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Jam-Duration Optimization for Responsive Vehicle-Protection Jammers

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Introduction

- **Responsive Jamming:** Emerging technology for electronic warfare (EW)

- Most jamming systems currently in operation are **proactive**
  - Jamming parameters (center frequency, bandwidth, waveform type, …) selected a-priori
  - Typically broadband jammers, continuously active – irrespective of spectrum activity

  ⇒ **Relatively high energy consumption per protection band**

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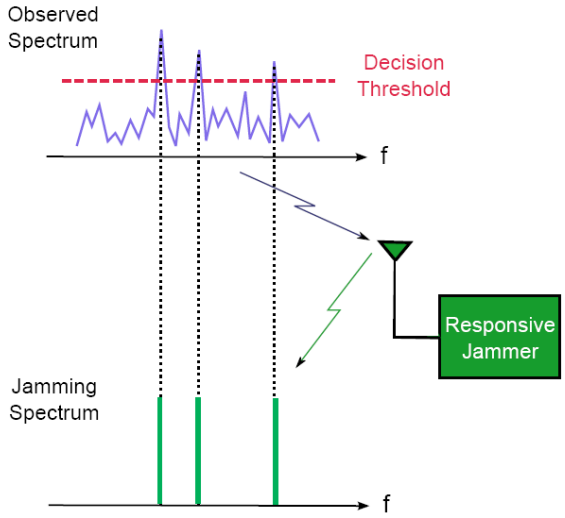
- **Responsive** jammers
  - Scan radio spectrum during periodic lookthrough (LT)
  - Able to react to upcoming signal activities

  ⇒ **Jammer focuses on currently relevant spectral areas**

Advantage: Improved jamming efficiency

Challenge: Novel theoretical & practical issues



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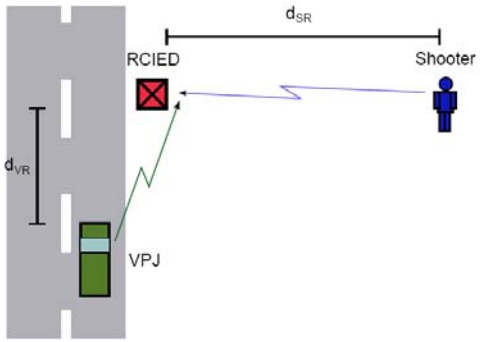

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- **Proactive** anti-RCIED VPJs are in operation already today

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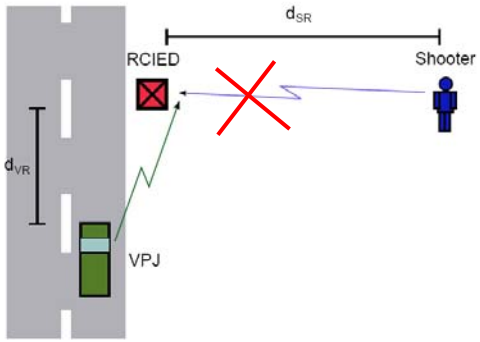

- **Focus here:** Vehicle-Protection Jammers (VPJs) against radio-controlled improvised explosive devices (`RCIEDs´)
- **Proactive** anti-RCIED VPJs are in operation already today
- **Responsive VPJ** (VPJ-R)
  - With sufficiently fast reaction time upcoming RCIED-trigger signal can be detected and jammed before RCIED can be detonated

Advantages:

(i) Jamming signals are directly allocated to potential trigger signals
(ii) Wide bands can be covered without excessive energy consumption
(iii) Even trigger signals at unexpected frequencies can be corrupted

Introduction

- Paper is **semi-tutorial** in nature

- First part points out various **theoretical** and **practical issues** associated with responsive jamming technology (with focus on VPJs)
  ⇒ **Experiences from VPJ-R product development**

Introduction

- Paper is **semi-tutorial** in nature
- First part points out various **theoretical** and **practical issues** associated with responsive jamming technology (with focus on VPJs)
  ⇒ **Experiences from VPJ-R product development**
- Second part deals with the problem of **jam-duration optimization** as one example for a theoretical issue
  ⇒ **Jamming is by definition not continuous; proper choice of jam duration is important**
- **Design issues** for responsive jammers have **not** yet been **addressed** in the (academic) literature
  ⇒ **Paper may serve as starting point for further research**

