Butterfly Attack: Adversarial Manipulation of Temporal Properties of Cyber-Physical Systems

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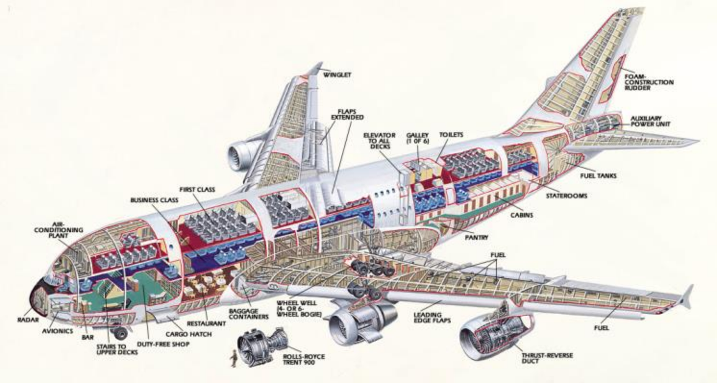
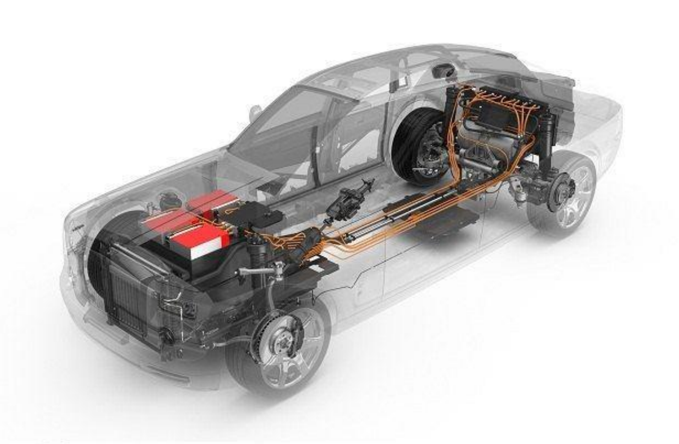
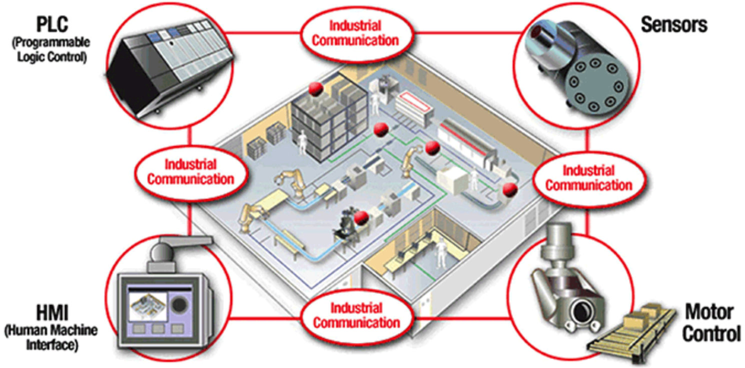
2) École Polytechnique Fédérale de Lausanne, Switzerland

3) General Motors R&D, US

Cyber-Physical Systems

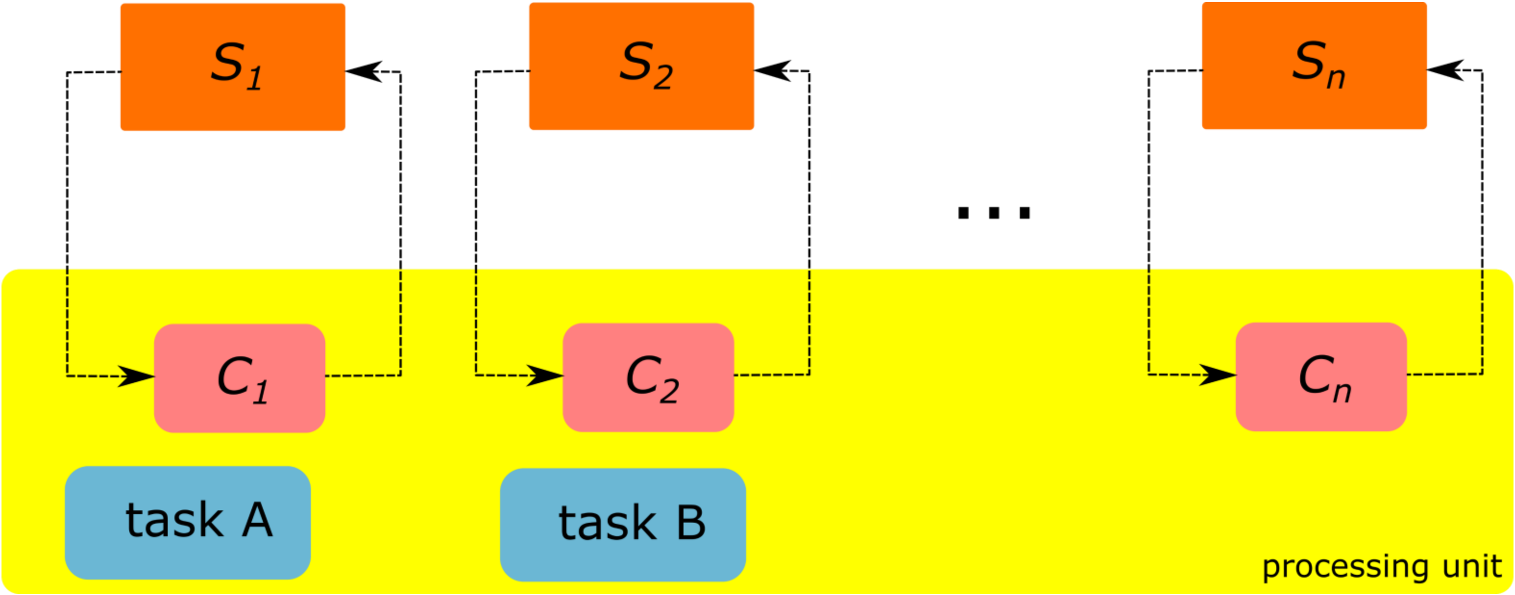






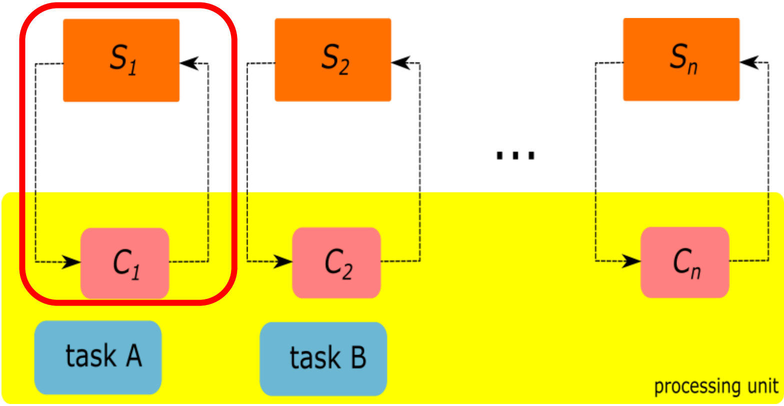
Images from: Electricity Forum, ACS solutions, eeNews

Shared Processor



- ❖ **Shared platform**
- ❖ **Mixed-critical tasks**
- ❖ **Control applications**

Latency, Jitter

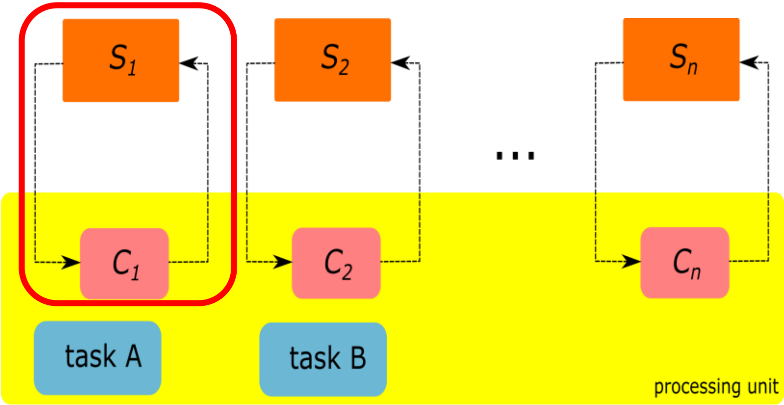


Latency, Jitter

$h =$ sampling period

$L = R^b$ (Latency)

$J = R^w - R^b$ (Jitter)



