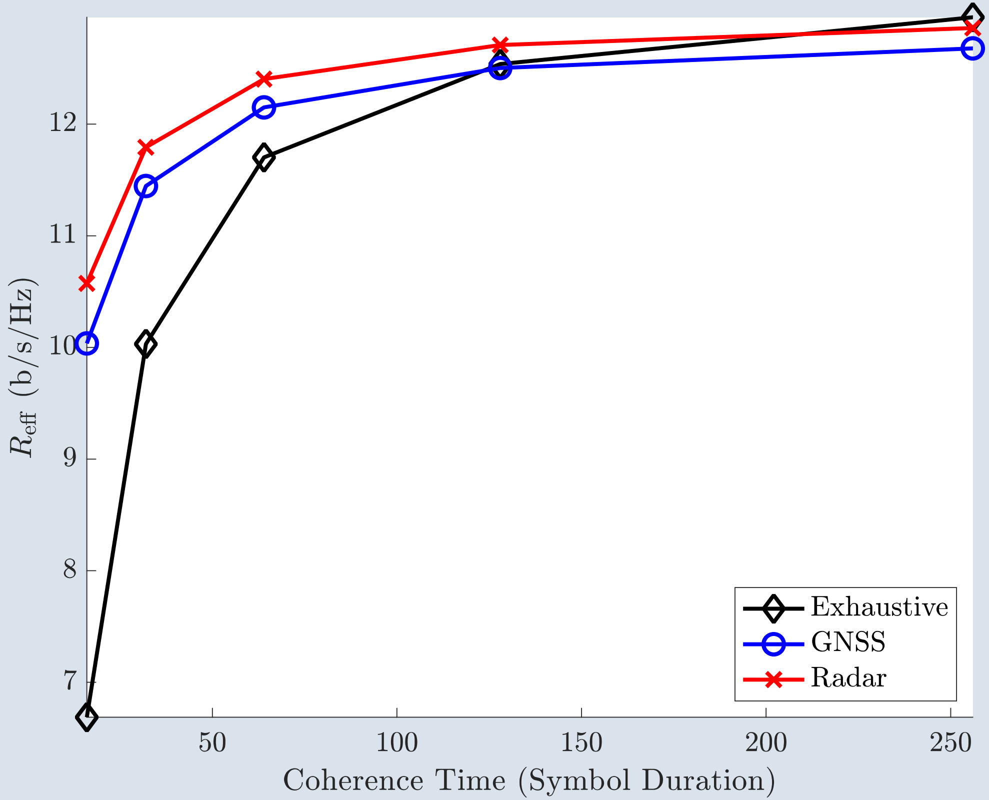
For GPS, use a reduced codebook assuming up to 10m error

