Automotive radar and mmWave MIMO V2X communications: Interference or fruitful coexistence

Andrew Graff[1], Anum Ali[1], Nuria González-Prelcic[1,2], Amitava Ghosh[3]

[1] **Wireless Networking and Communications Group,**
Department of Electrical and Computer Engineering,
The University of Texas at Austin, Austin, Texas

[2] **Universidade de Vigo, Vigo, Spain.**

[3] **Nokia Bell Labs, USA.**

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Outline

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Main idea

Radar-aided training with radar-to-communication (R2C) interference

Interference measurements

Quantify the worst-case R2C interference in lab

Spectral efficiency with interference

Simulation using the lab data

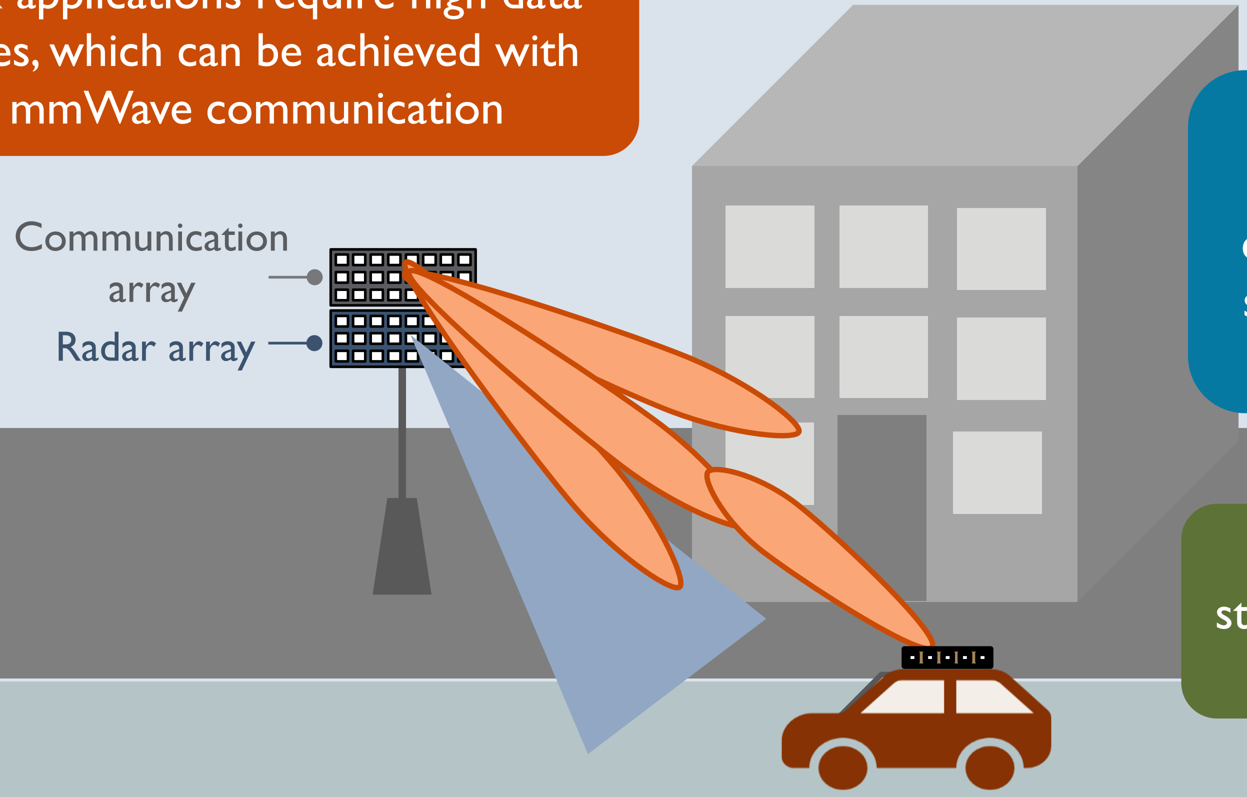
Conclusion

Impact on radar and communication coexistence

Main idea

Main idea

V2X applications require high data-rates, which can be achieved with mmWave communication



However, a significant portion of the channel coherence time may be spent training = limited data-rate