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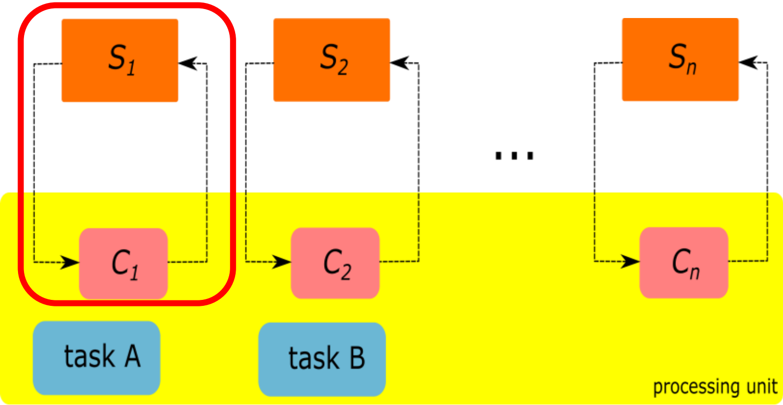

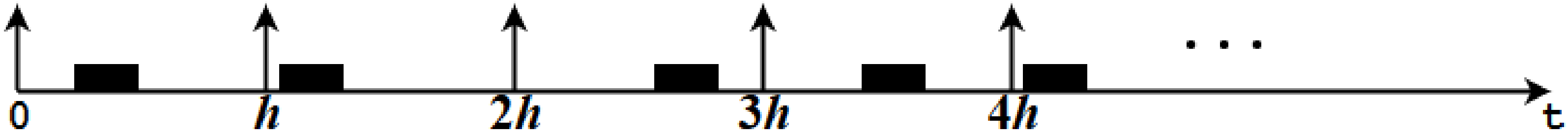

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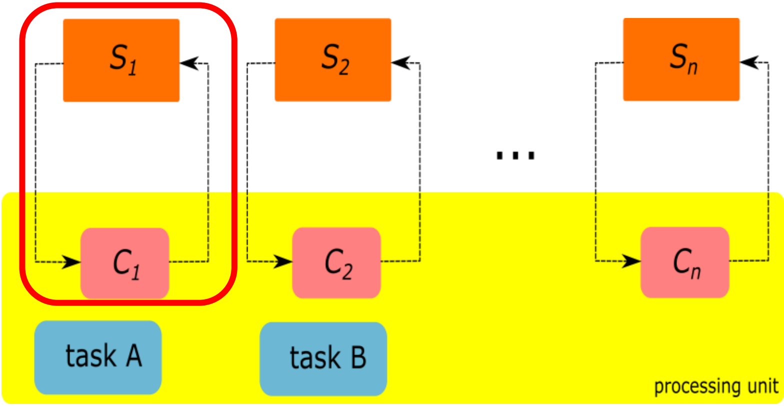

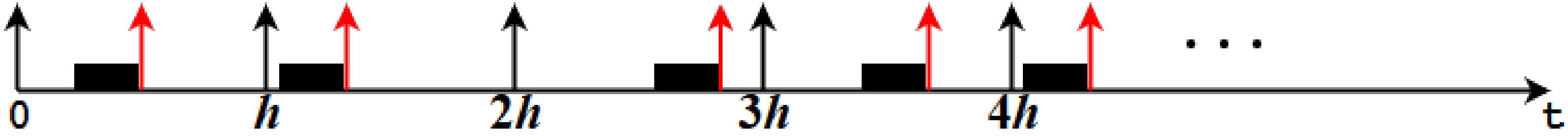

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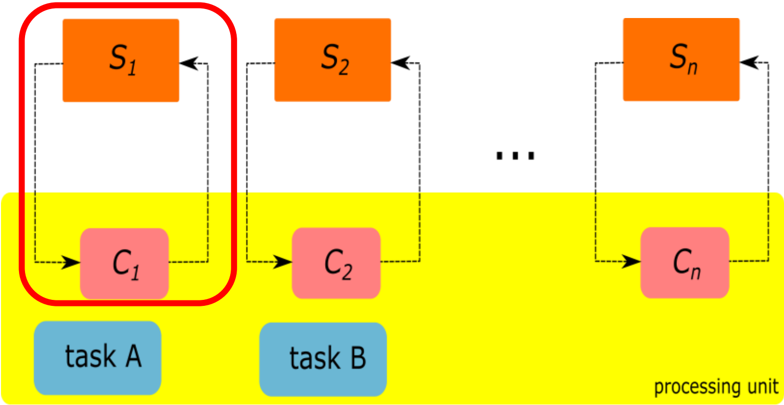

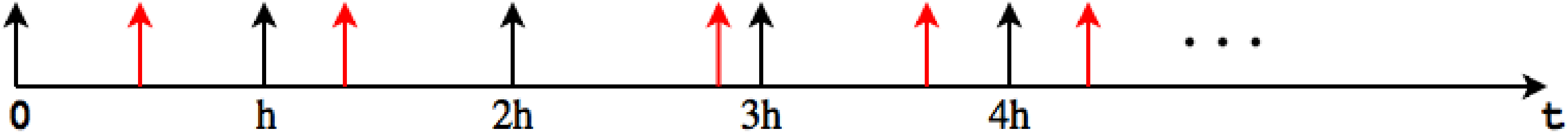

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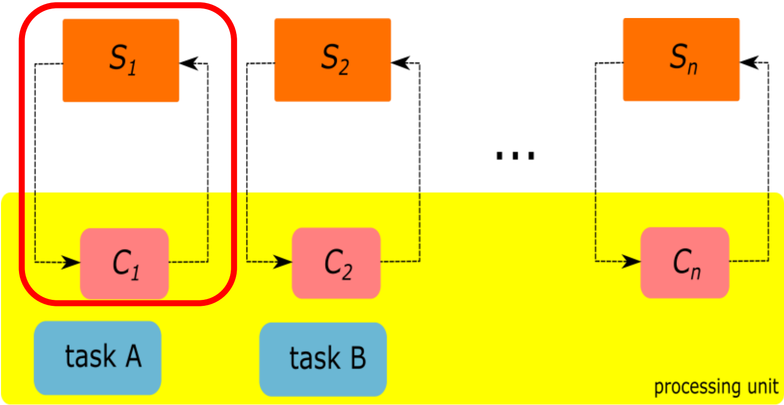

