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

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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

$$[c]_n = Q \left( \frac{1}{\sqrt{N_{BS}}} a_{BS} \left( \arcsin \left( \frac{2n - N_{BS} - 1}{N_{BS}} \right) \right) \right)$$

Quantization due to phase shifters

# array elements at base-station

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

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

Interference measurements
INRAS Radarbook

MmWave Receiver

“Base-station”

“Vehicle”

$d_I$

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

INRAS Radarbook

MmWave Receiver

“Base-station”

“Vehicle”

$d_I$
**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 Parameters

- **Analog RF architecture**
- **2-bit phase shifters** \(D_{BS} = D_V = 2\)
- **ULA** \((N_{BS} = 64)\)
- **ULA** \((N_V = 16)\)
- **ULAs**
- **512 subcarriers** \((K = 512)\)
- **240 kHz subcarrier spacing** (5G NR maximum)
- **Cyclic Prefix (CP) length** of 3x RMS delay spread. CP length of 0.6 \(\mu\)s
- **Total OFDM block duration** of 4.7 \(\mu\)s
Simulations

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

\[ h_{BS} = 5 \, \text{m} \]
\[ ISD = 100 \, \text{m} \]
\[ d = 10 \, \text{m} \]
\[ f_c = 73 \, \text{GHz} \]

Spectral efficiency

\[
SE = \mathbb{E} \left[ \frac{1}{K} \sum_{k=1}^{K} \log_2 \left( 1 + \frac{P_c |q^* H[k] w|^2}{K(N_0 + I)} \right) \right]
\]

Function of transmit power (fixed at 2 m)

- \( \Delta f = 0 \text{ GHz} \)
- \( \Delta f = 0.5 \text{ GHz} \)
- \( \Delta f = 1 \text{ GHz} \)

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

Function of frequency separation

- \( P_c = 15 \text{ (dBm)} \), \( d_t = 2 \)
- \( P_c = 15 \text{ (dBm)} \), \( d_t = 5 \)
- \( P_c = 30 \text{ (dBm)} \), \( d_t = 2 \)
- \( P_c = 30 \text{ (dBm)} \), \( d_t = 5 \)

At 5 m separation, there is nearly no degradation at all
Conclusion and future work
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 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