Radars at the base-station can provide useful position information

Position information can significantly reduce training overhead

Radar-aided training

Use DFT codebook

Beamformers correspond to a quantization of the array response at Nyquist-spaced angles

$$[\mathbf{c}]_n = \mathcal{Q}\left(\frac{1}{\sqrt{N_{\mathrm{BS}}}}\mathbf{a}_{\mathrm{BS}}(\arcsin(\frac{2n - N_{\mathrm{BS}} - 1}{N_{\mathrm{BS}}}))\right)$$

Codebook

Base-station array response

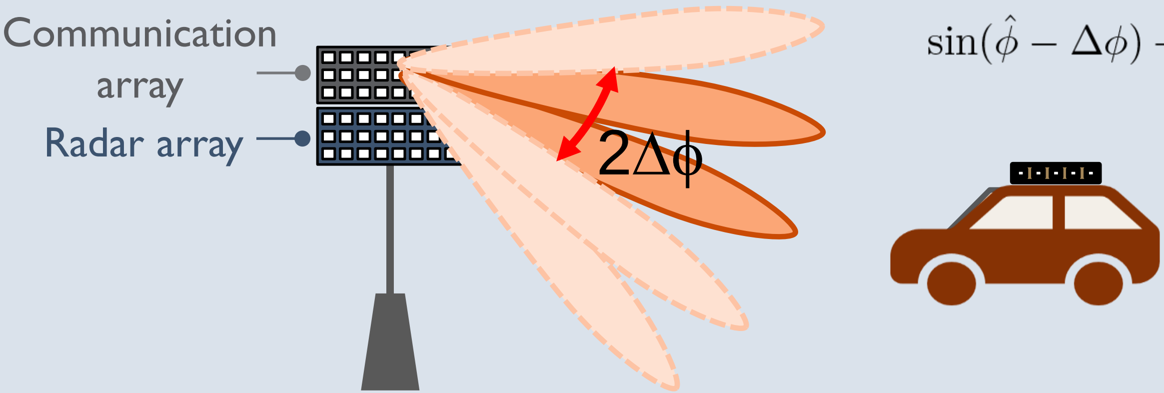
Direction index

Quantization due to phase shifters

array elements at base-station

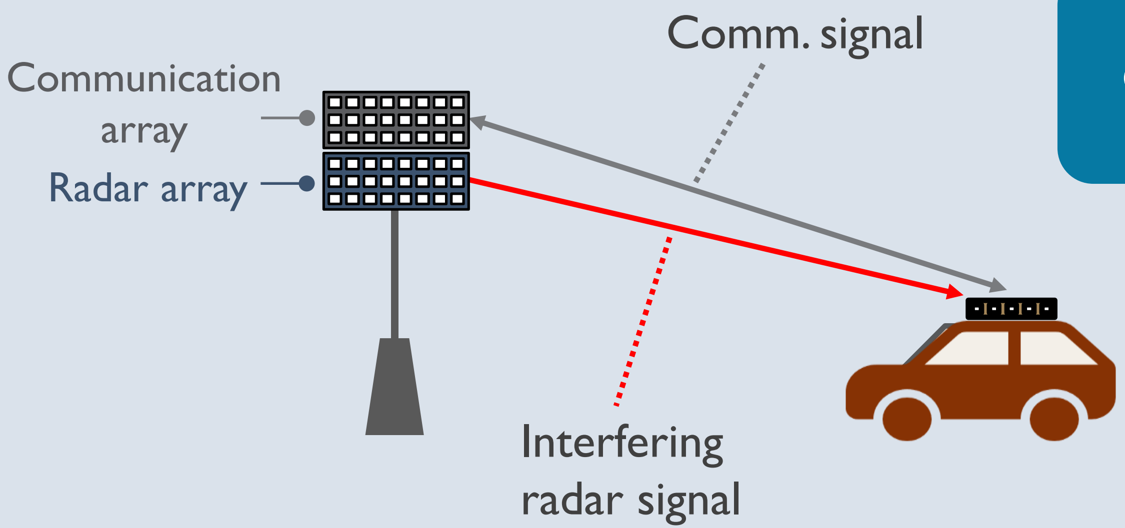
Restrict our codebook to beams aligning with the radar-estimated angle $\hat{\phi}$:

$$\sin(\hat{\phi} - \Delta\phi) + 1 \leq \frac{2n}{N_{\mathrm{BS}}} \leq \sin(\hat{\phi} + \Delta\phi) + 1 + 2/N_{\mathrm{BS}}$$



Radar-to-comm. (R2C) interference

What if the radar signals interferes with our communications?



