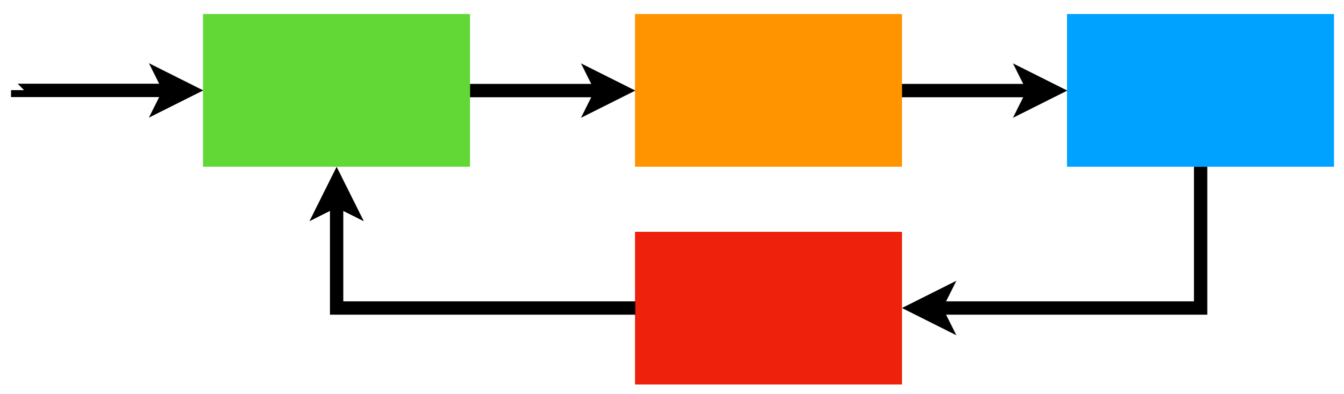
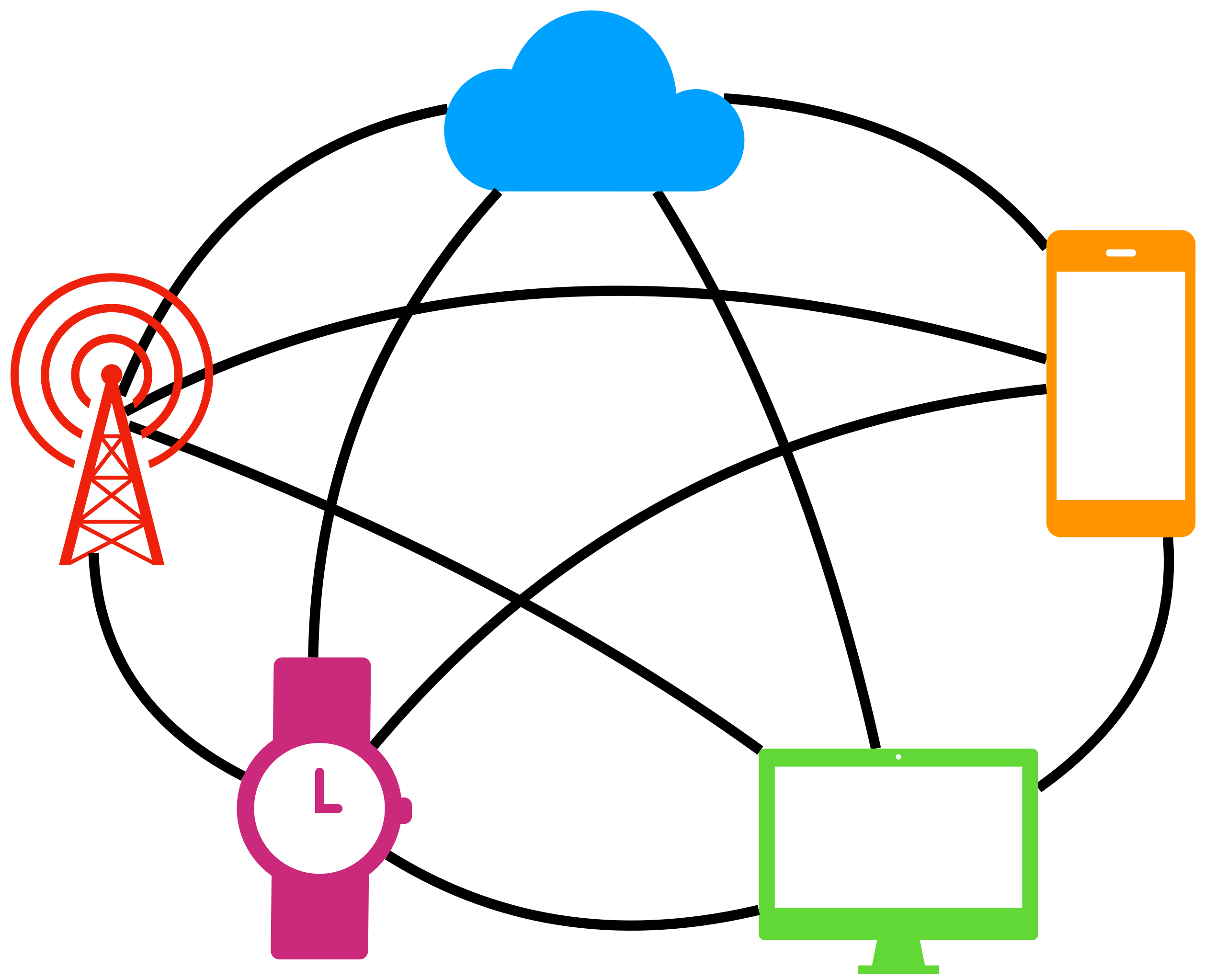
Packet Priority Assignment for Wireless Control Systems of Multiple Physical Systems

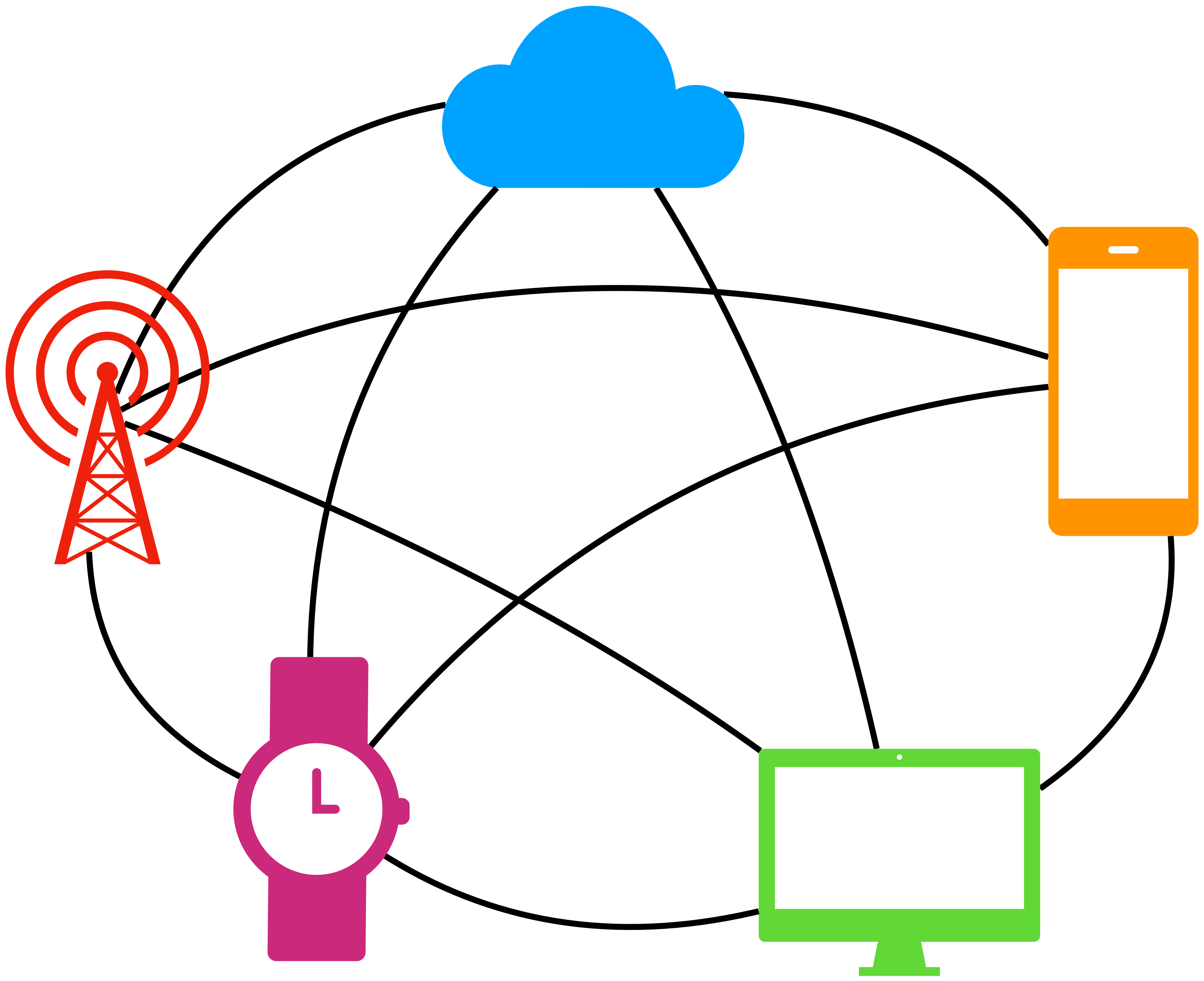
Wenchen Wang, Daniel Mosse, and Alessandro V. Papadopoulos