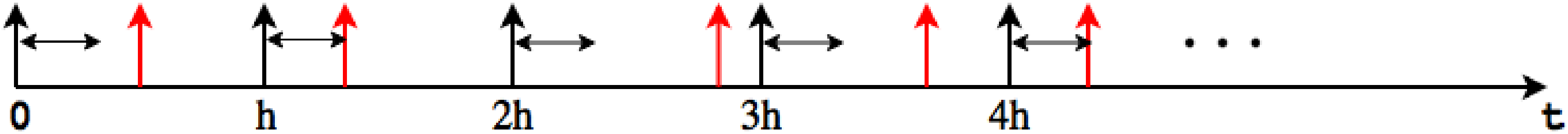

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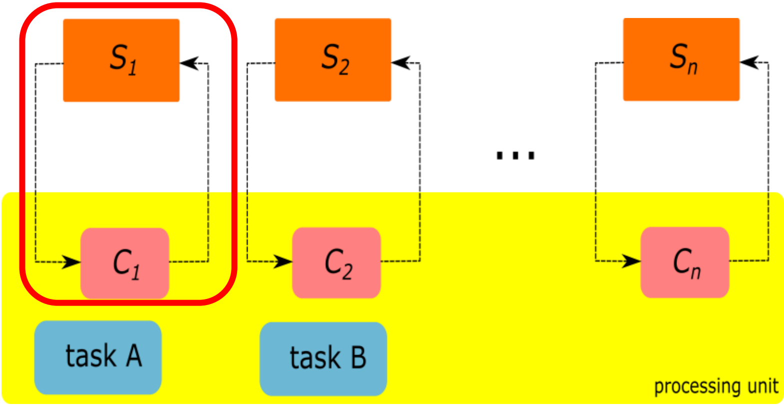
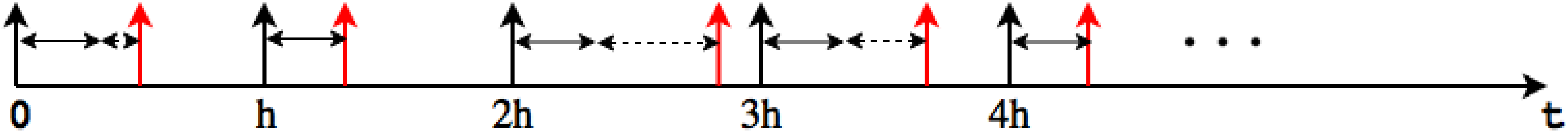
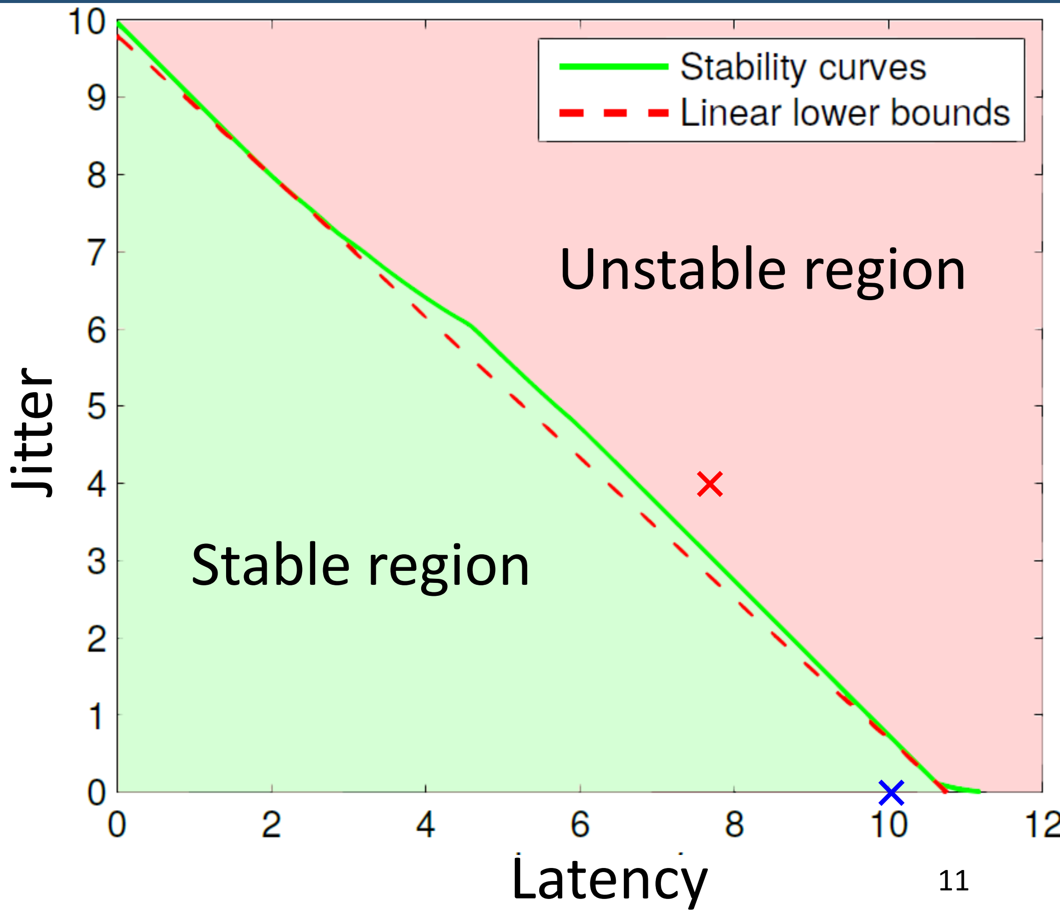


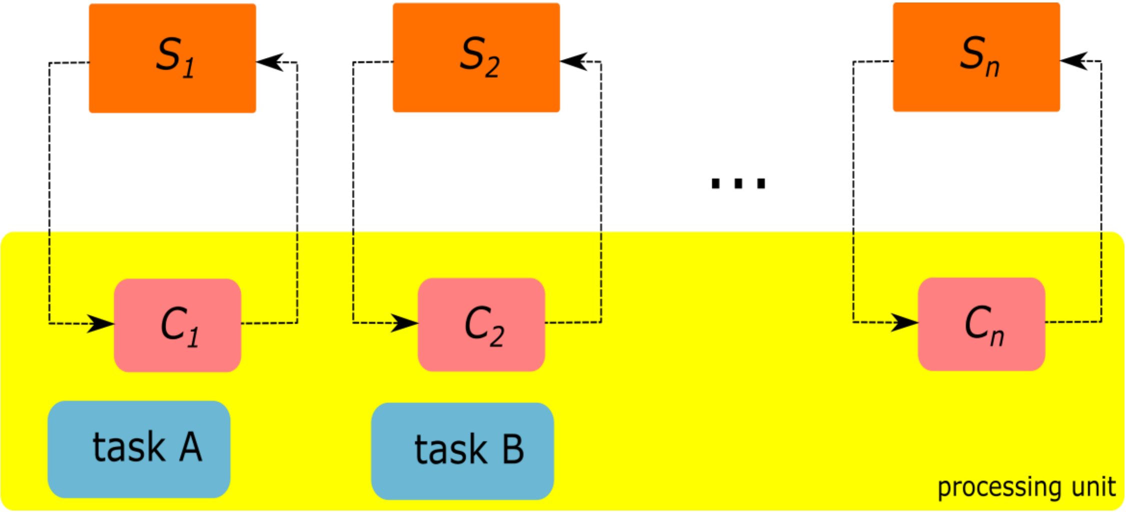


Stability

Stability curve derived with Jitter Margin toolbox



Common Belief*

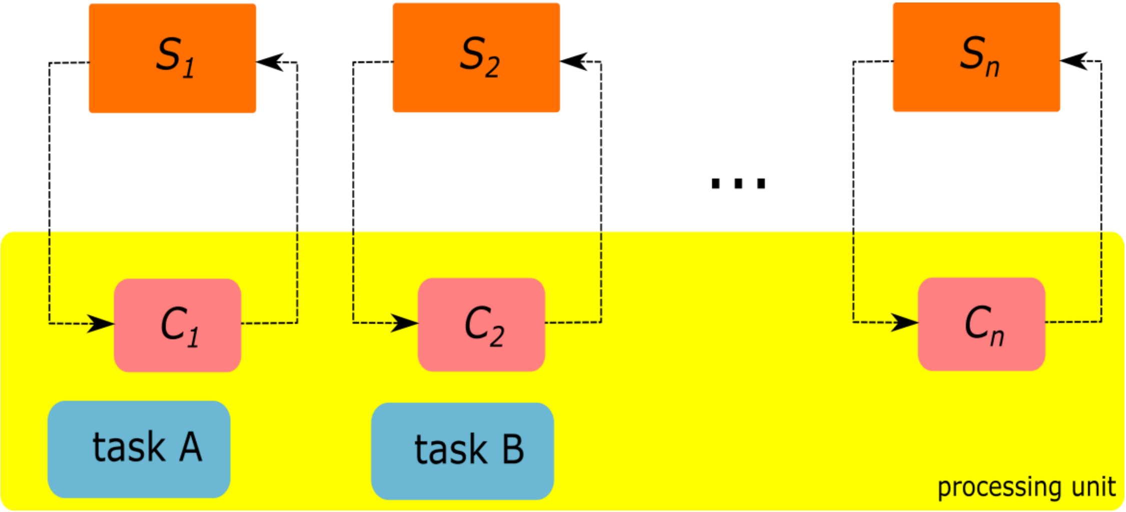


- Main thread: Exceeding a certain worst-case execution/computation time
- Giving more resource to a controller leads to better control quality
- Security measures: prevent tasks from consuming more resources

*Vestal S. Preemptive scheduling of multi-criticality systems with varying degrees of execution time assurance. In28th IEEE International Real-Time Systems Symposium (RTSS 2007)

Common Belief*

Our Contribution!



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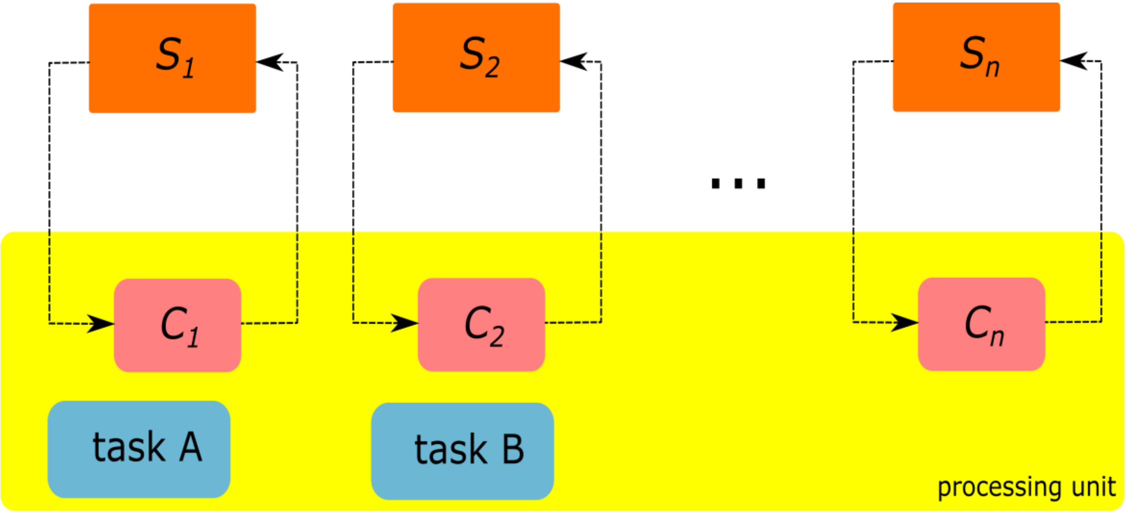
Common Belief*

Our Contribution!

Wrong!