The mmWave comm. band (71-76 GHz) is adjacent to the automotive radar band (76-81 GHz)

The vehicle receiver will experience interference from any overlap or out-of-band leakage

How is our comm. data-rate affected by this R2C interference?

Prior work

Radar-aided beam training

97% training overhead reduction [1]

Radar and comm. congruence [2]

Radar-to-radar (R2R) interference

Mitigation methods in automotive radars [3]

Radar-to-comm. (R2C) interference

Communication receiver design for mitigation [4,5]

Does not consider mmWave MIMO systems

R2C interference has not been analyzed in the context of mmWave MIMO

[1] A. Ali, N. González-Prelcic, and A. Ghosh, "Millimeter wave V2I beam-training using base-station mounted radar", IEEE Radar Conf., 2019

[2] A. Graff, A. Ali, N. González-Prelcic, "Measuring radar and communication congruence at millimeter wave frequencies", Asilomar Conf. Signals, Syst. Comput., 2019

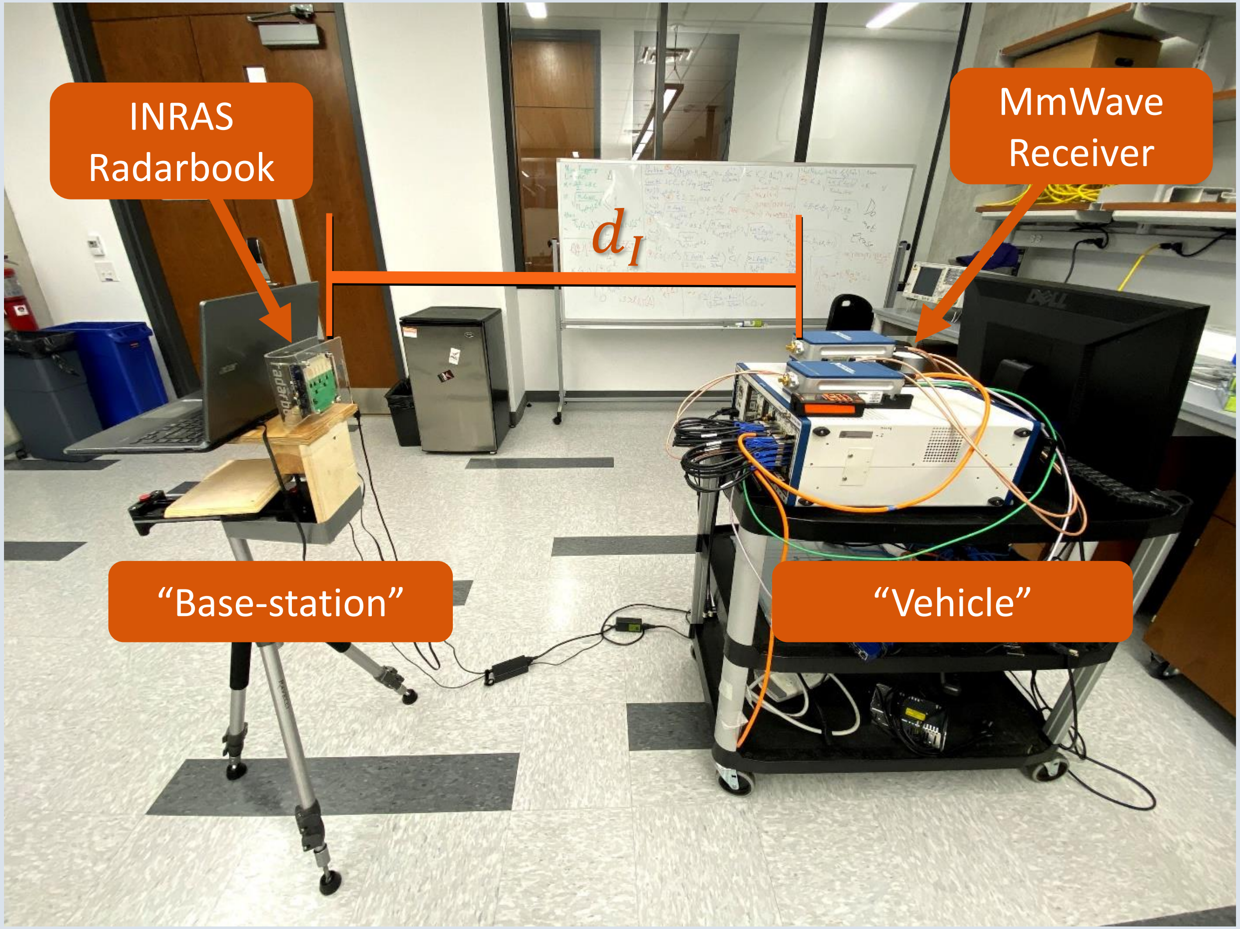
[3] M. Toth et al., "Performance comparison of mutual automotive radar interference mitigation algorithms," IEEE Radar Conf., 2019