Overview

- **Part I: Theoretical and Practical Issues for Responsive VPJs**
- **Part II: Jam-Duration Optimization for Responsive VPJs**
- **Conclusions**

Practical Issues for Responsive VPJs

- **Hardware/Software (HW/SW) Implementation**
  - Fast reaction times required ⇒ Corrupt RCIED trigger signals in real time
  - Usually large instantaneous observation bandwidth desired ⇒ Broad protection
  - High sensitivity required ⇒ Capture also low-power signals

  ⇒ Substantial challenges for HW (analog filters, local oscillators, ADCs/DACs, …) & SW (digital signal processing part)

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CASSIDIAN VPJ-R prototype

- Large instantanous bandwidths already realized while offering a good sensitivity
- Agile readjustment of key parameters using software-defined radio (SDR) concepts
- Very short time frame for entire process from spectrum observation to jamming signal allocation (compared with transmission times of potential threat signals)
- Digital signal processing part based on FPGA technology
- Spectrum analysis based on FFT algorithm

Practical Issues for Responsive VPJs

- **Antenna Subsystem**
  - Efficient power amplifiers (PAs) required ⇒ Effective corruption of threat signals
  - Small installation size of PAs and Rx/Tx antennas ⇒ Confined platform (Jeep, …)
  - Suitable choice of number of parallel Rx/Tx chains ⇒ Multiple instantaneous bands
  - Careful design of antenna platform ⇒ Avoid shadowing in case of multiple antennas

  ⇒ System engineering must define sustainable overall solution

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- **Further Practical Issues**
  - Ensure robust design of system components
  - Limit interference on friendly communications
  - …

Theoretical Issues for Responsive VPJs

- Efficient algorithms for **spectrum sensing & signal categorization** required to distinguish potential threat signals from noise

- Efficient algorithms for **jamming signal generation & allocation** required

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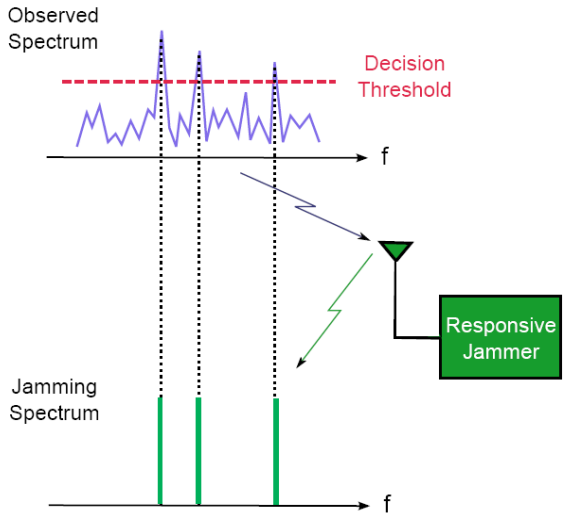
- Efficient algorithms for **spectrum sensing & signal categorization** required to distinguish potential threat signals from noise
- Efficient algorithms for **jamming signal generation & allocation** required
- If jamming signals are multi-carrier signal, techniques for **Crest-factor reduction** are desired to improve jamming efficiency
- **Optimization** of jamming parameters (frequency resolution, jamming signal forms, jam duration,…)



More details can be found in the paper

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Problem Statement

- Responsive VPJs **interrupt** jamming activity periodically to allow for wide-band spectrum scans during **LT-phases** (fixed length T_{LT})

⇒ For given length T_h of threat signal, jam duration T_{jam} must be chosen carefully

Problem Statement

- Responsive VPJs **interrupt** jamming activity periodically to allow for wide-band spectrum scans during **LT-phases** (fixed length T_{LT})

⇒ For given length T_h of threat signal, jam duration T_{jam} must be chosen carefully

  - If $T_{jam} << T_h$, time fraction of jamming might be too small for effective signal corruption
  - If $T_{jam} \geq T_h$, threat signal might be missed entirely, as gap between LT-phases too large