For radar, select 3 beams around the angle obtained from the position estimate

Used our position estimates to evaluate assisted beam selection

Rate Results

Average rate using aided beam selection

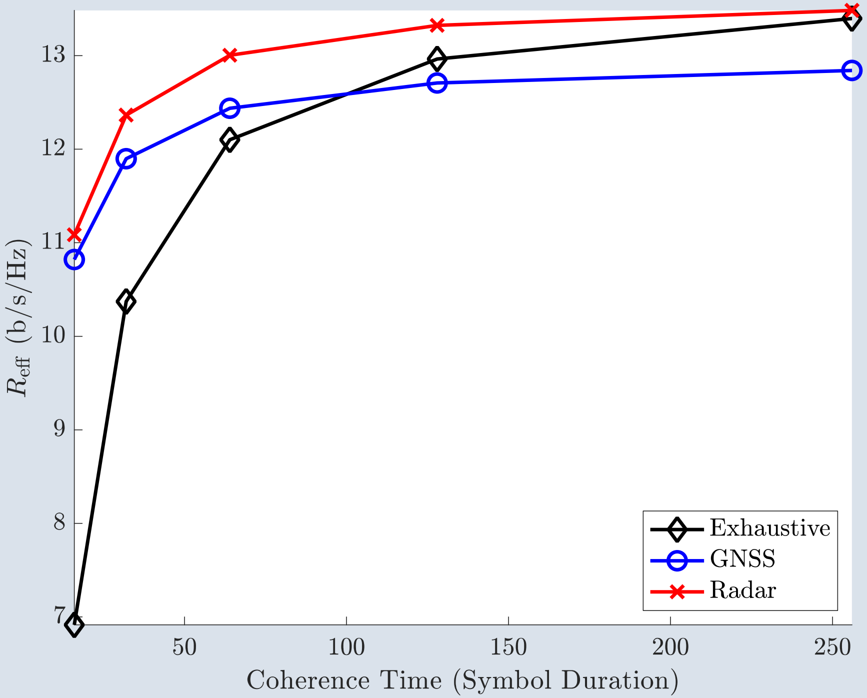


Parameter	Value
SNR	10 dB
TX-RX Distance	~10 m
Codebook Size	8 Beams
Channel Covariances	82
Epochs per Channel Cov.	1000

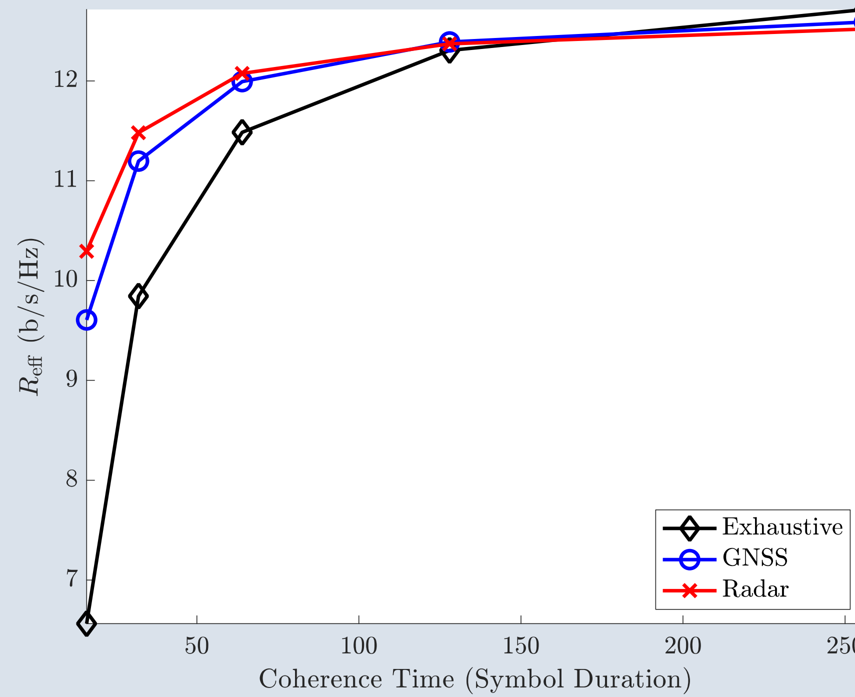
Radar-assistance outperforms GNSS

Rate Results

Urban scenarios



Open scenarios



Larger benefit from radar in urban environments

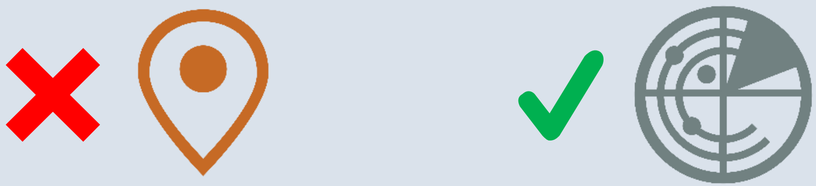
Conclusion

Conclusion

Verified the positioning accuracy of BS radar against GPS

Evaluated the congruence between millimeter wave radar and comm. channels with our measurement campaign

Compared the impact of position error in position aided beam training assisted by radar or GPS



Radar-assisted outperforms GNSS, especially in urban environments

Thanks