[4] A. Ayyar and K. V. Mishra, "Robust communications-centric coexistence for turbo-coded ofdm with non-traditional radar interference models," IEEE Radar Conf., 2019

[5] N. Nartasilpa et al., "Let's share commrad: Co-existing communications and radar systems," IEEE Radar Conf., 2018

Interference measurements

Measurement setup



Measurements taken at distances of 1, 2, 3, and 5 m

Radar transmitted at 76 Ghz

Receiver center frequency swept from 74 to 76 GHz (100 MHz increments) at each distance

Measured interference power at the mmWave receiver

Equipment

INRAS Radarbook

Equipped with "Infineon 77-GHz frontend"

Transmitted a 76 GHz CW signal to capture worst-case interference

Output power of 14 dBm (the device's maximum power)

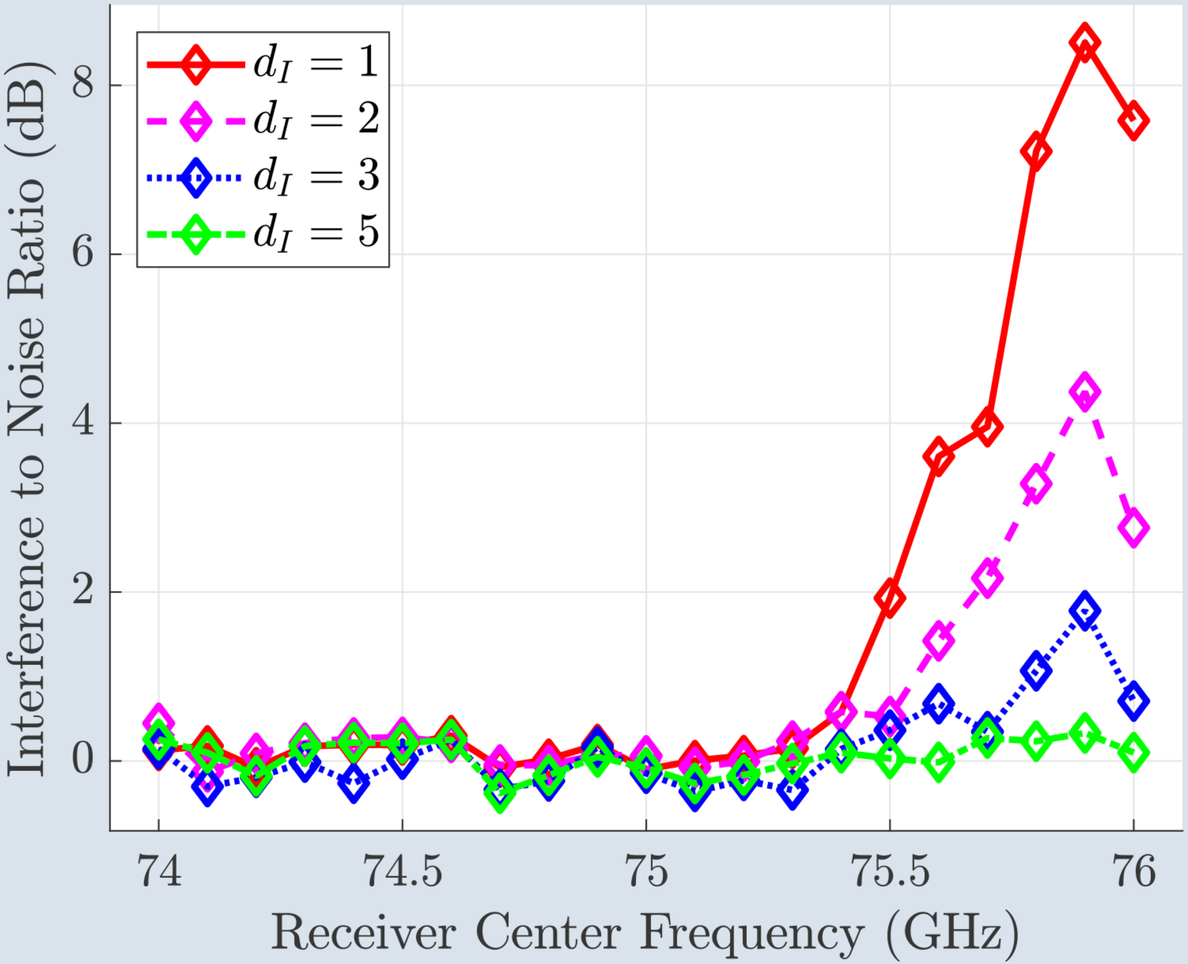
mmWave Transceiver

71-76 GHz mmWave radio head with 17 dBi pyramidal horn antenna

2 GHz bandwidth

Power averaged over 32 acquisitions for each environment setup (one receiver center frequency at one distance)