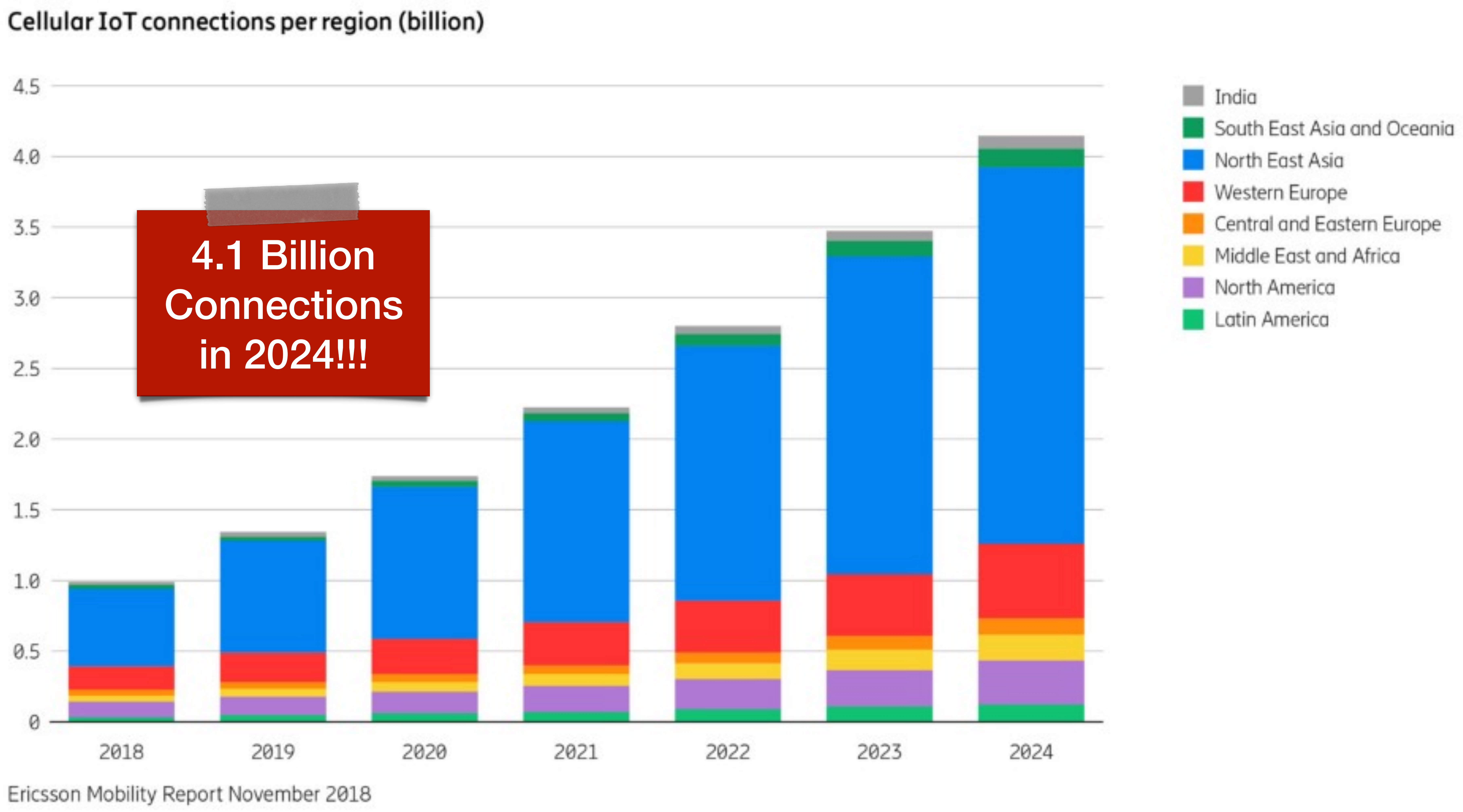


May 8th, 2019 @ISORC, Valencia, Spain

Interconnected World
Made of Computing Systems



IoT Connections



Whoops, something went wrong...

Netflix Streaming Error

We're having trouble playing this title right now. Please try again later or select a different title.

Photo-illustration: iStockphoto


Autonomous
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CAR
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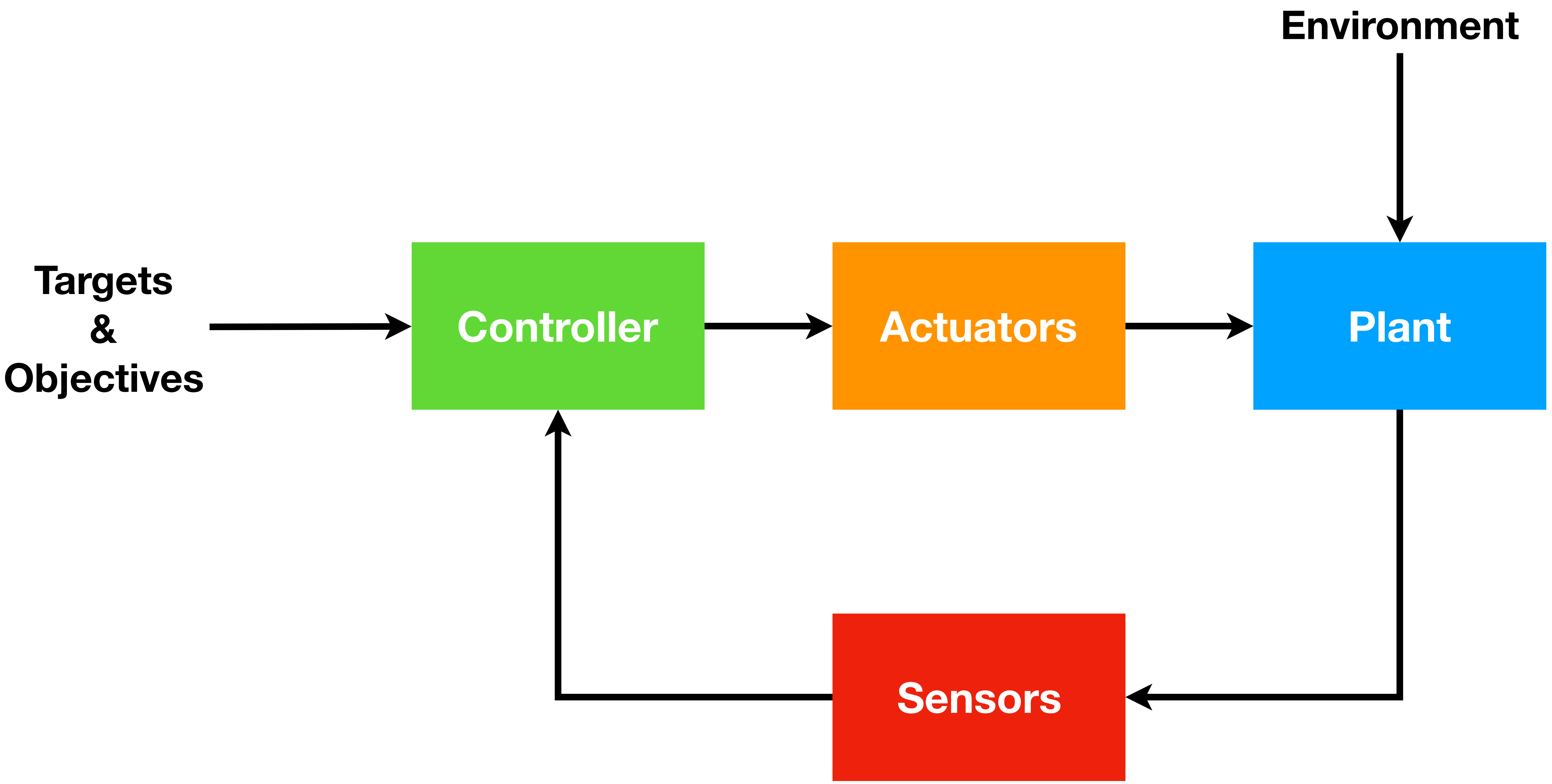
FOUND
Photo-illustration: iStockphoto

Wired Control System



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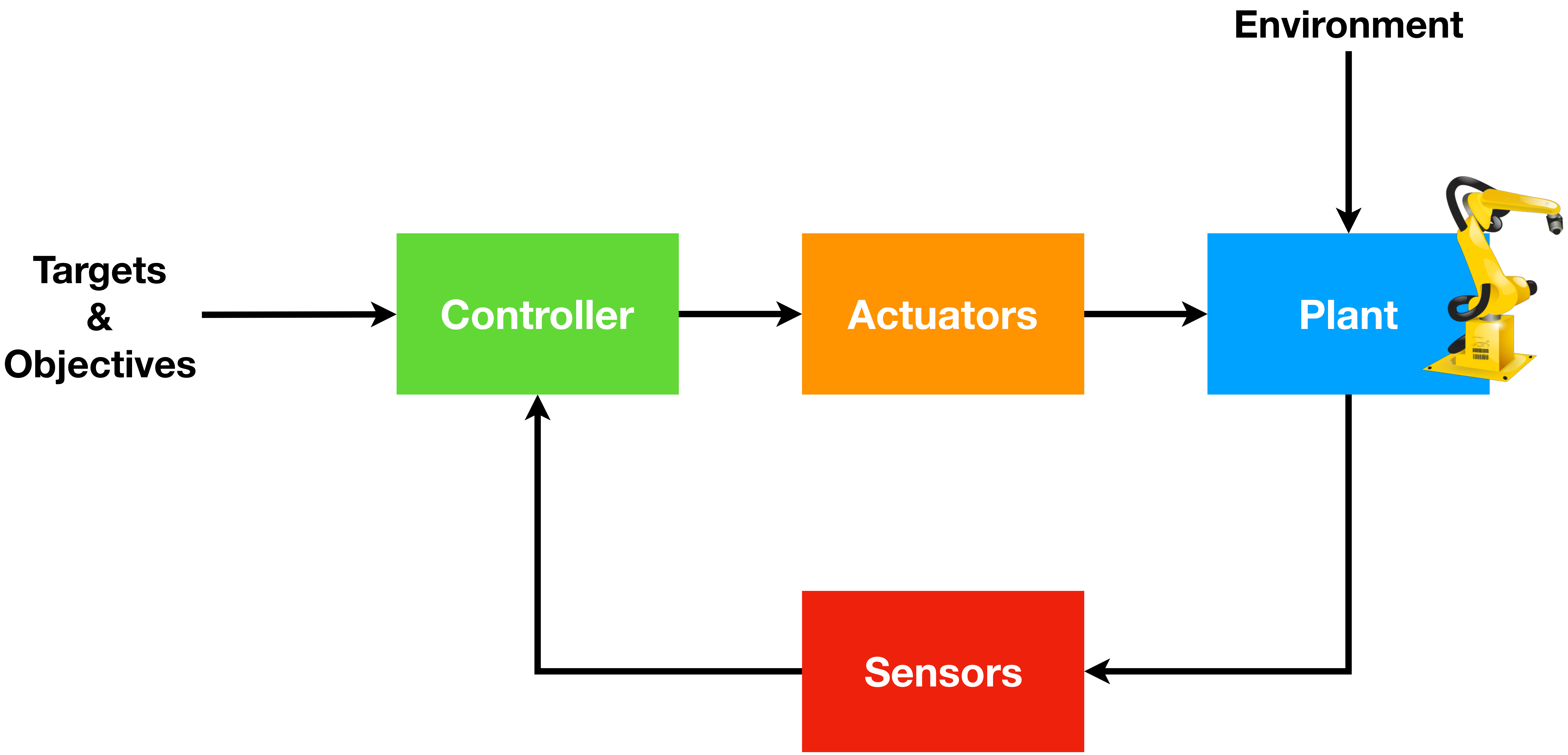