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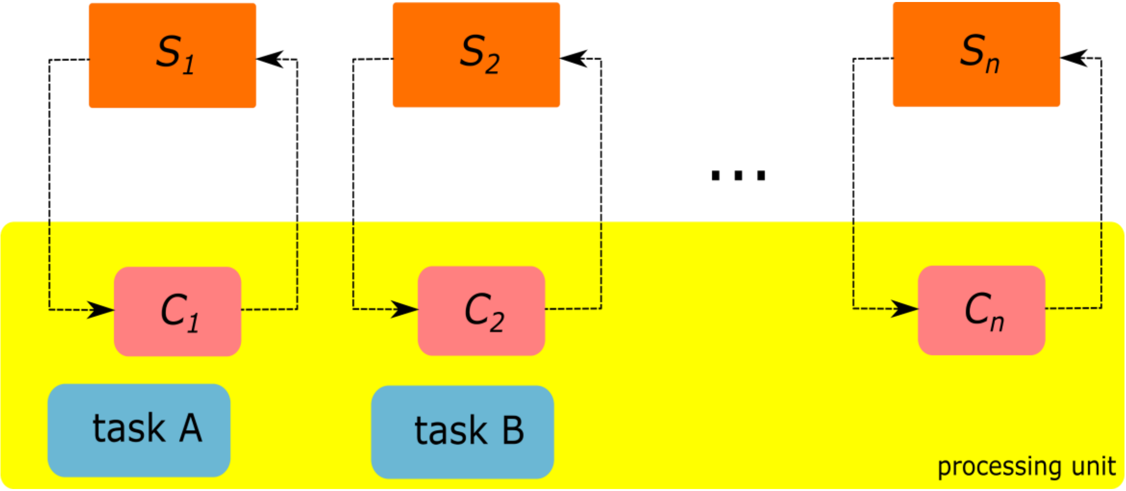
Control Tasks Characteristics

- **Inter-dependency**
- **Non-monotonicity**



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$$\boldsymbol{\tau}_i = (\rho_i, \boldsymbol{c}_i, \boldsymbol{h}_i)$$
$$\boldsymbol{\tau}_1 = (H, 3,6)$$
$$\boldsymbol{\tau}_2 = (M, 2,8)$$
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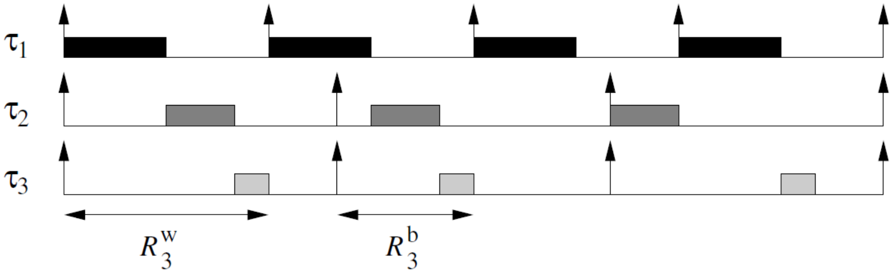

(a) Original task set

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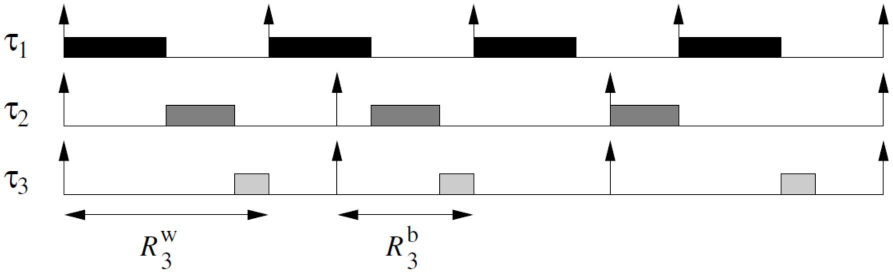

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$$J_3 = R_3^w - R_3^b = 2$$

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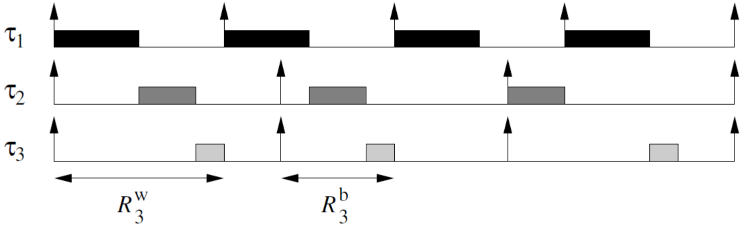

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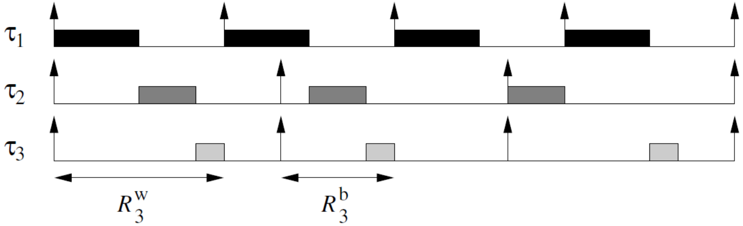

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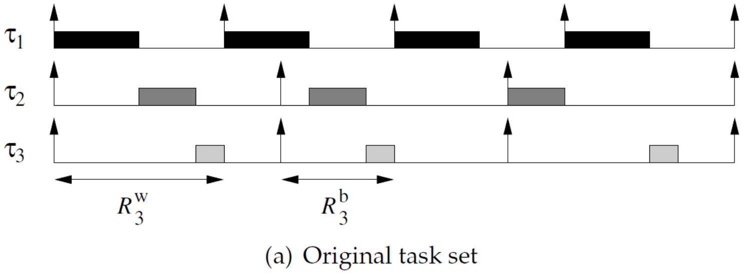

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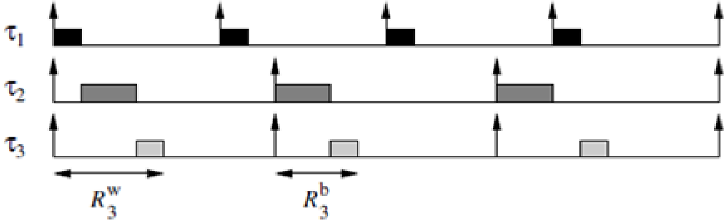

(e) Decreasing computation time c_1

$$J_3 = R_3^w - R_3^b = 1$$

Control Tasks Characteristics

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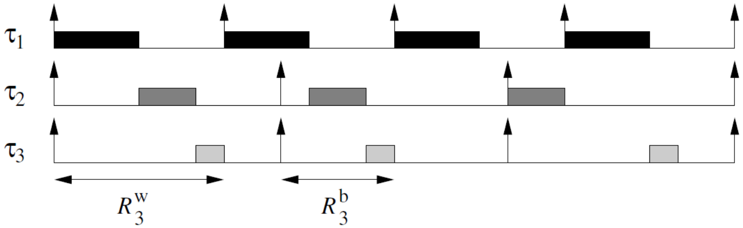

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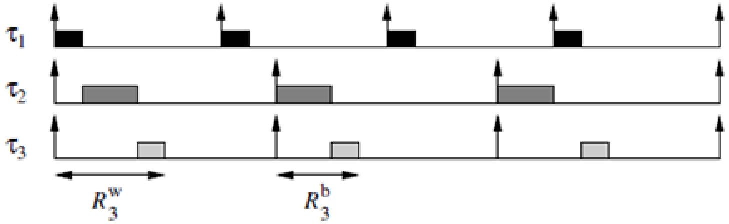

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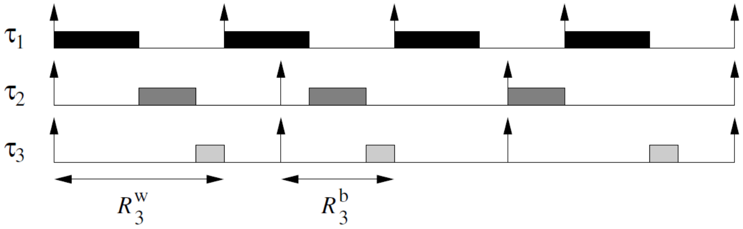

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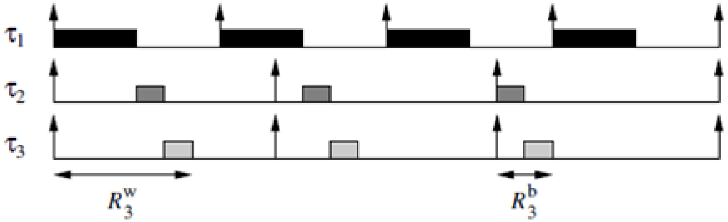
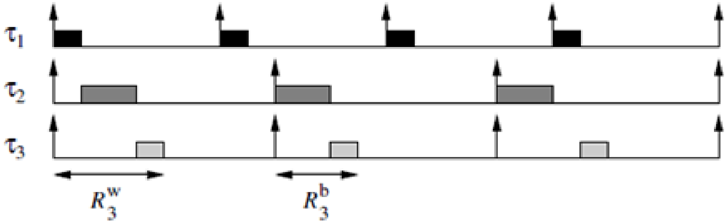
$$J_3 = R_3^w - R_3^b = 2$$