Interference results



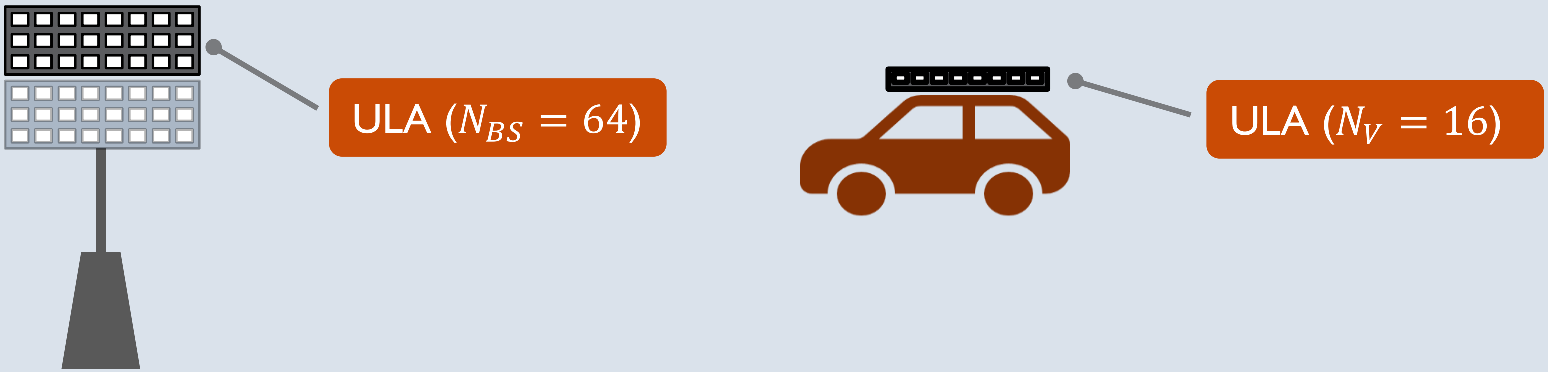
Negligible interference below 75.4 GHz

Interference to noise ratio (INR) predictably decreases as d_I increases

At 5 m, interference is nearly indistinguishable from noise

Spectral efficiency with interference

Communication system