T_{jam} is **global parameter**, as typically LT-phases should be synchronized across all bands

- **Definition:** Effective jam ratio τ

$$\tau := \frac{T_{jam,ov}}{T_h} \leq 1$$

Simulation Examples

- **Example:** Threat signal length $T_h = 35 \cdot T_{LT}$, random arrival time t_0
- **Assumption:** 50% of signal must be jammed for effective corruption ($\rightarrow \tau_{des}$)

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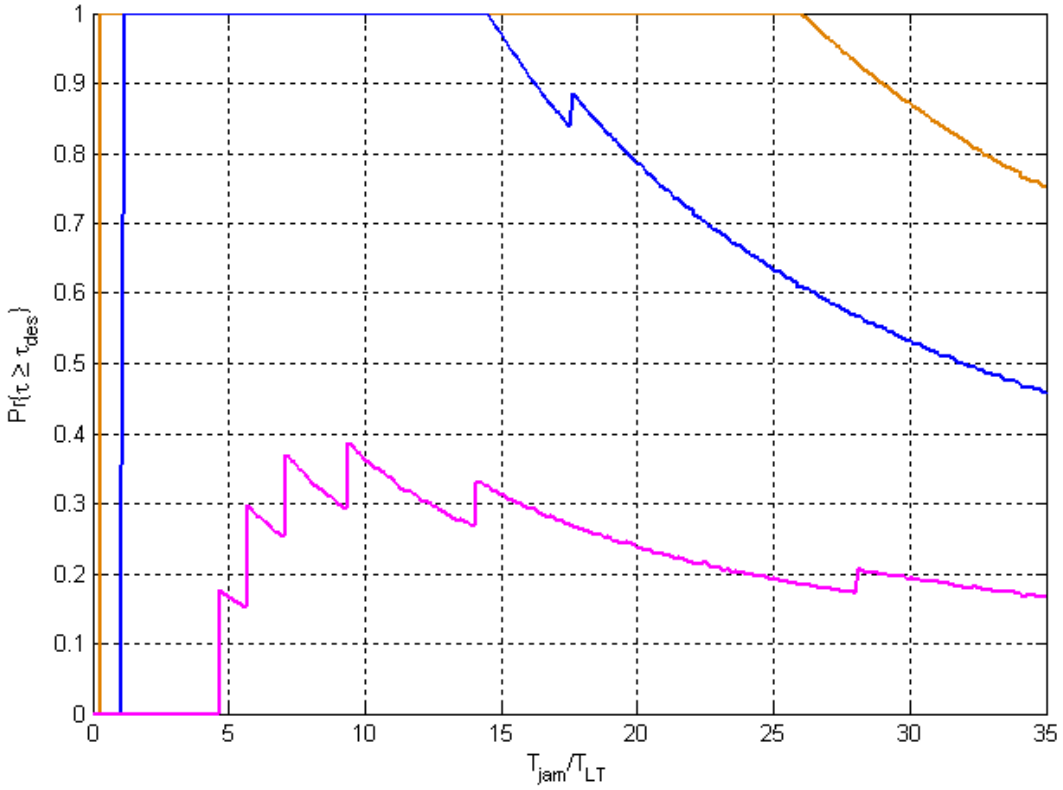
• Probability $Pr\{\tau \geq \tau_{des}\}$ vs. T_{jam}