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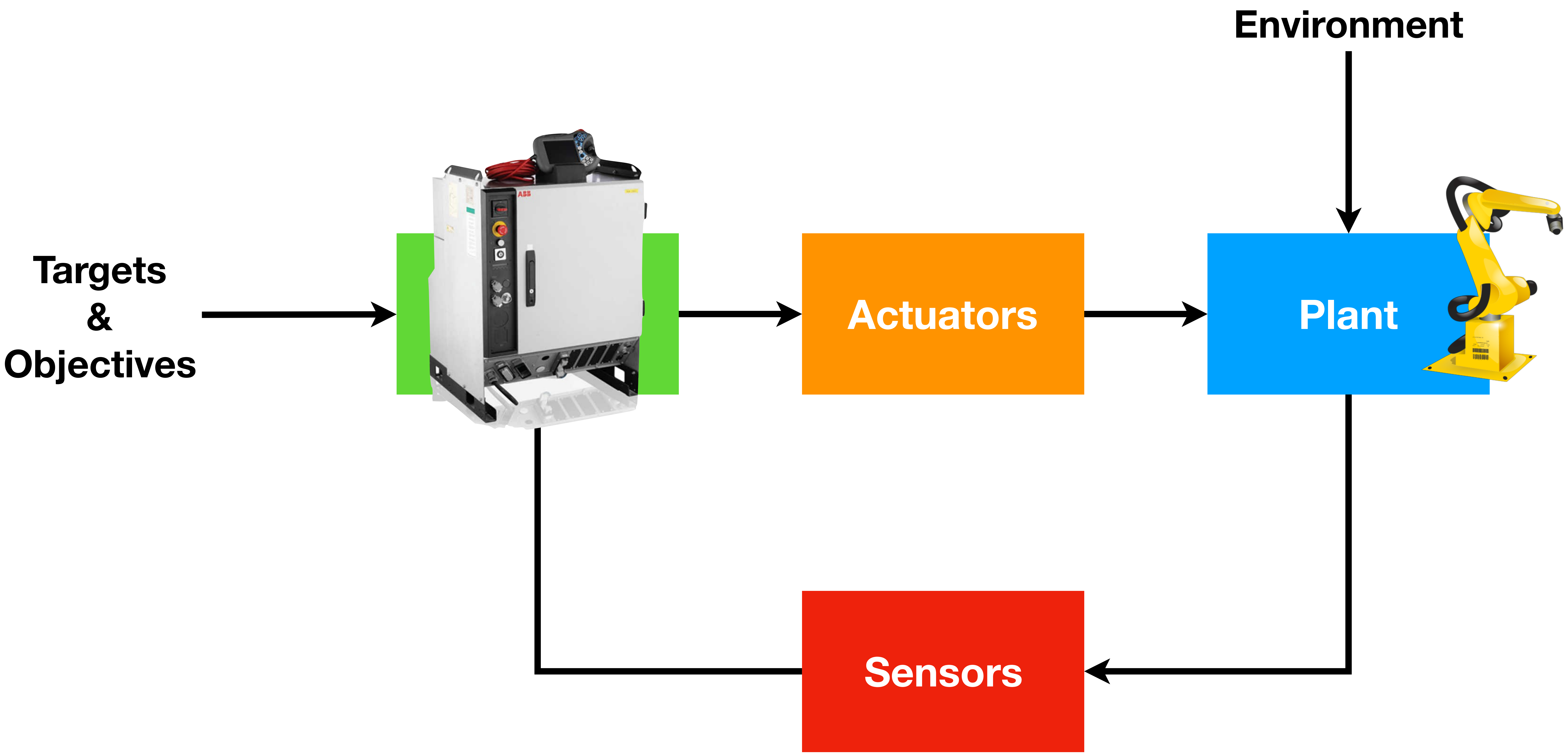

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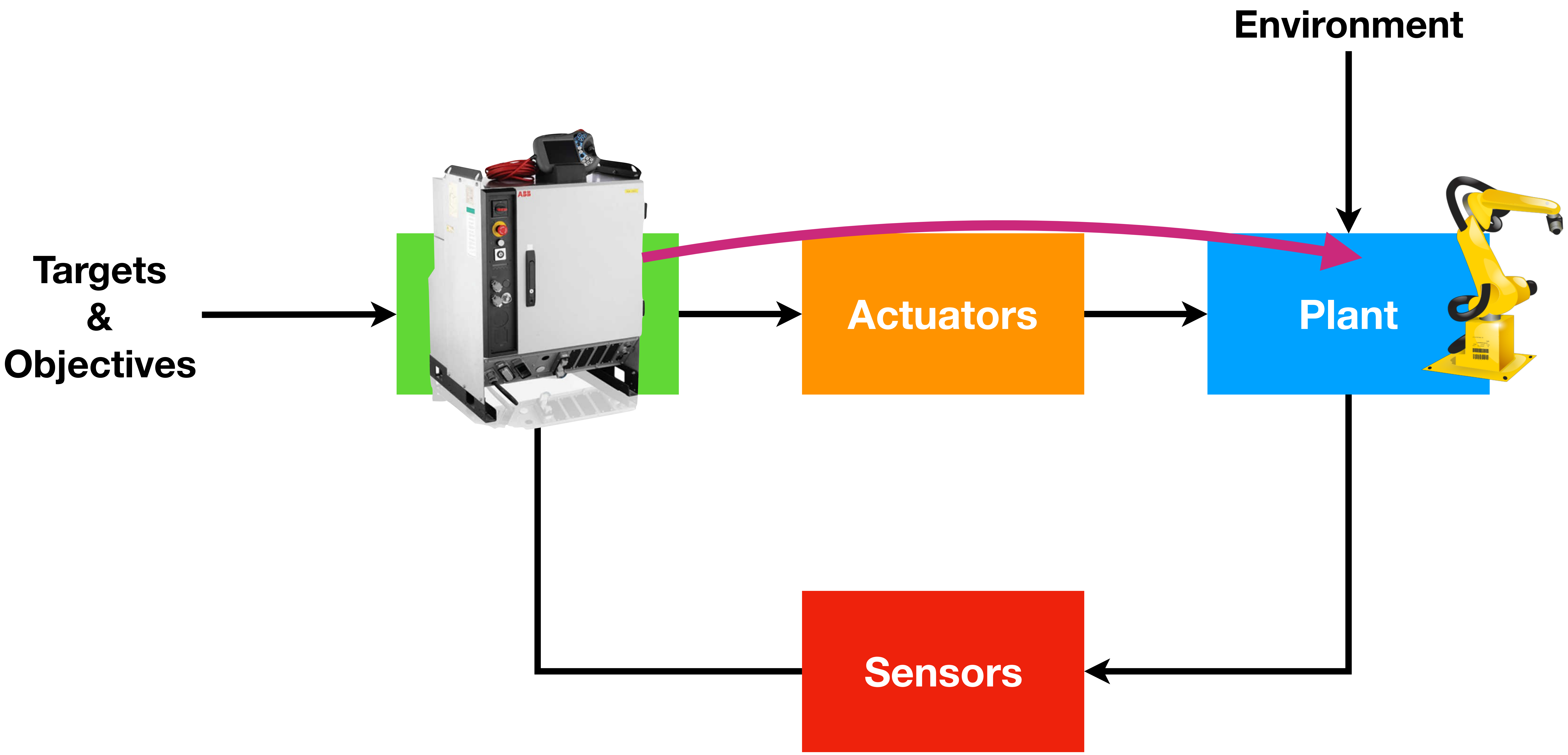

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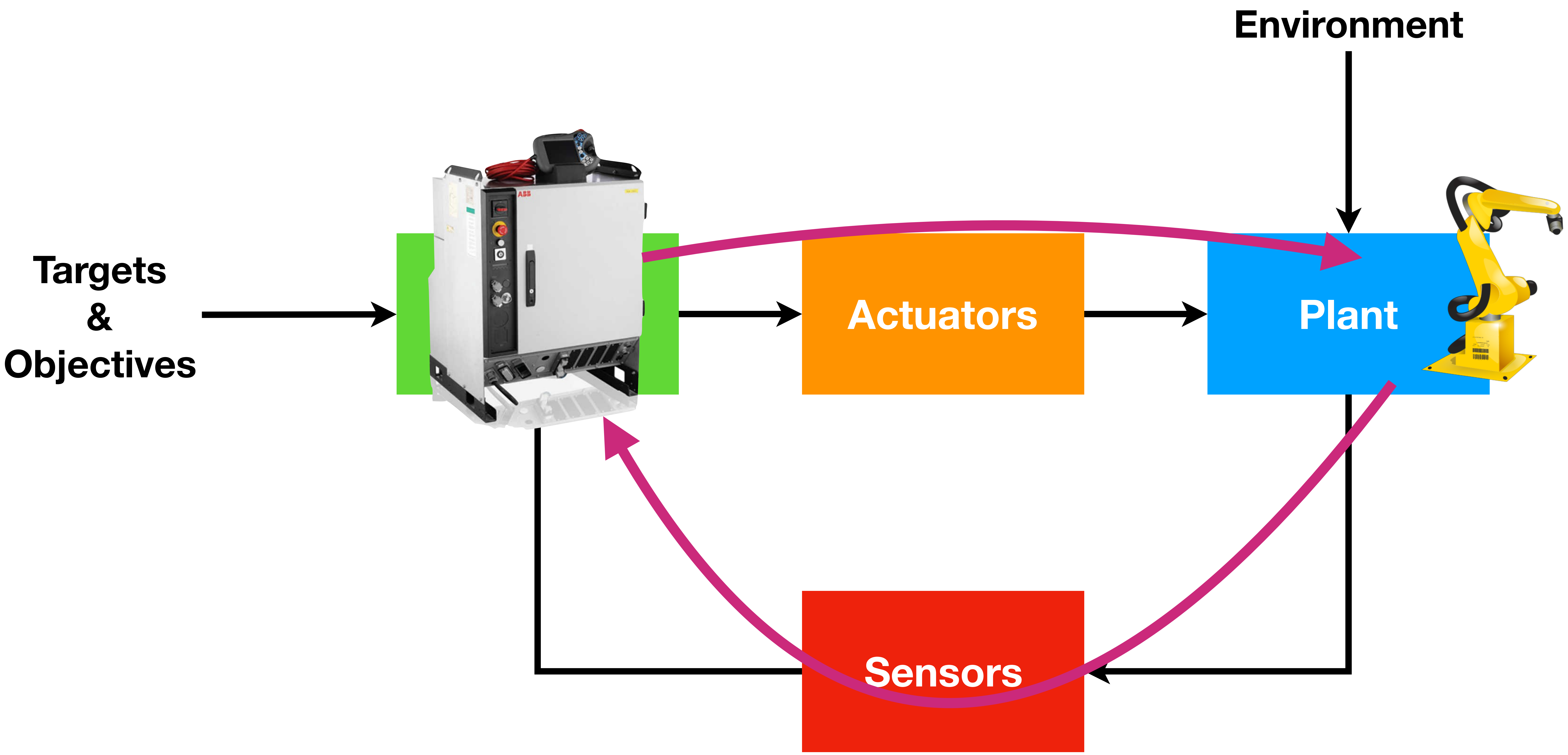