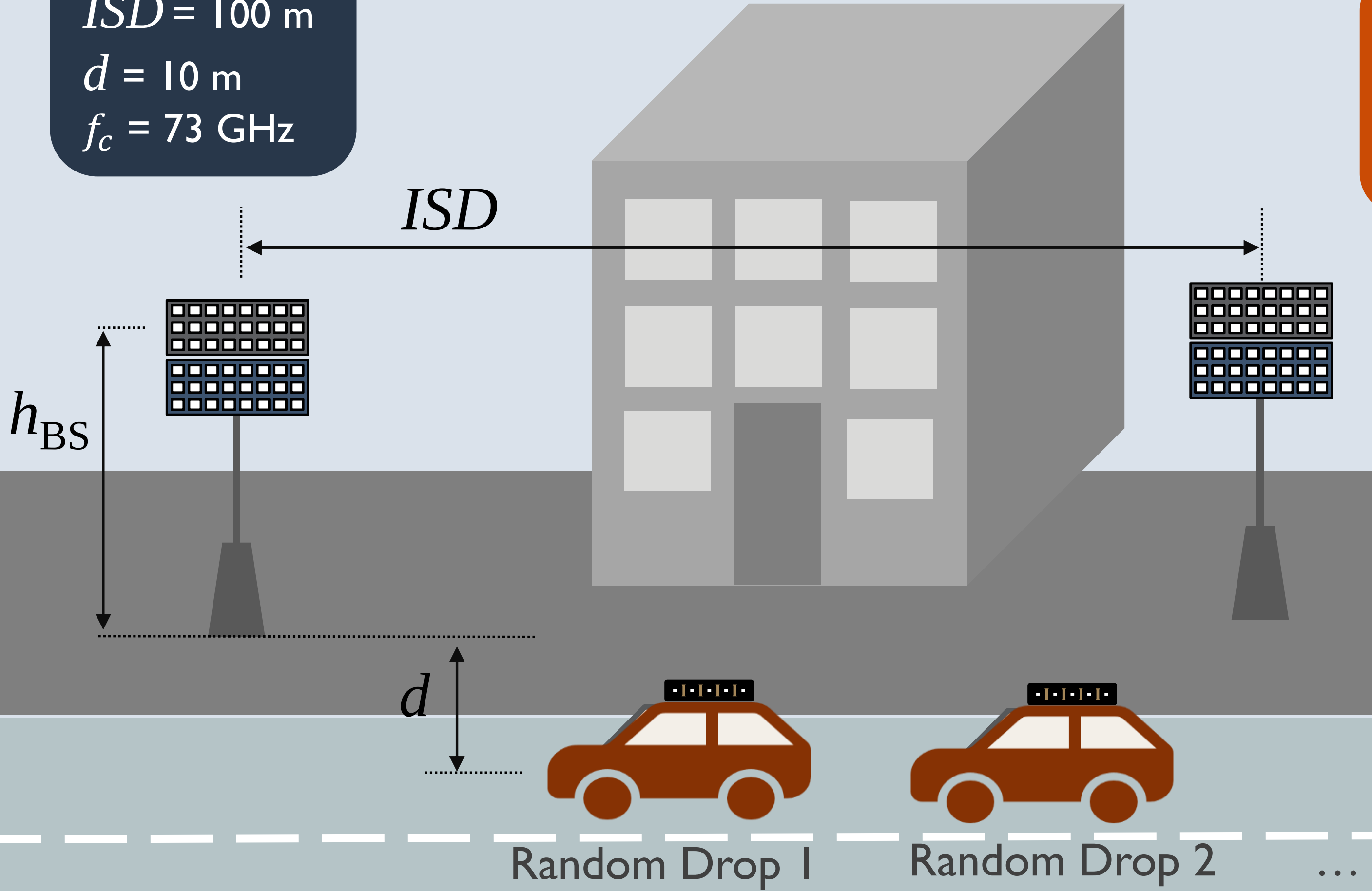


Communication System Parameters

- Analog RF architecture
- 512 subcarriers ($K = 512$)
- Cyclic Prefix (CP) length of 3x RMS delay spread. CP length of 0.6 μs
- 2-bit phase shifters ($D_{BS} = D_V = 2$)
- 240 kHz subcarrier spacing (5G NR maximum)
- Total OFDM block duration of 4.7 μs