(d) Decreasing computation time c_2

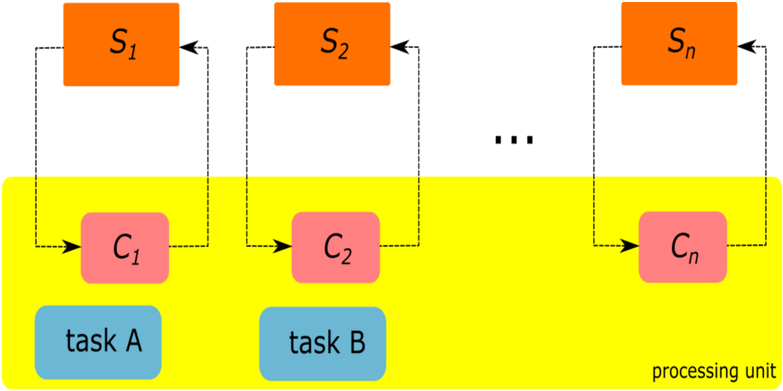
$$J_3 = R_3^w - R_3^b = 3$$



(e) Decreasing computation time c_1

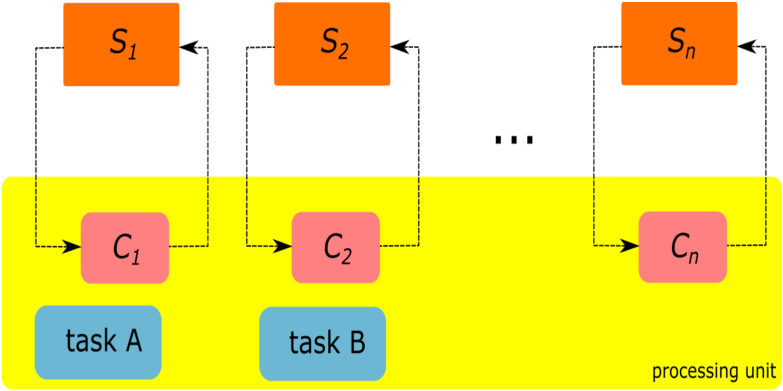
$$J_3 = R_3^w - R_3^b = 1$$

Butterfly Attack



❖ **Indirectly manipulate** **less critical tasks to** **increase jitter** **of a critical task and destabilize the physical system**

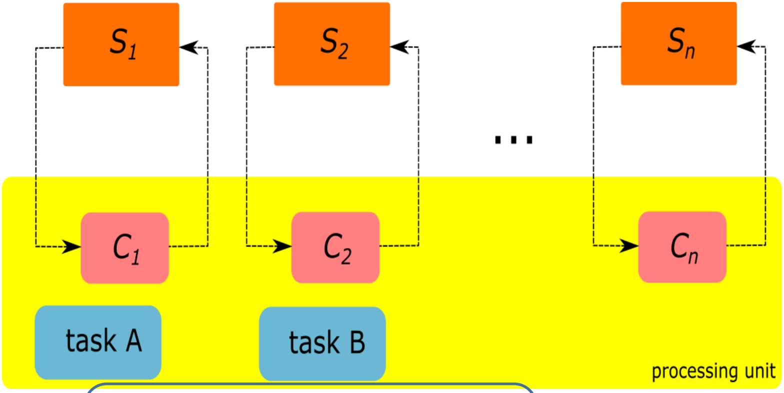
Butterfly Attack



Inter-dependency

- **Indirectly manipulate less critical tasks to increase jitter of a critical task and destabilize the physical system**

Butterfly Attack



Inter-dependency

Non-monotonicity

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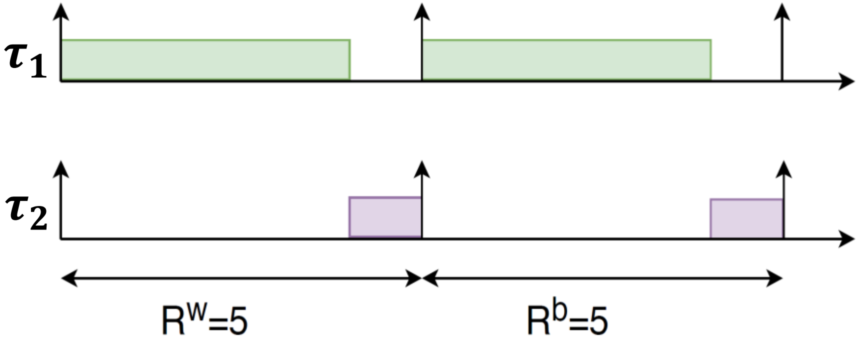
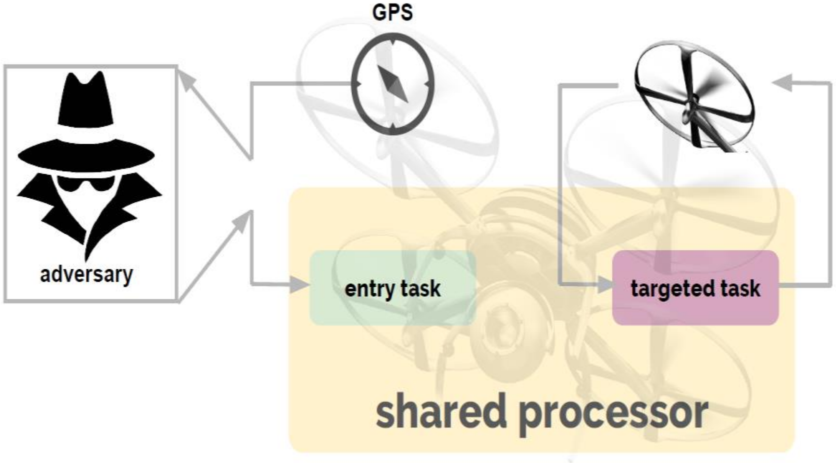
Experimental Results





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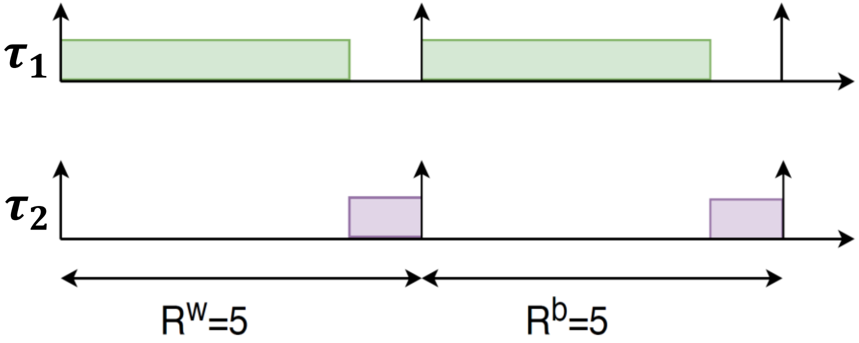
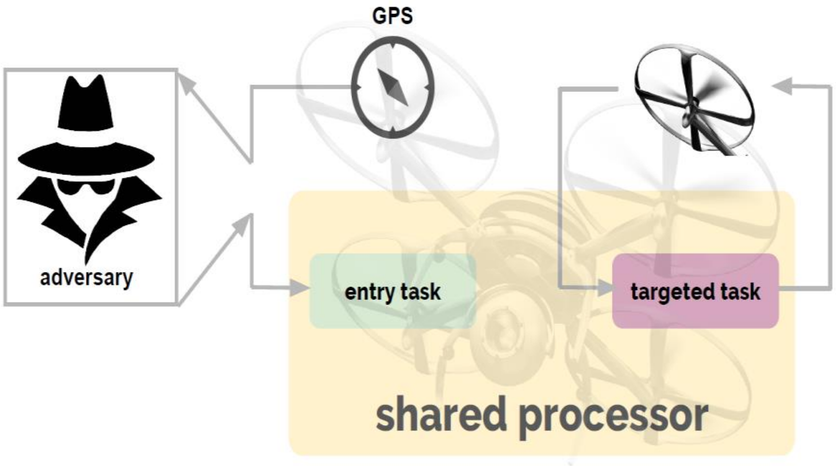
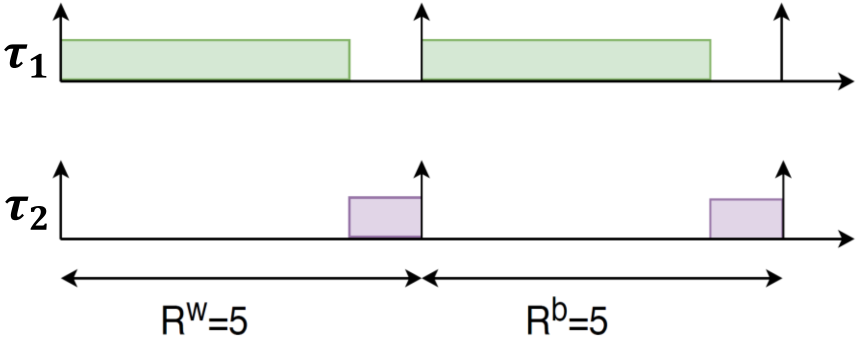