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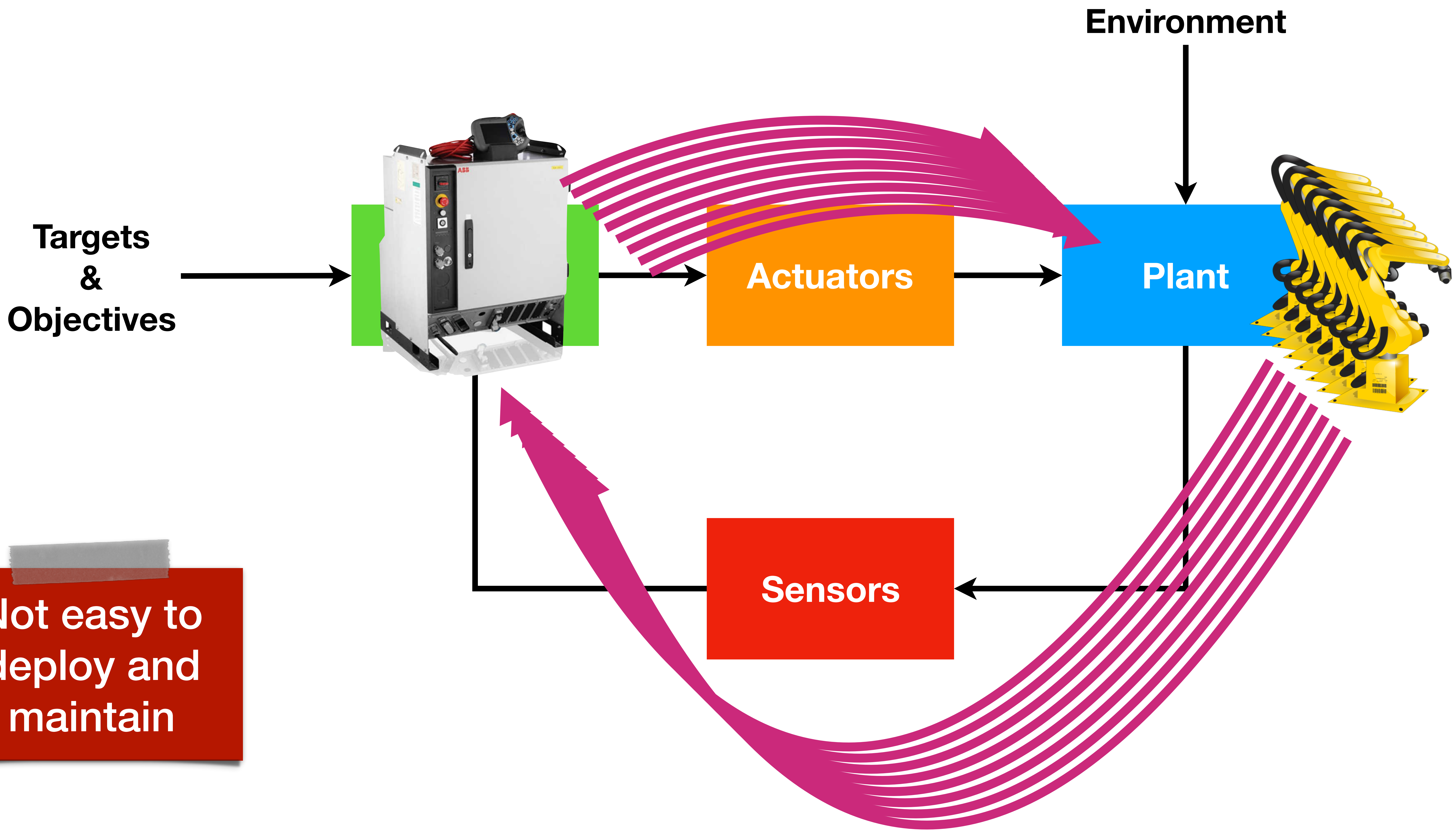
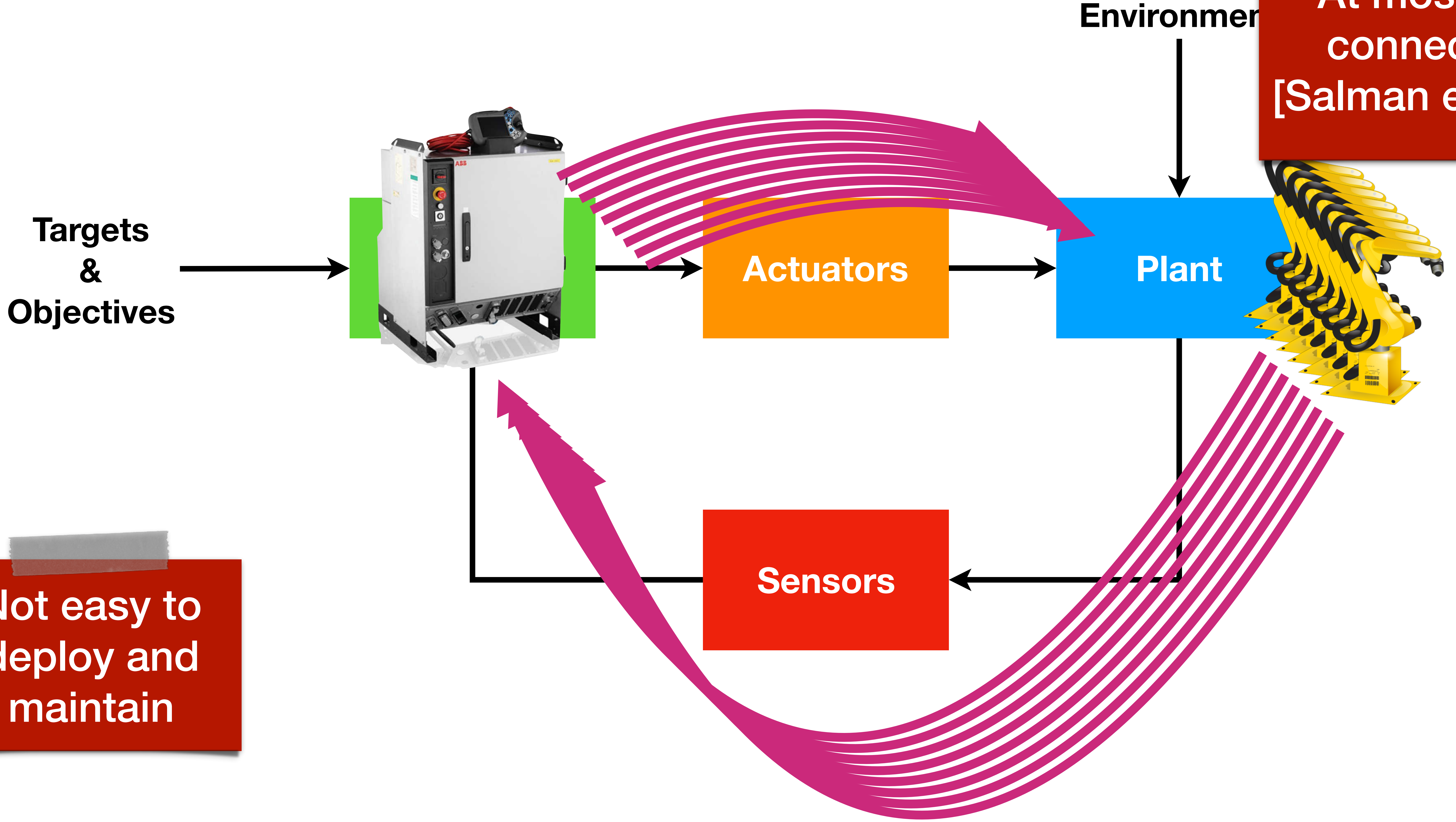