Simulations

h_{BS} = 5 m
ISD = 100 m
d = 10 m
f_c = 73 GHz



Channels generated using QuaDRiGa [1] based on Uma LOS scenario

100 drop at random locations on the road

Simulation results are averaged over these random drops

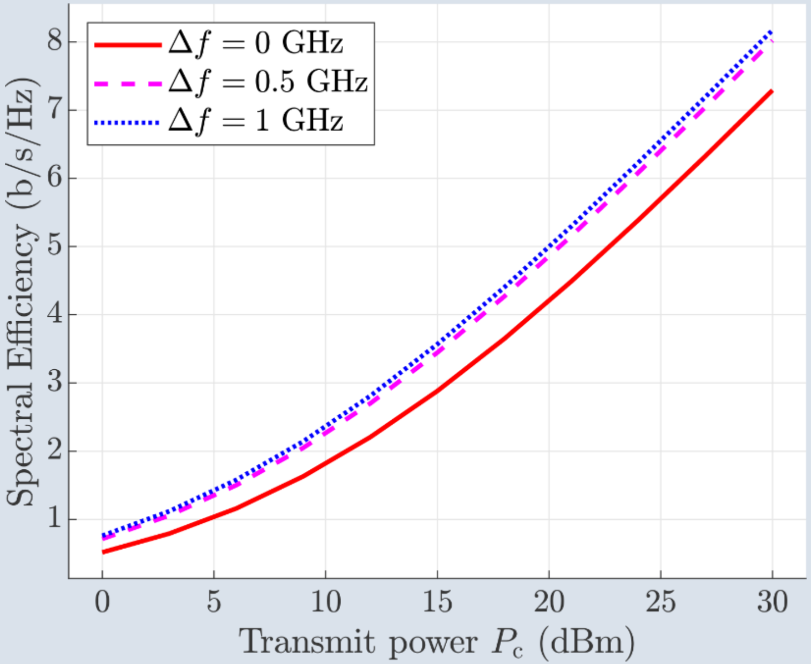
[1] S. Jaeckel et al., "QuaDRiGa-Quasi deterministic radio channel generator, user manual and documentation," Fraunhofer Heinrich Hertz Institute, Tech. Rep. v2.0.0, 2017

Spectral efficiency

$$\mathrm{SE} = \mathbb{E}\left[\frac{1}{K}\sum_{k=1}^{K}\log_2\right]\left(1+\frac{P_c|\mathbf{q}^*\mathbf{H}[k]\mathbf{w}|^2}{K(N_{0,c}+I)}\right)\Bigg]$$

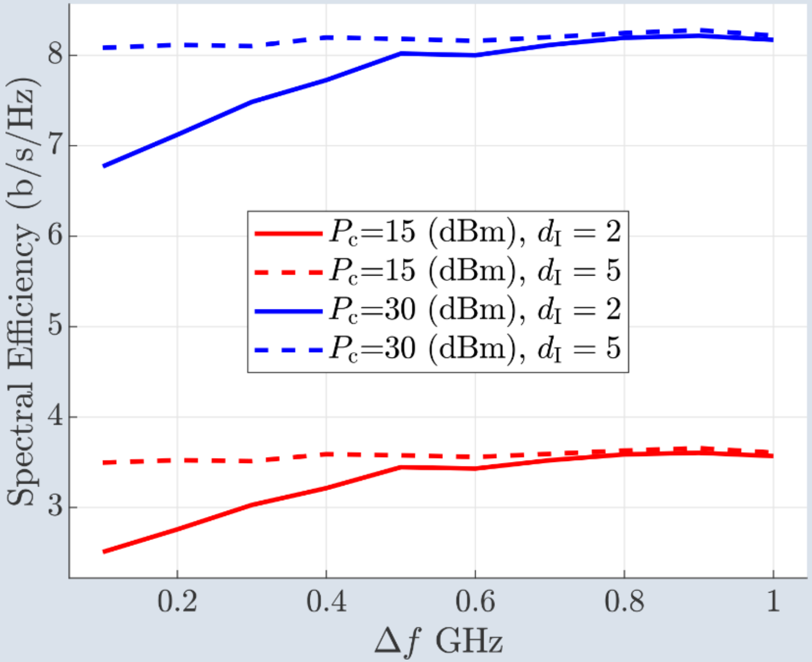
interference power

Function of transmit power (fixed at 2 m)



Comm performance did not degrade significantly, even with no frequency separation

Function of frequency separation



At 5 m separation, there is nearly no degradation at all

Conclusion and future work

Conclusion

With our mmWave radar equipment, R2C interference power was comparable to the noise power when:

- Frequency separation exceeded 0.6 GHz
- Distances exceeded 5 m

We experienced losses of up to 1 b/s/Hz (at a throughput of 8 b/s/Hz) in spectral efficiency, but these losses reduce significantly with frequency separation and distance

When the theoretical 97% overhead reduction of radar-aided training is considered, this degradation can be further neglected

Shows promising opportunity for radar and communication coexistence on base-stations, especially in practice with current off-the-shelf systems

Future work

C2R interference

Study the interference from to communications to the radar systems

Impact on positioning error and training overhead reduction

Theoretical analysis

Compare results with theoretical link budget analysis

Optimal system configurations to maximize spectral efficiency

Thank you