- $\tau_{des} = 20\%$
- $\tau_{des} = 50\%$
- $\tau_{des} = 80\%$

⇒ Very long and very short jam durations are **inefficient**



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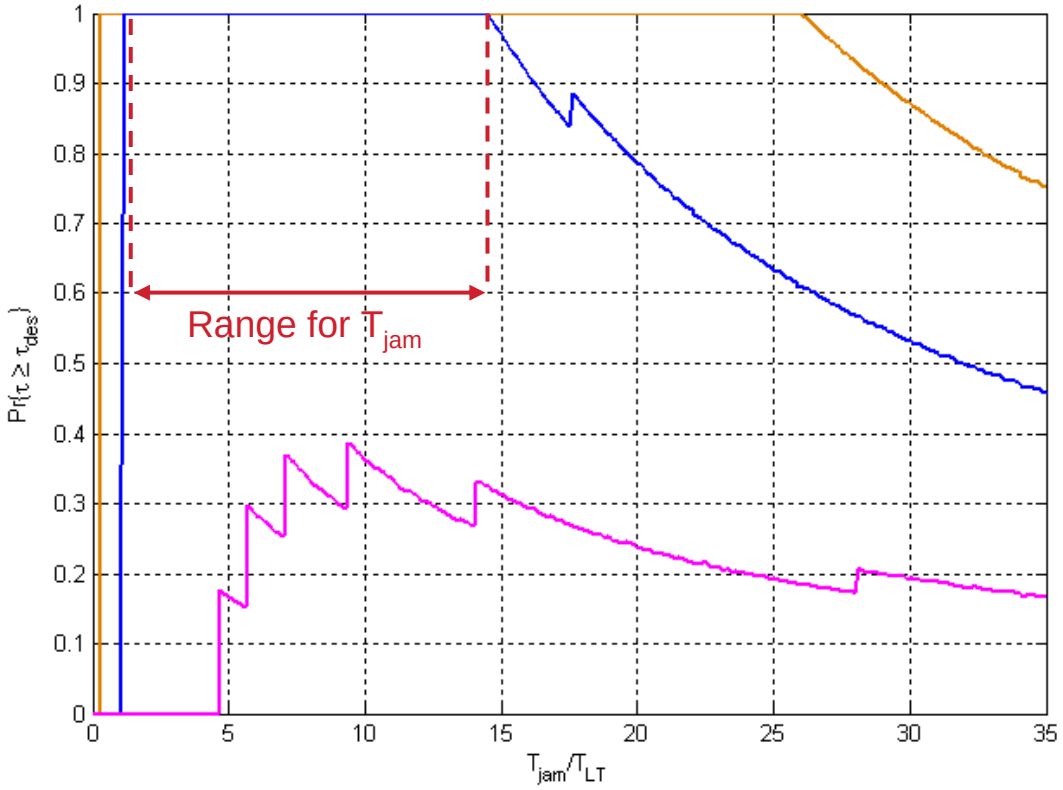
⇒ If τ_{des}=50% is supposed to be met with probability 1 (for any t_0), T_{jam} should be chosen between $1.2 \cdot T_{LT}$ and $14.5 \cdot T_{LT}$



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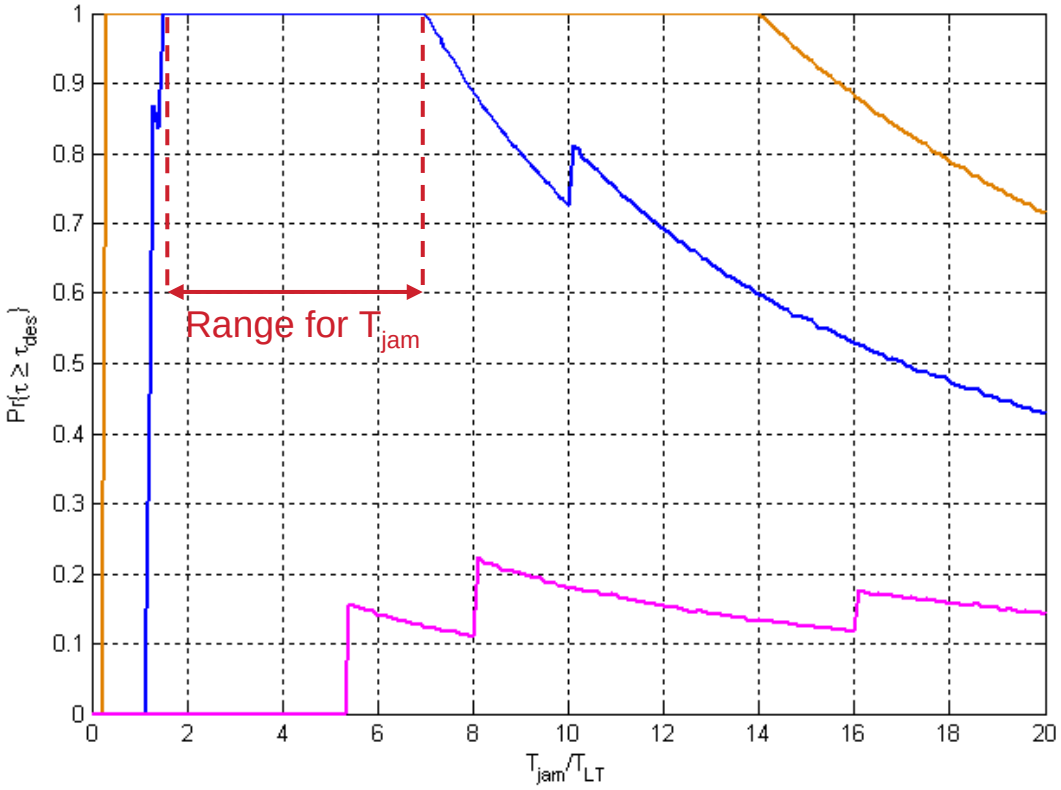