$$L_2 = 5,\ J_2 = R_2^w - R_2^b = 0$$

Experimental Results



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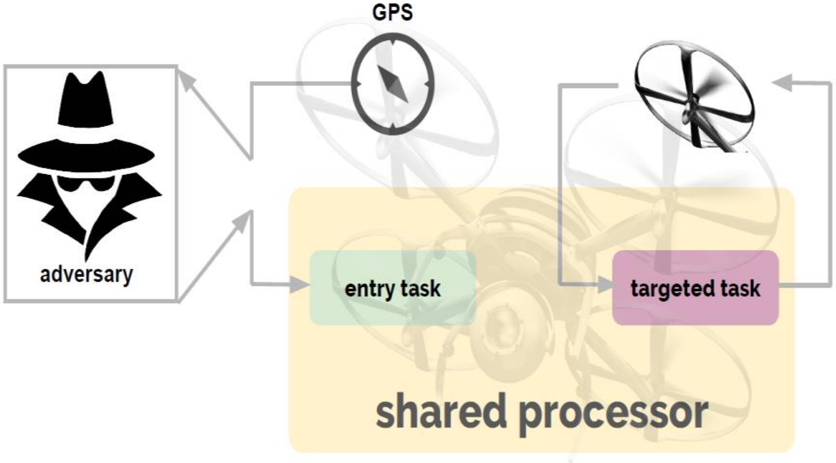

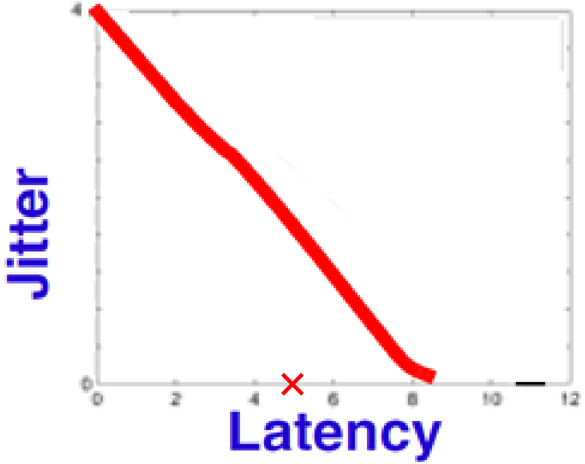

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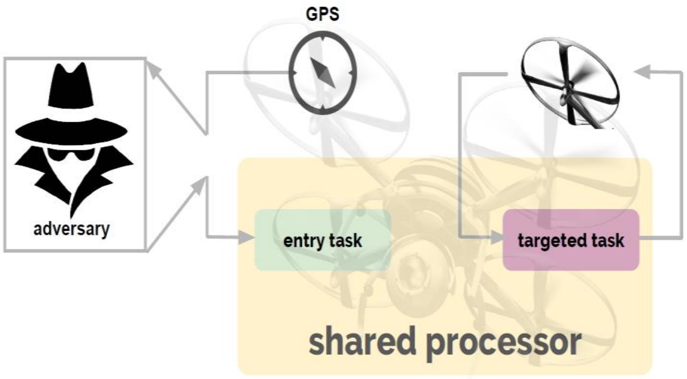
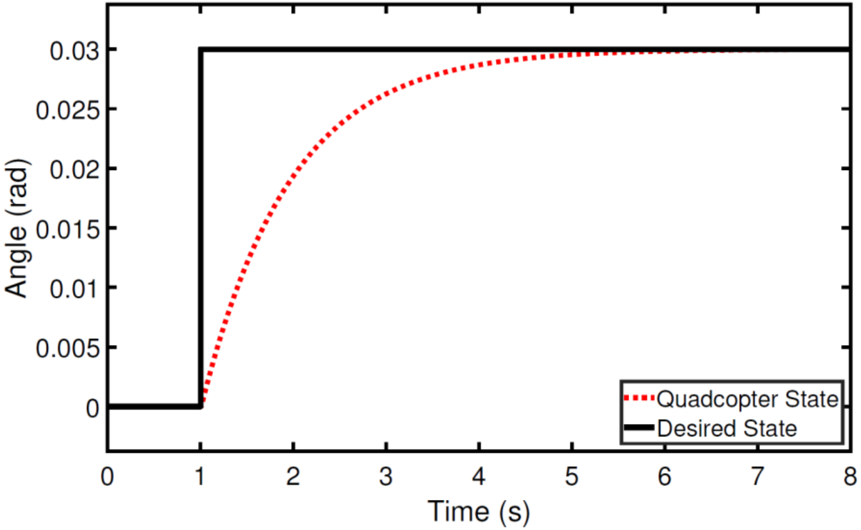
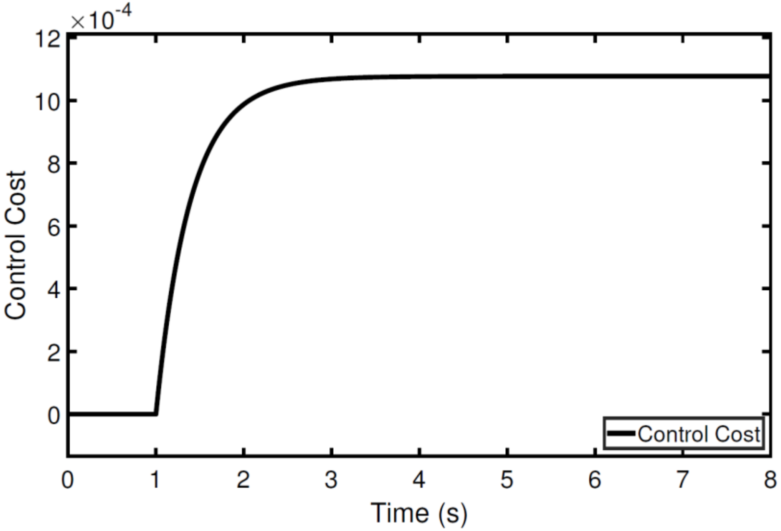


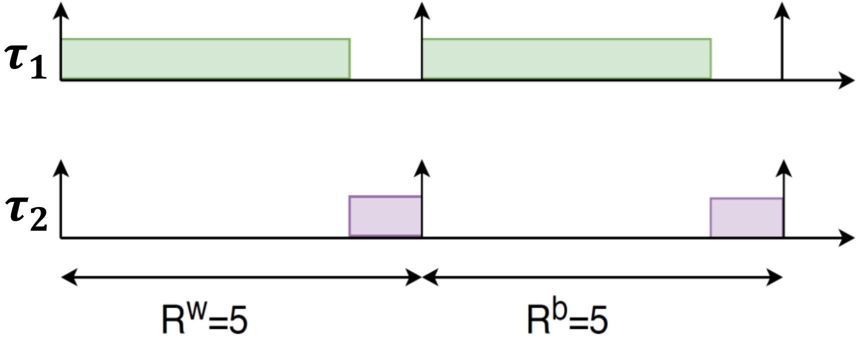


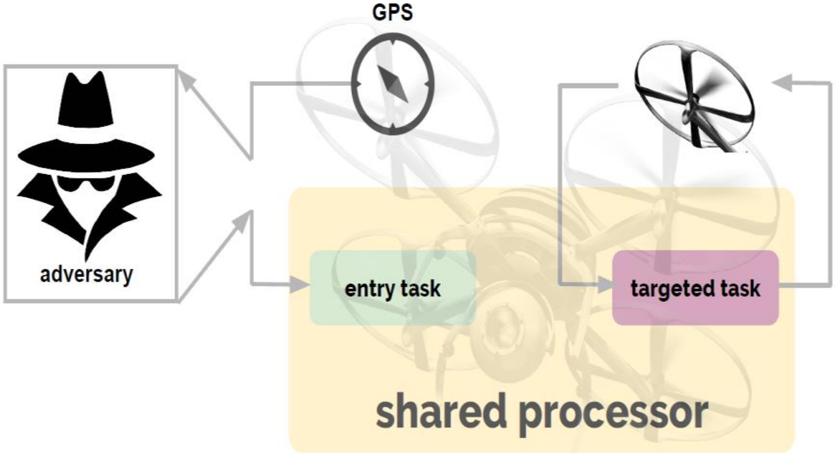
(a) Quadcopter vertical angle (stable).



(b) Quadcopter control cost (stable).