Not easy to deploy and maintain

Wired Control System



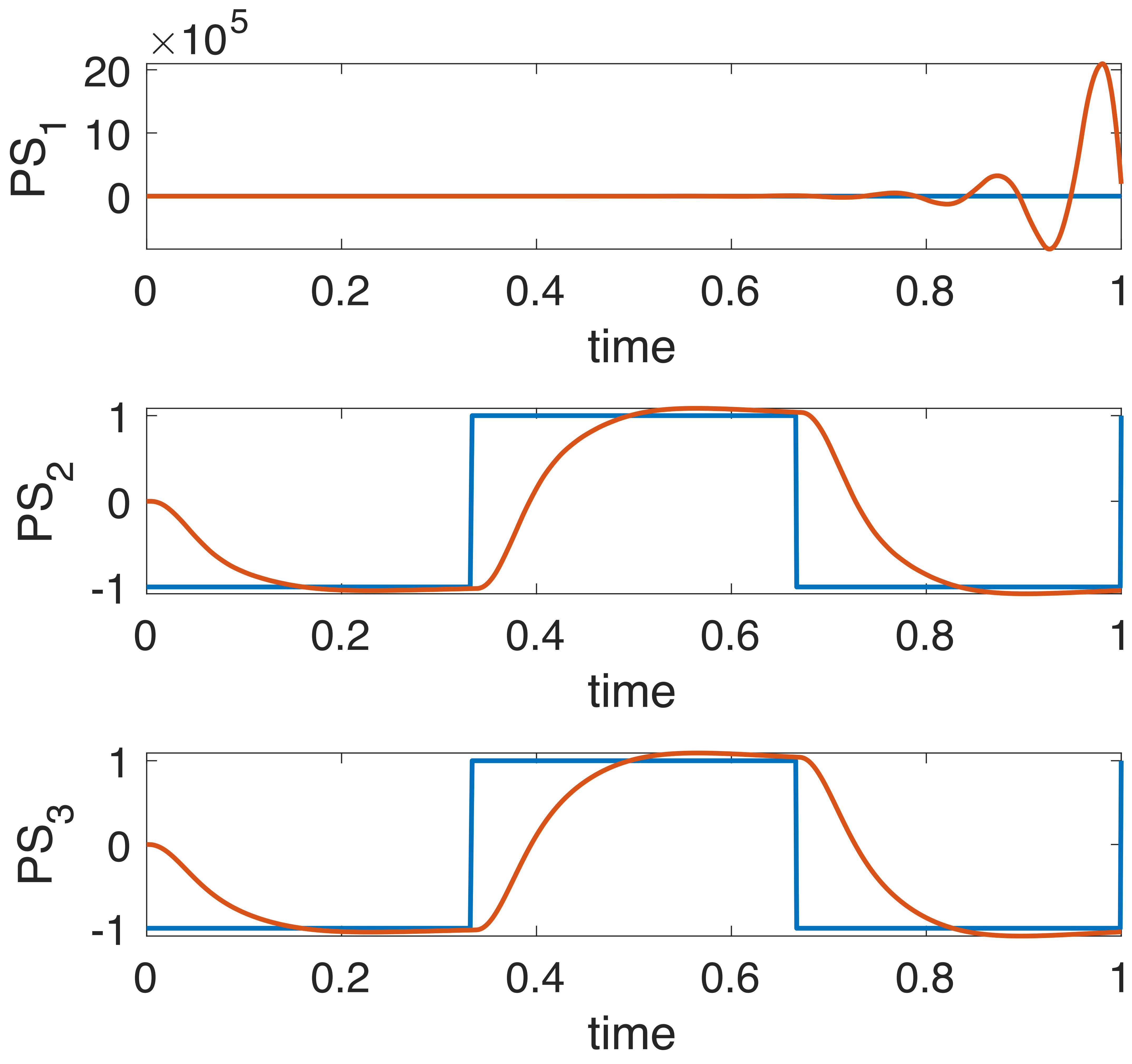
At most 4 robots can be connected to 1 cabinet [Salman et al., Fog-IoT 2019]

Not easy to deploy and maintain

Wireless Control System (WCS)

Major Challenges of WCS

- **Instability**
  - When the physical system is unstable, the plant or the device can be damaged and leads to serious safety issues and financial loss.
- **Performance Degradation**
  - Induced additional error
    - **Network-induced error**



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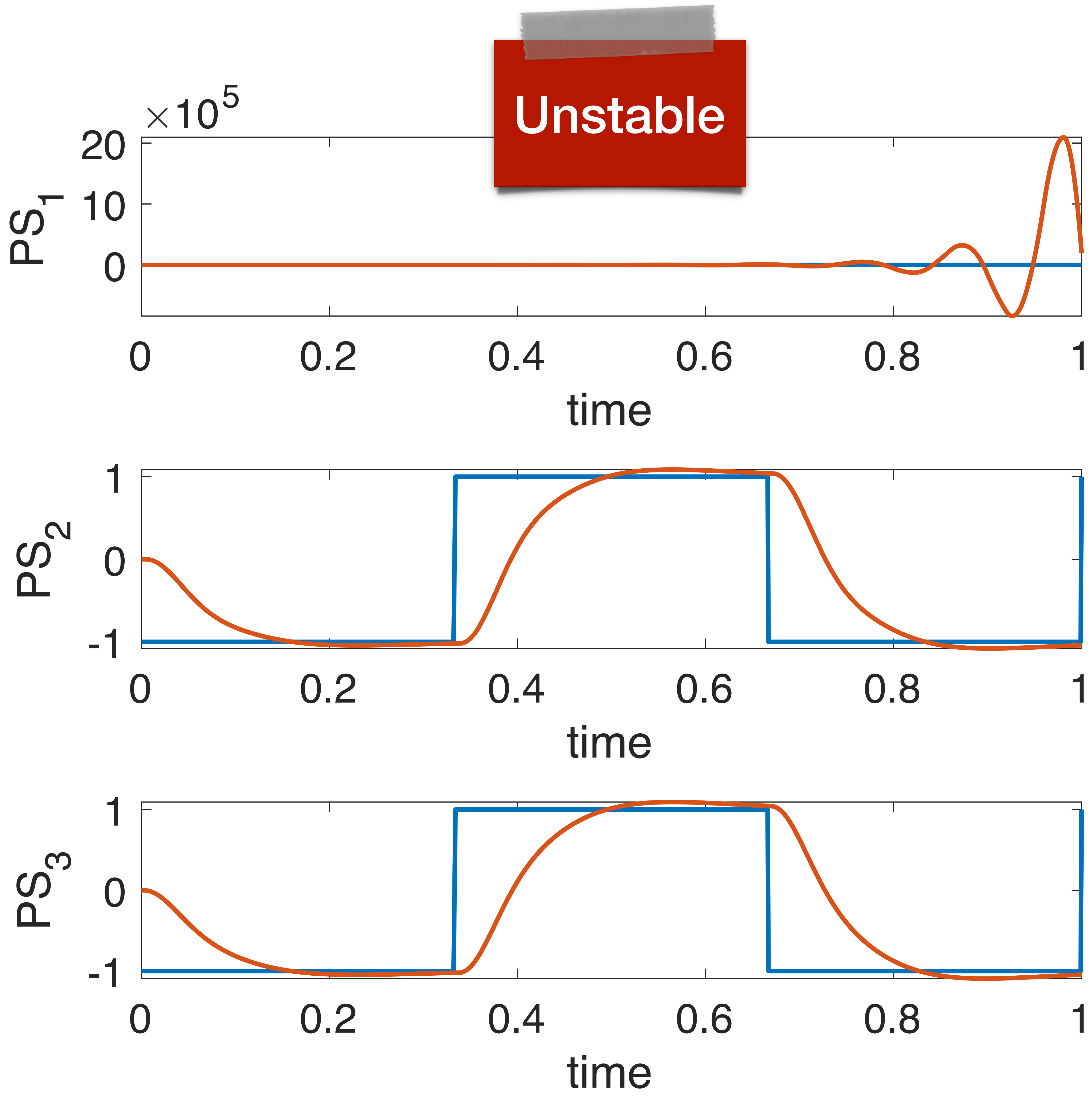