Analytical Rule-of-Thumb

- Simulations can be time-consuming and provide little theoretical insight
  ⇒ Analytical guidelines are of interest
- **Definition:** Function $f(T_{jam})$

$$f(T_{jam}) := \max\left\{0, \left(\left\lfloor \frac{T_h}{T_{LT} + T_{jam}} \right\rfloor - 1\right) \frac{T_{jam}}{T_h}\right\}$$

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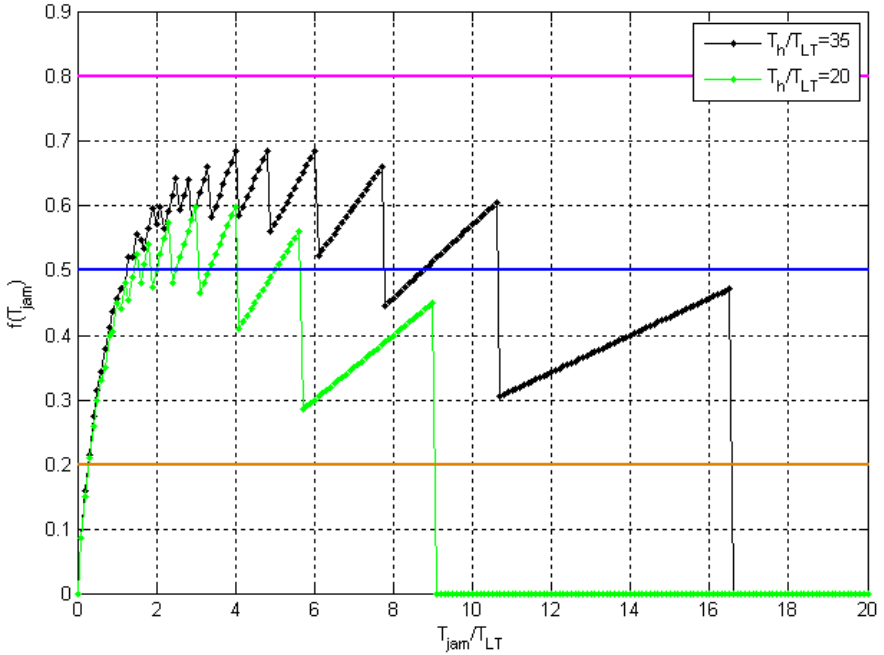
Shown in the paper:
For a given τ_{des} choose T_{jam} such that $\tau_{des} < f(T_{jam})$ holds. Then, τ_{des} is met with probability 1 (for any t_0)



- In case of **multiple** threat signals with different lengths T_h, valid intervals for T_{jam} must be **combined**

Conclusions

- **Responsive jamming** is a promising new EW technology
- Responsive VPJs against RCIEDs promise **higher efficiency** than proactive VPJs
- Overview of **theoretical** and **practical issues** provided
- Topic of **jam-duration optimization** discussed in more detail
  ⇒ With suitable choice of jam duration excellent jamming performance is obtained

Thank you for your attention!

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