Experimental Results





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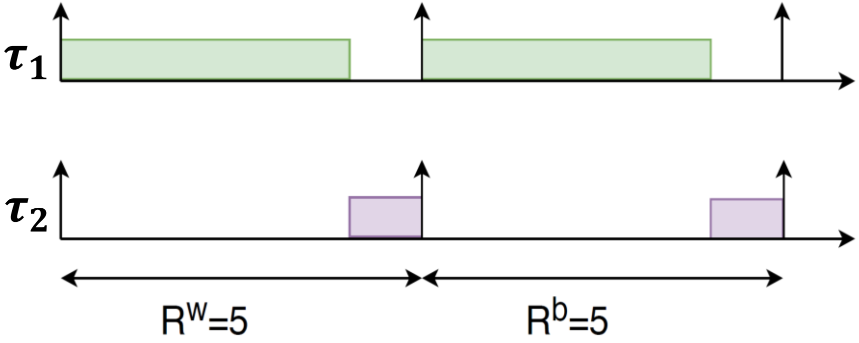

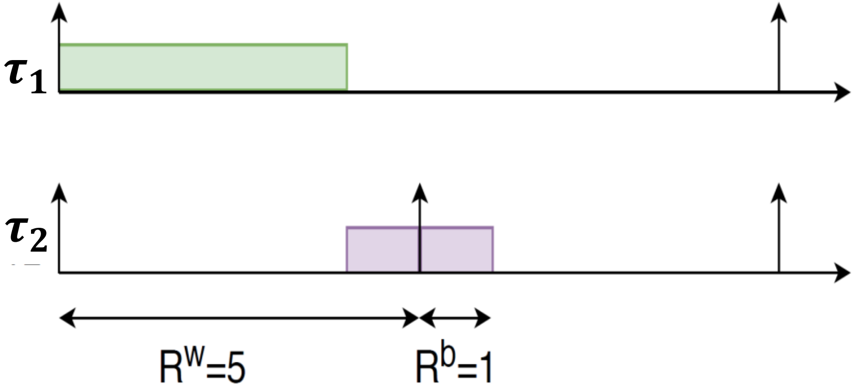

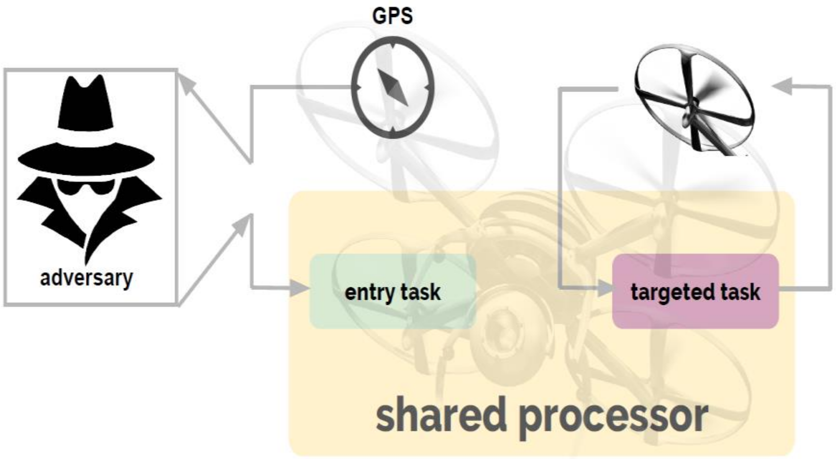

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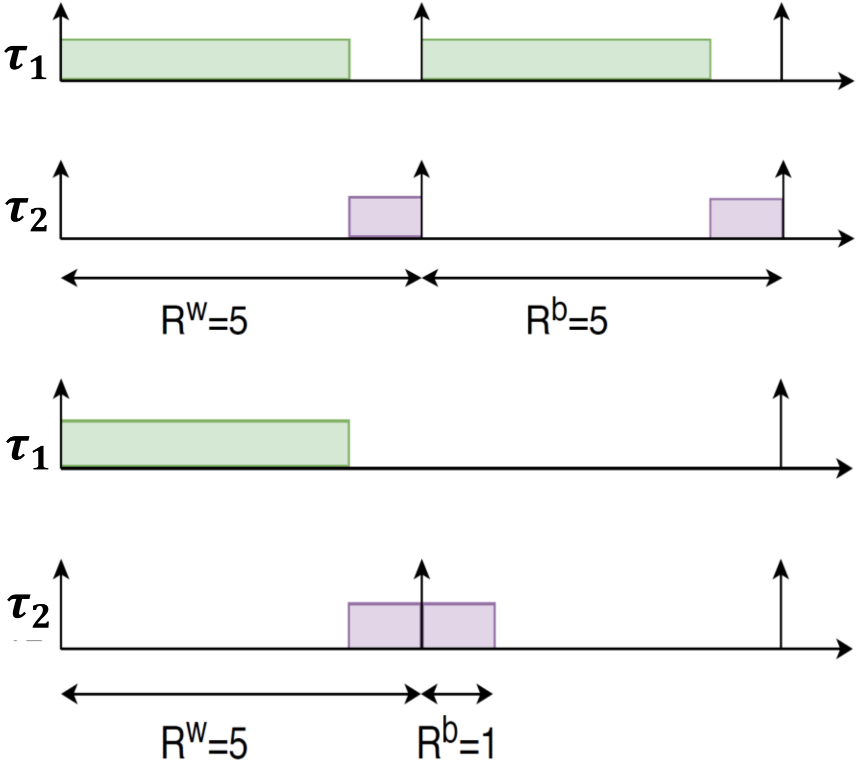
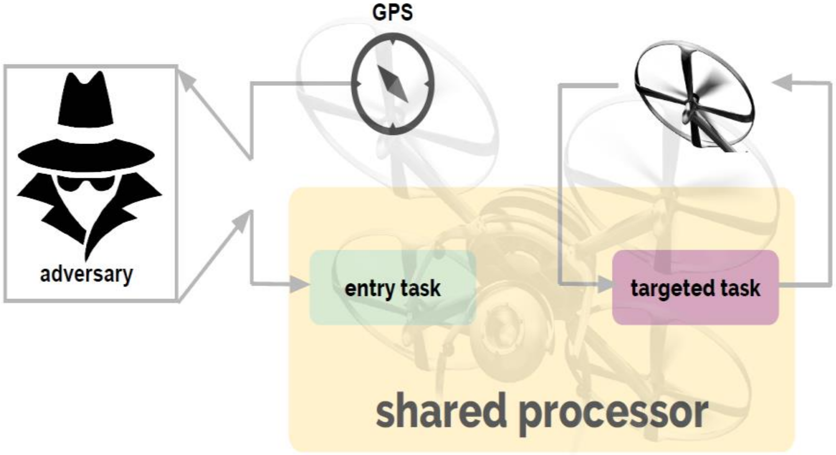
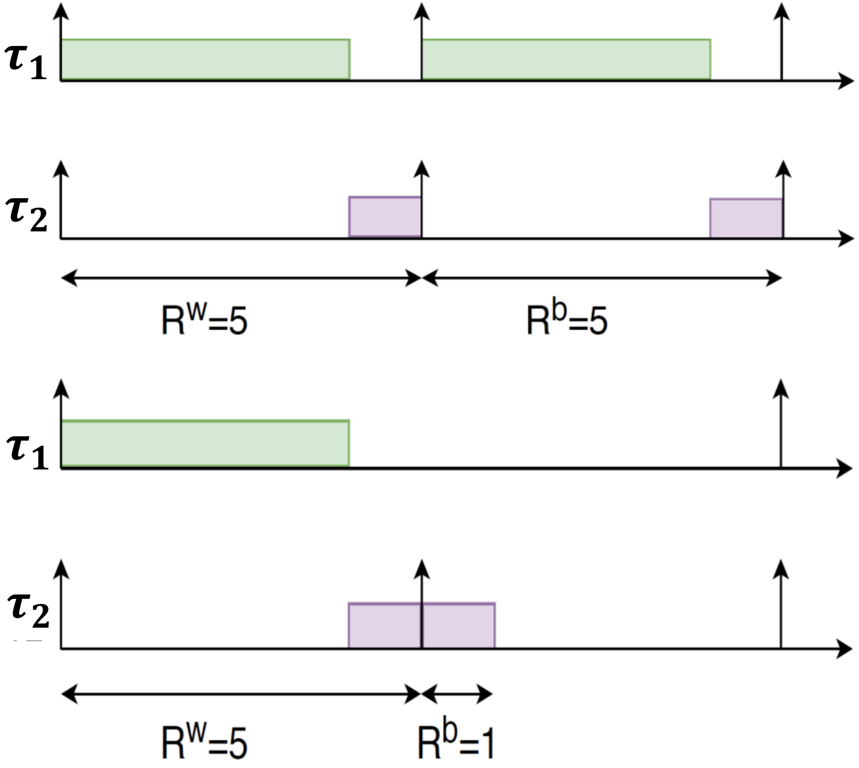




$$L_2 = 1,\ J_2 = R_2^w - R_2^b = 4$$

Experimental Results



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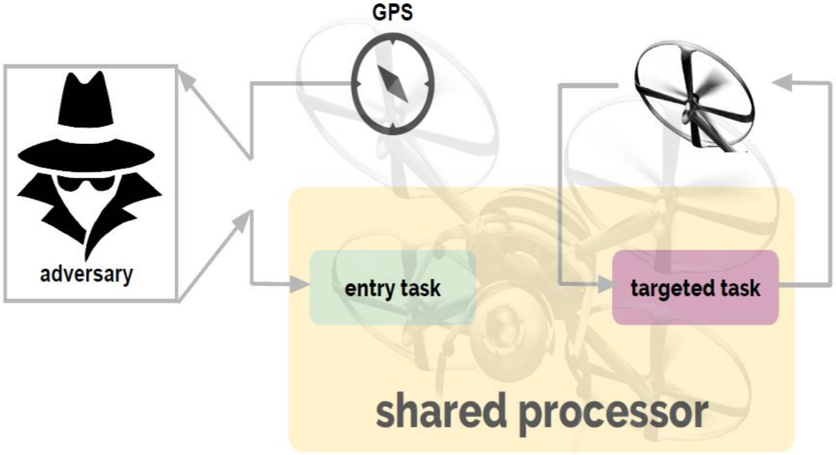