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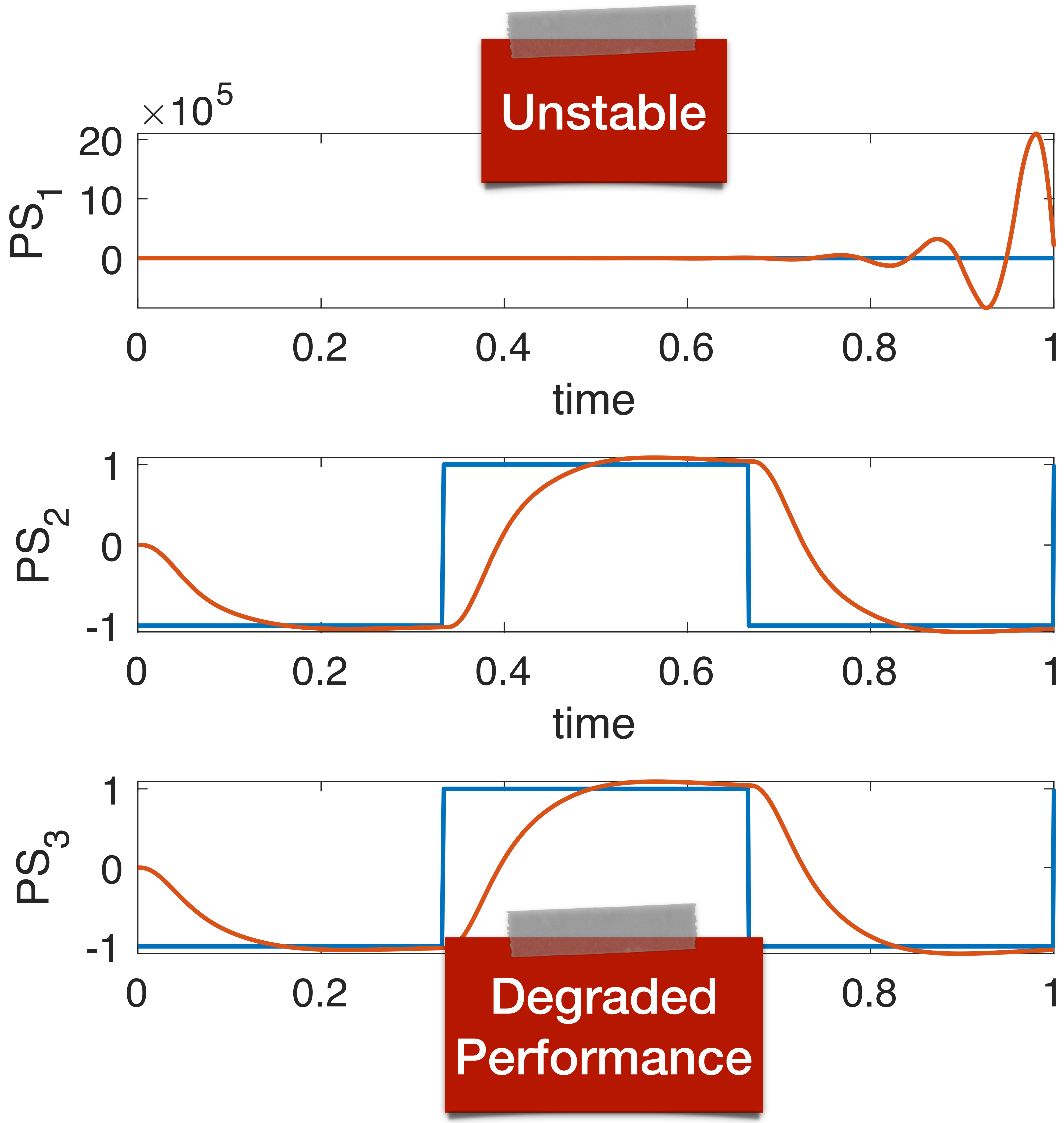
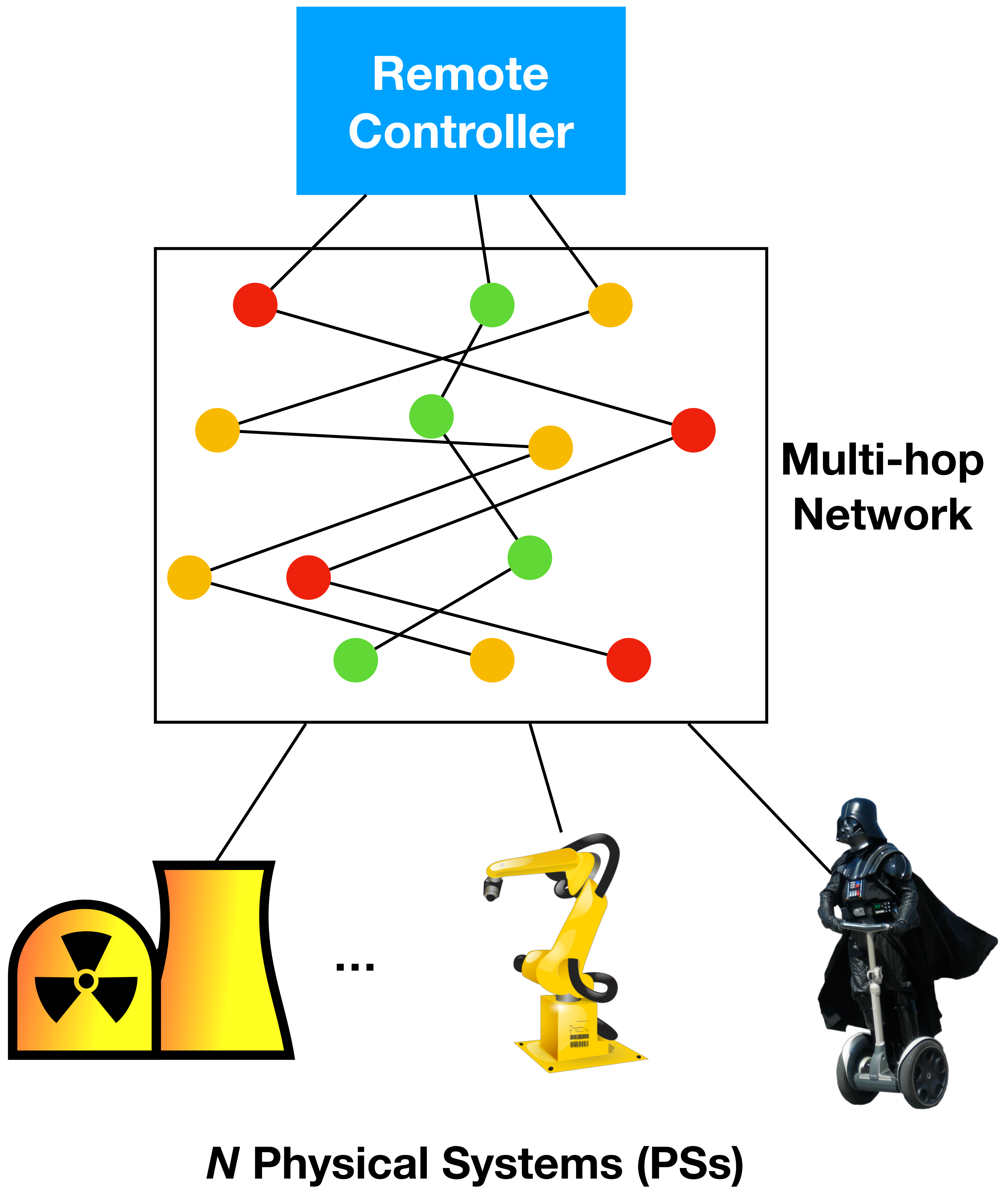


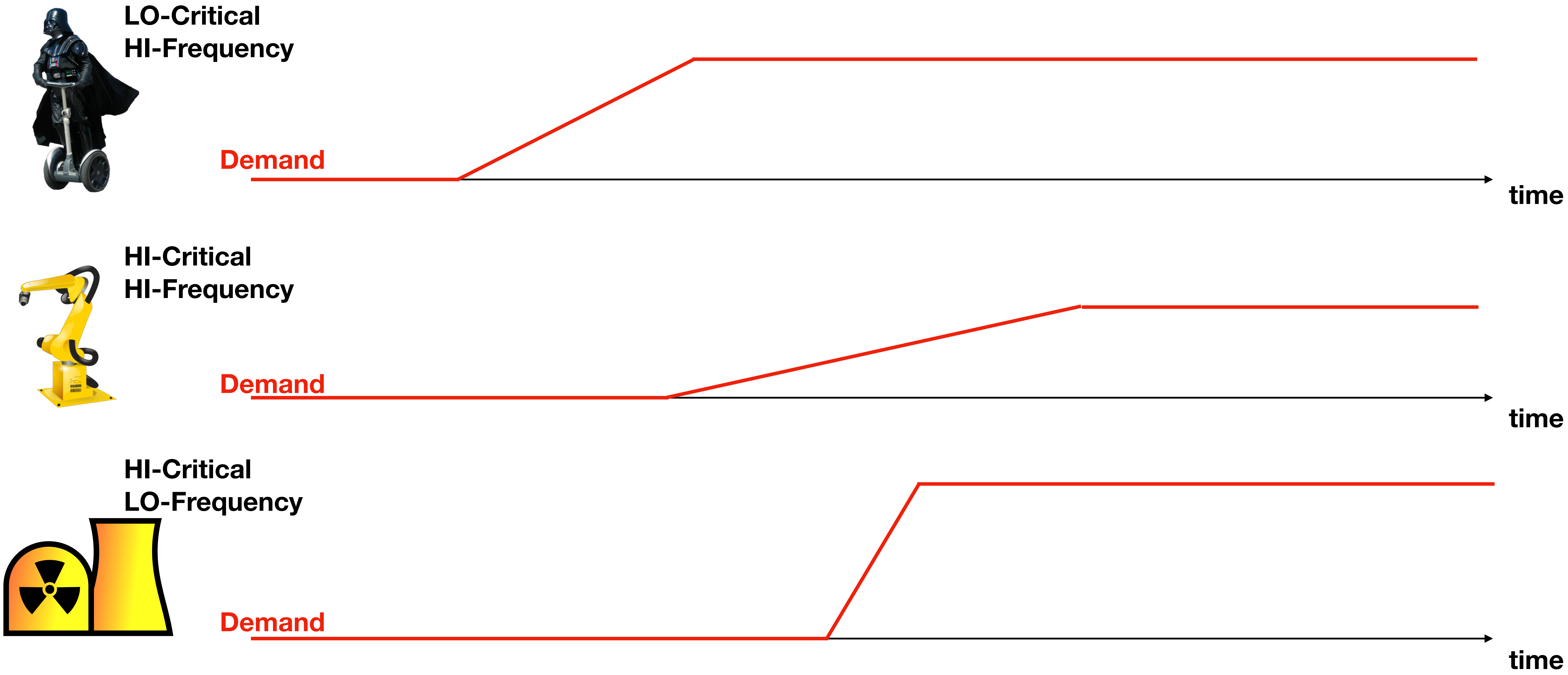
Problem Formulation

- Shared multi-hop network
  - Different paths $p\_1, p\_2, \ldots, p\_m$
  - Each path with delay D_j
  - TDMA fixed topology
  - Time-varying delivery ratio dr_j



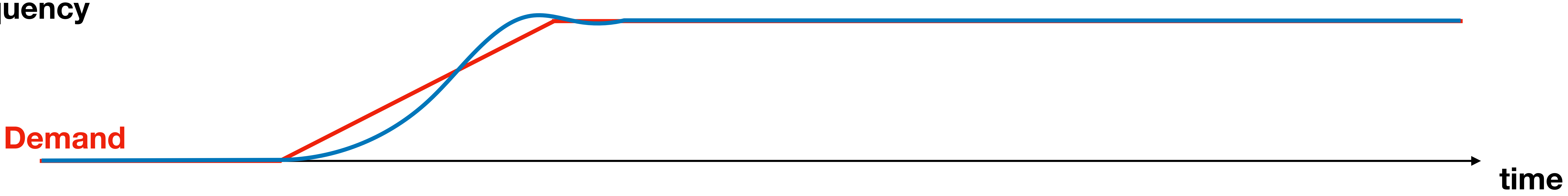
Dynamic network reconfiguration in [Wang, RTNS 2018]

Different Requirements, Shared Network



Different Requirements, Shared Network

LO-Critical
HI-Frequency



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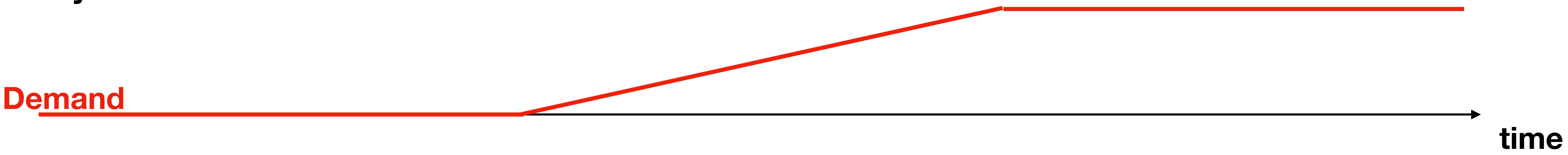

