Radar Communications: A solution for mitigating automotive radar interference

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Outline

- Problem: Mutual radar interference
- Background: Automotive radars
- Proposed solution: Radar Communications
- Results
- Conclusions
Problem

- Mutual radar interference
  - Interference has higher power than target itself
  - Interference range is twice radar range \((2d_{max})\)
  - Safety ↓
    - Radars per vehicle ↑
    - Vehicles with radars/ Autonomous vehicles ↑

Interference = ghost target

Increased noise floor
When do we have mutual radar interference?

- **Facing radars** (radars receiving each other’s direct or reflected radar signals)

- Facing radars transmit during a ‘vulnerable period’
Background

- **Automotive radars**
  - 77 GHz (76-77) - used today most frequently
  - 79 GHz (77-81)
  - The most common modulation format used for automotive radars is **frequency modulated continuous-wave (FMCW)**
    - Inefficient spectrum use
    - Idle time for processing, i.e. **inefficient use of time**
Proposed Solution

- **Radar Communications (RadCom)**
  - Single hardware for two functions

- Data communication (See-through driving, radar map dissemination, etc.)

- Removal of mutual interference
Radar Communications

- **How can RadCom remove mutual interference?**
  - Make use of idle times
  - Squeeze other radars into one chirp sequence
    - But be cautious!
    - Is it enough for 'gray regions' not to overlap?

![Diagram showing frame and half of ADC sampling frequency relates to idle time and ADC frame.]
Vulnerable Period

- **Vulnerable period V:** Set of $\tau$, given FMCW transmissions start at
  - $t = 0$ for the ego vehicle and
  - $t = \tau$ for the facing vehicle

- Imperfect ADC low-pass filters lead to mutual interference for negative frequencies also

- Counting for propagation delay, Doppler, imperfect filtering:
  - $V = \frac{2T}{BT_s}$
  - $T$: Chirp duration, $B$ total bandwidth, $T_s$: ADC sampling period

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Vulnerable period:
- \( V = \frac{2T}{BT_s} \)

Extended vulnerable period:
- \( V_{ext} = 2NTV \), \( N \) number of chirps per frame

Probability of interference without Radar Communication:
- \( p_{int}^f = \frac{V_{ext}}{T_f} \) per frame
- \( P_{int} = 1 - (1 - p_{int}^f)^M \), \( M \) facing vehicles
One proposal:
- Use different frequency bands for radar ($B_r$) and communication ($B_c$)
- Switch in time between radar and communication

Radar Medium Access: rTDMA
- Different radars allocated rTDMA slots

Communication Medium Access for scheduling radars:
- Non-persistent CSMA with backoff (no ACK)
Radar Communications

- Overall time-frequency domain for the proposed RadCom
Non-persistent cCSMA:
- Used to broadcast rTDMA slots
- No ACKs (due to high mobility)
- CommTO: timeout for communication
- RadarTO: timeout for radar transmission

State Diagram for proposed Radar Communications:

1. **(rIDLE,cIDLE)**
   - If CommTO = 0
   - Start backoff counter
   - Decrement counter at each idle comm slot
   - Set RadarTO

2. **(rTX/RX,cIDLE)**
   - Broadcast RadarTO

3. **(rIDLE,cTX)**
   - Broadcast RadarTO

4. **(rIDLE,cRX)**
   - Freeze counter
   - Update RadarTO

5. **(rTX/RX,cTX)**
   - Comm. reception ends
   - CS=1

6. **(rTX/RX,cRX)**
   - Comm. transmission ends
   - CS=0

7. **(rIDLE,cTX)**
   - Comm. transmission ends
   - RadarTO expires
   - Radar transmission ends

8. **(rIDLE,cRX)**
   - Freeze counter
   - Update RadarTO
Assumptions/Parameters

- Automotive radars
  - Homogeneous
  - FMCW
- Single-hop network

### TABLE I
SIMULATION PARAMETERS.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chirp duration ($T$)</td>
<td>20$\mu$s</td>
</tr>
<tr>
<td>Frame duration ($T_f$)</td>
<td>20 ms</td>
</tr>
<tr>
<td>Time slots per frame ($K$)</td>
<td>10</td>
</tr>
<tr>
<td>Radar bandwidth</td>
<td>0.96 GHz–1 GHz</td>
</tr>
<tr>
<td>$d_{\text{max}}$ for $B_c = 0$</td>
<td>150 m</td>
</tr>
<tr>
<td>$v_{\text{max}}$</td>
<td>140 km/h</td>
</tr>
<tr>
<td>$P_{\text{tx}}$</td>
<td>11 dB</td>
</tr>
<tr>
<td>$SNR$</td>
<td>10 dB</td>
</tr>
<tr>
<td>$N$</td>
<td>99</td>
</tr>
<tr>
<td>$f_c$</td>
<td>77</td>
</tr>
<tr>
<td>$T_s$</td>
<td>0.01 $\mu$s</td>
</tr>
<tr>
<td>Chebyshev low-pass filter order</td>
<td>13</td>
</tr>
<tr>
<td>Thermal noise temperature</td>
<td>290 K</td>
</tr>
<tr>
<td>Receiver’s noise figure</td>
<td>4.5 dB</td>
</tr>
<tr>
<td>Communication bandwidth $B_c$</td>
<td>20 MHz, 40 MHz</td>
</tr>
<tr>
<td>Packet size ($N_{\text{pkt}}$)</td>
<td>4800 Bits</td>
</tr>
<tr>
<td>Modulation</td>
<td>16-QAM</td>
</tr>
<tr>
<td>MAC</td>
<td>non-persistent CSMA</td>
</tr>
<tr>
<td>SlotTime</td>
<td>10$\mu$s</td>
</tr>
<tr>
<td>Backoff window size</td>
<td>6</td>
</tr>
</tbody>
</table>

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Results

- Probability of interference without Radar Communications

- Mutual interference is not negligible for automotive radars
Results

- Probability of false alarm

- Vulnerable period is observed to be complaint to calculations
Conclusions

Radar Capability

- Coordinated radar sensing (reduced mutual interference)
- Uncoordinated radar sensing

Safety

Efficiency (cost + spectral)

Current System

- Omni-directional
- Low throughput

RadCom

- Directional (low packet loss + low interference)
- High throughput

V2V Communication Capability
Future Work

- **FFI Project funded** (Träskäret och automatiserade fordon) “Combined Radar-Based Communication and Interference Mitigation for Automotive Applications”
  - Chalmers (coordinator), Volvo Cars, Autoliv, SAAB, QamCom, Halmstad
  - **Goal:** Hardware implementation of RadCom
Questions?

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