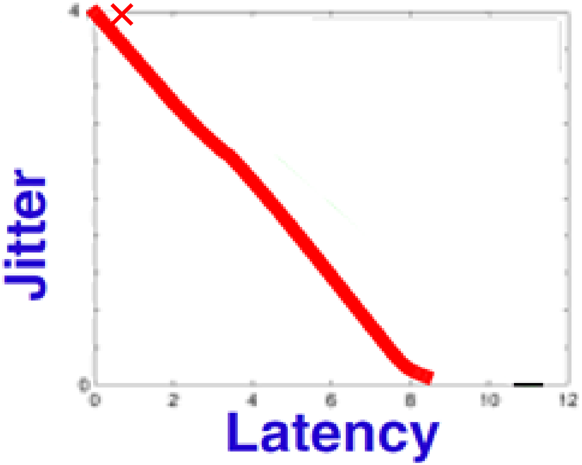

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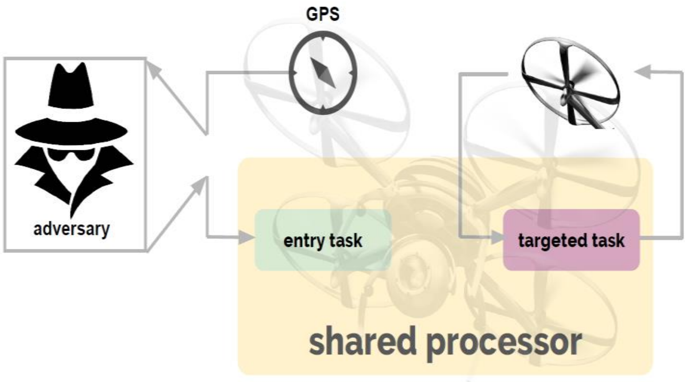
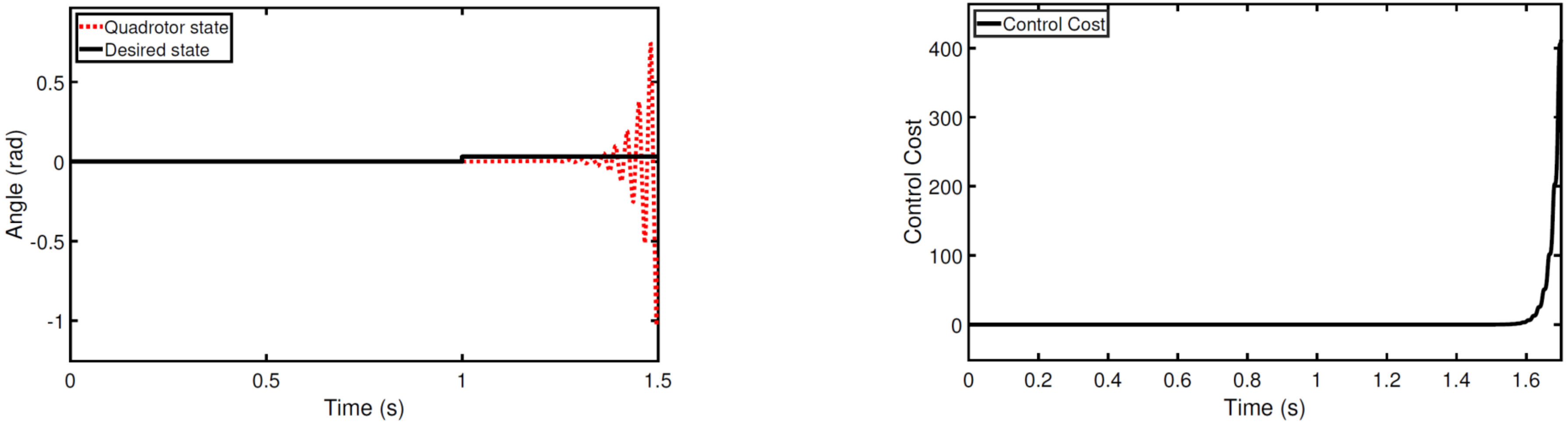




(a) Quadcopter vertical angle (unstable).

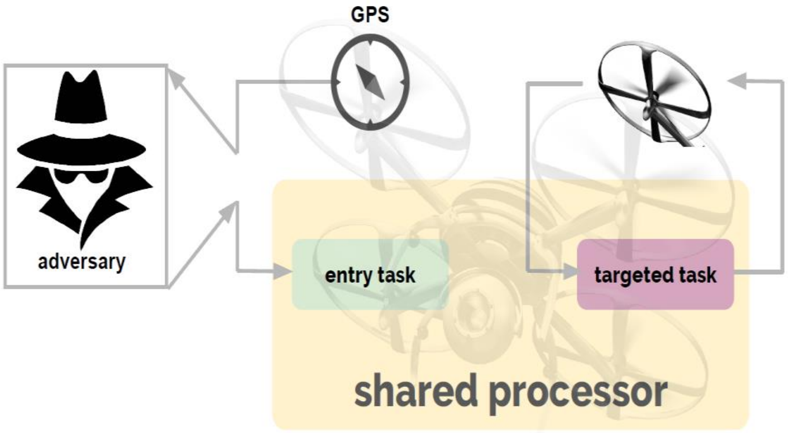
(b) Quadcopter control cost (unstable).

Butterfly attack

- Manipulating less critical (protected) task

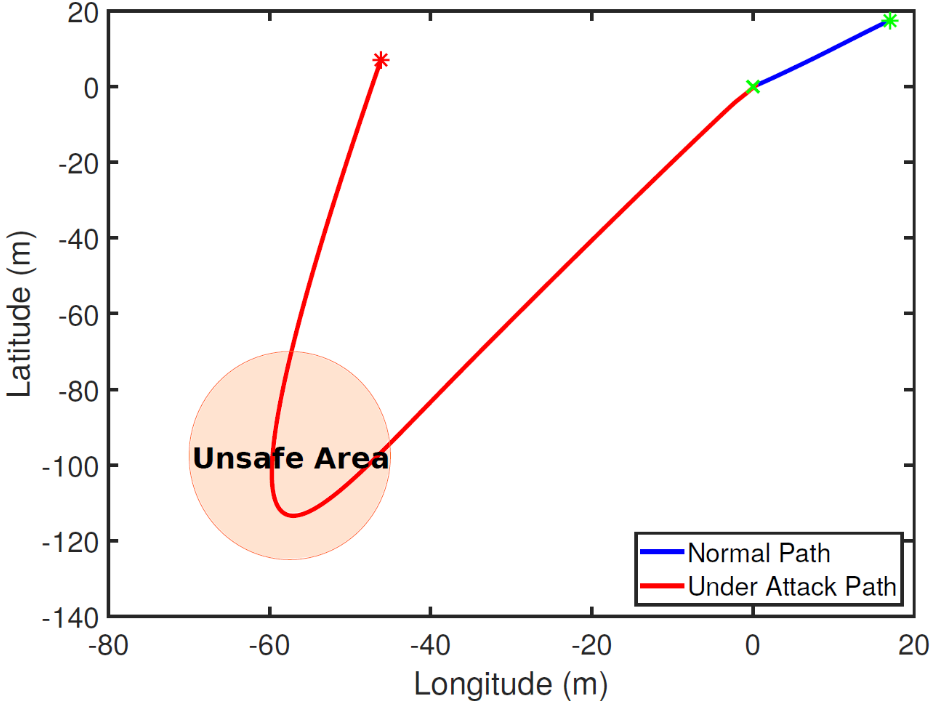
- Increase the available resource

- Difficult to detect attacker



Beyond Butterfly attack

- **Hijack the drone using Butterfly attack**
- **Launch the attack for short time**
- **Needs some extra knowledge**
- **Unpredicted results**



Mitigation

- Run a dummy task to compensate
- Design a robust controller
- Ensure temporal isolation using servers

Conclusion

- **Introduction to Butterfly attack**
- **Identify Inter-dependency and Non-monotonicity**
- **Demonstrate the possibility of attack experimentally**

Questions