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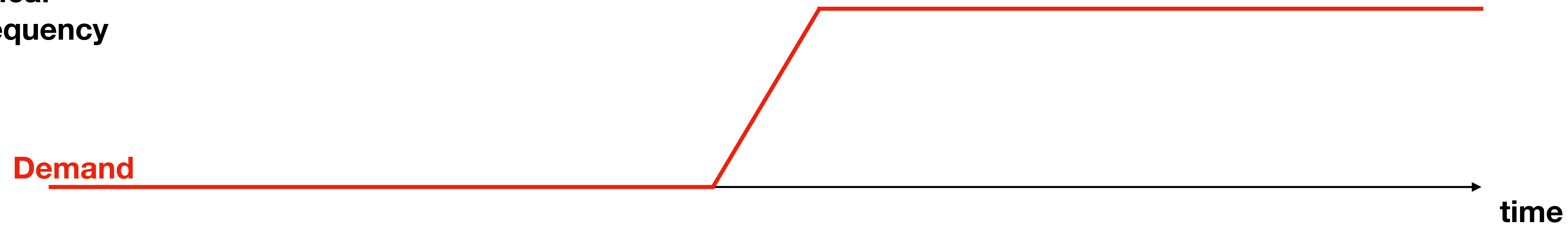

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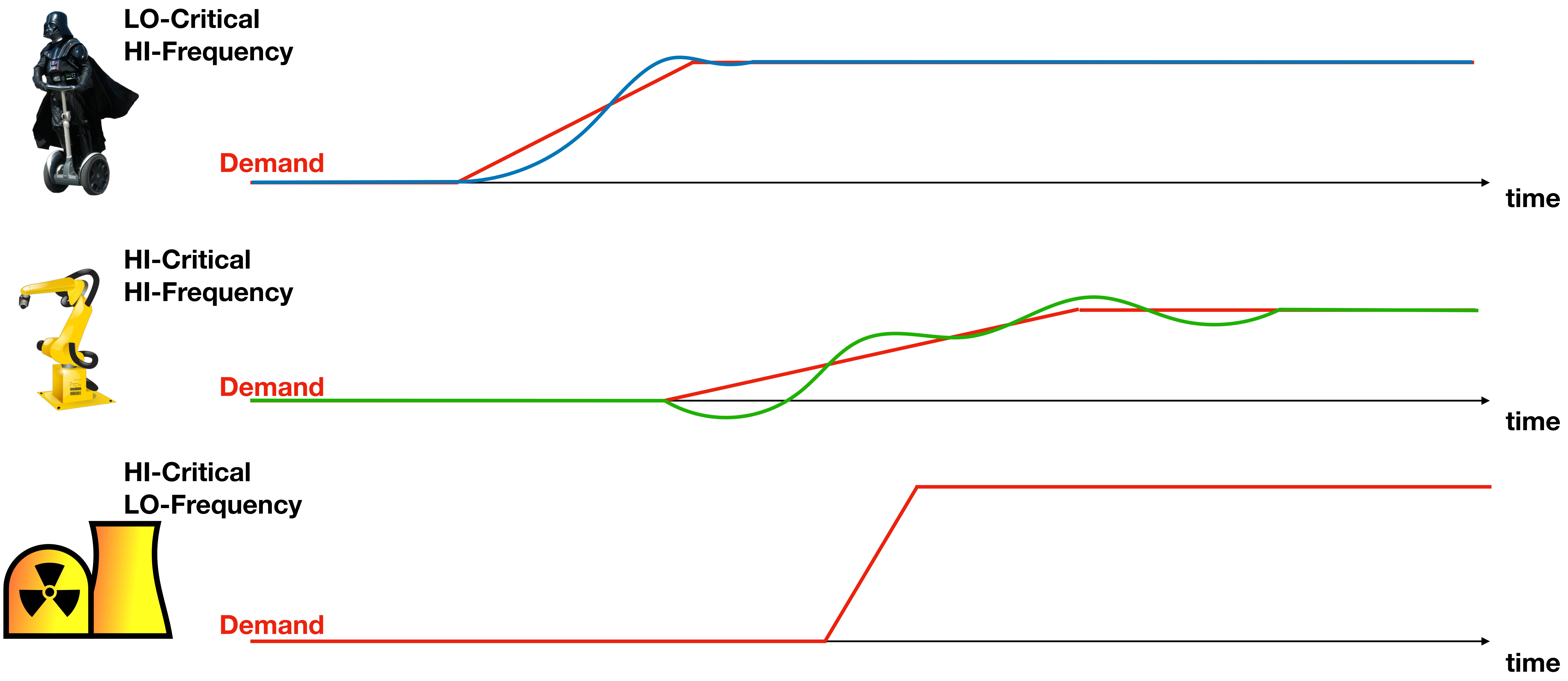

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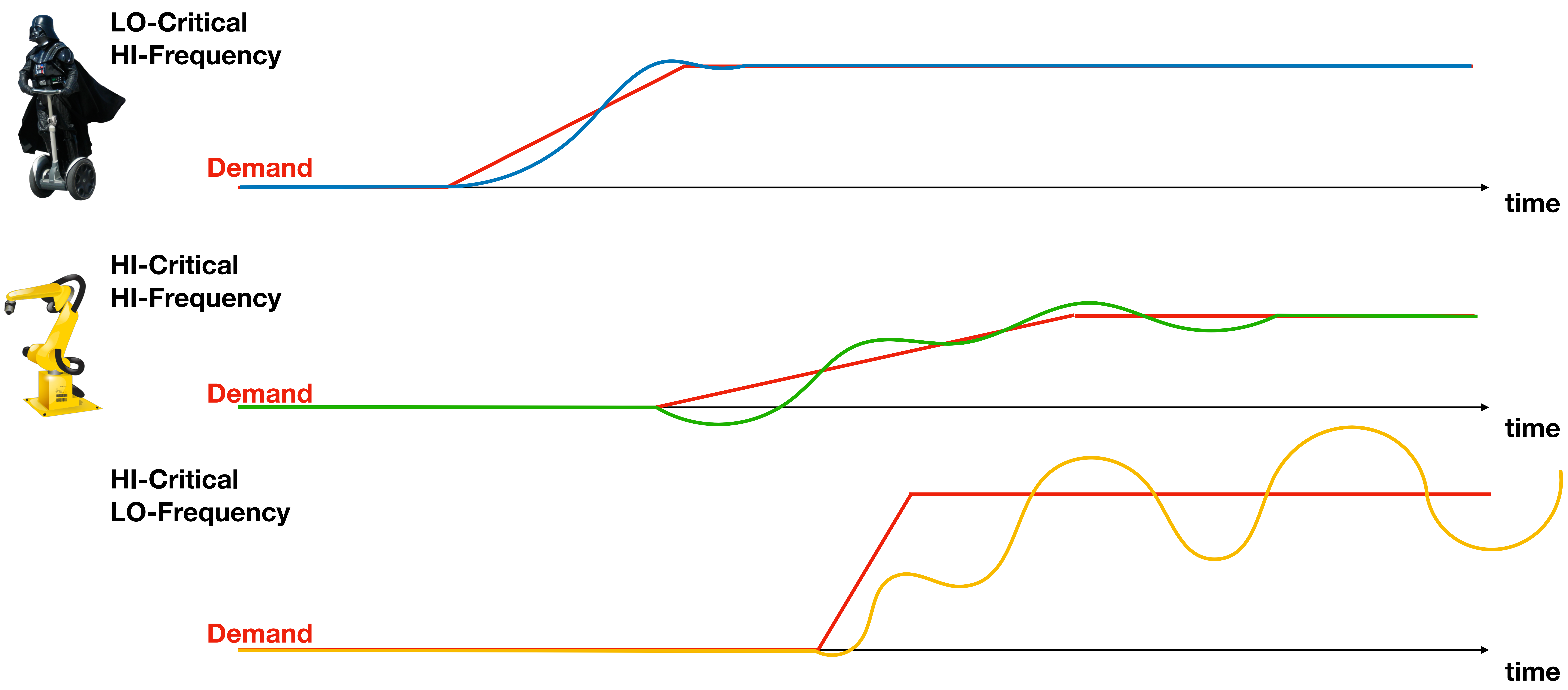
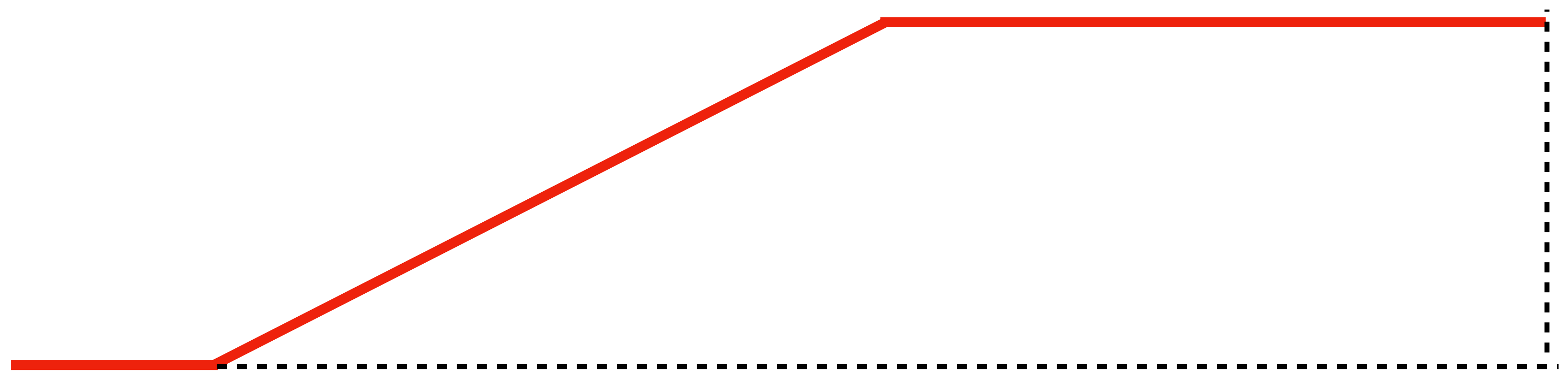


Problem Formulation

- The control is more or less difficult based on
  - **Setpoint (or reference) tracking**
  - **Nonlinearity** of the controlled system
  - **Reliability** of the communication path



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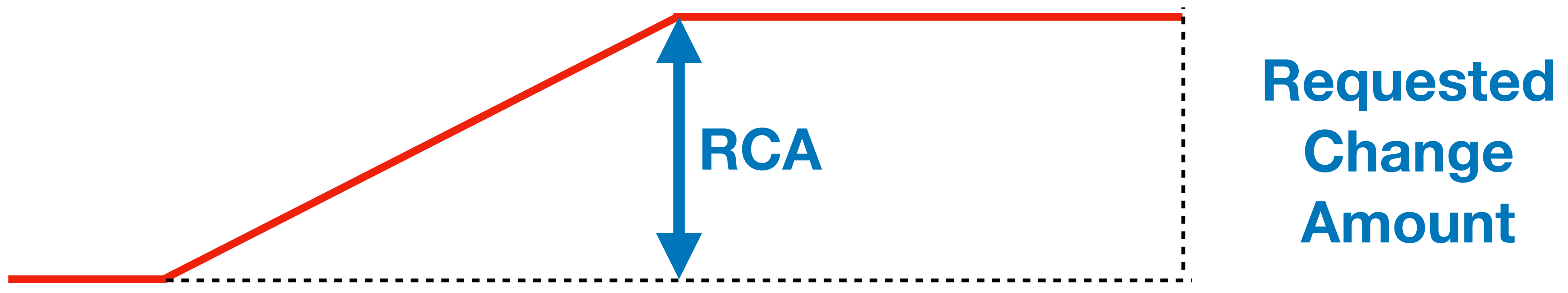

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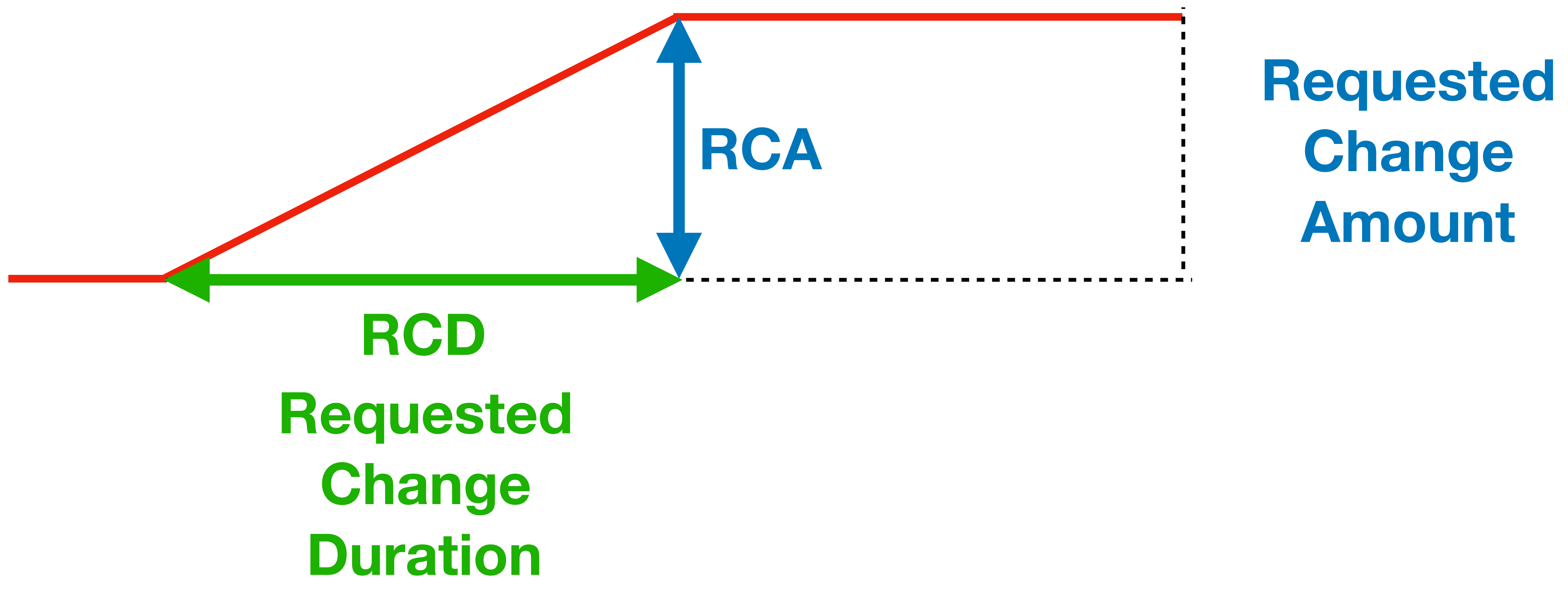

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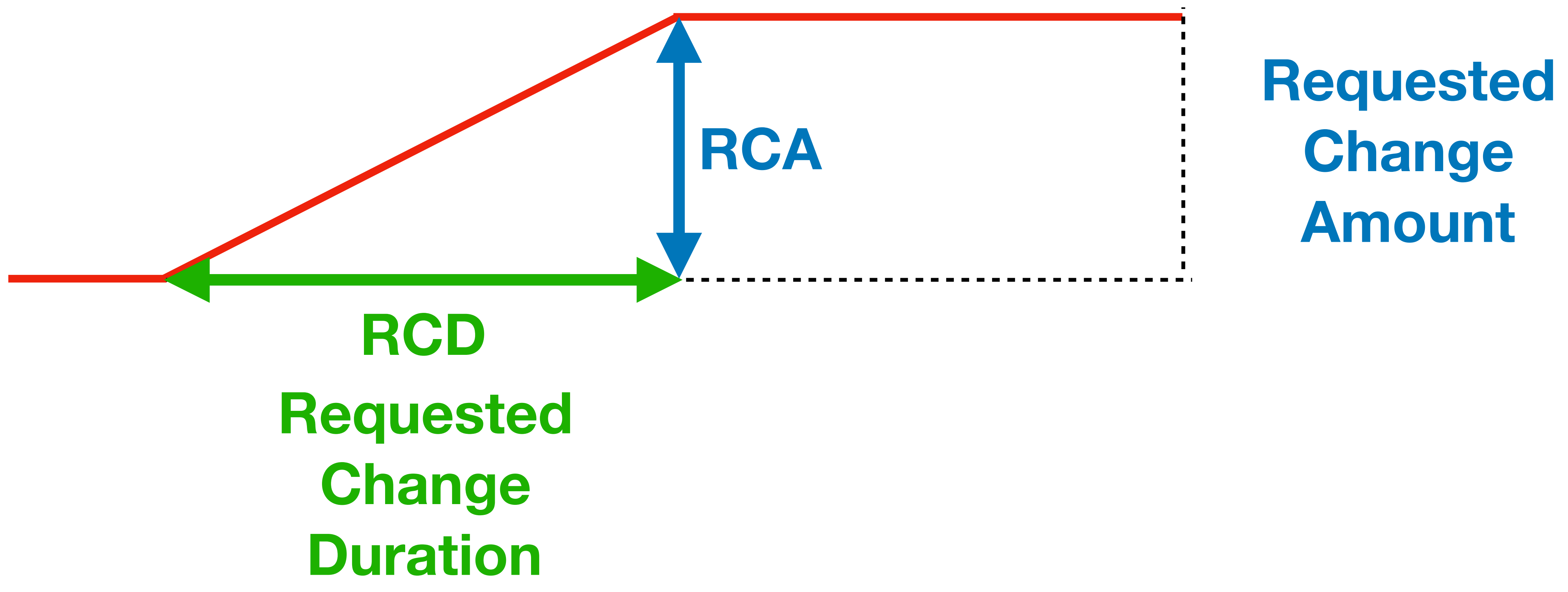

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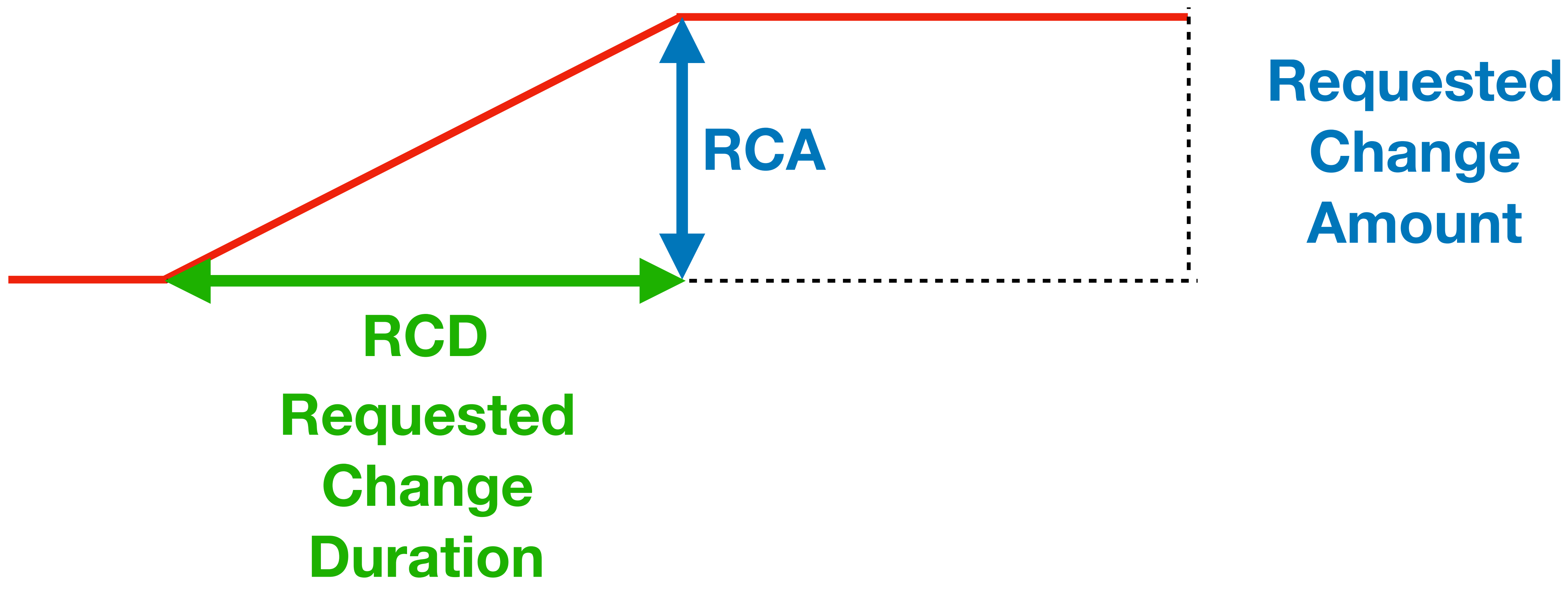

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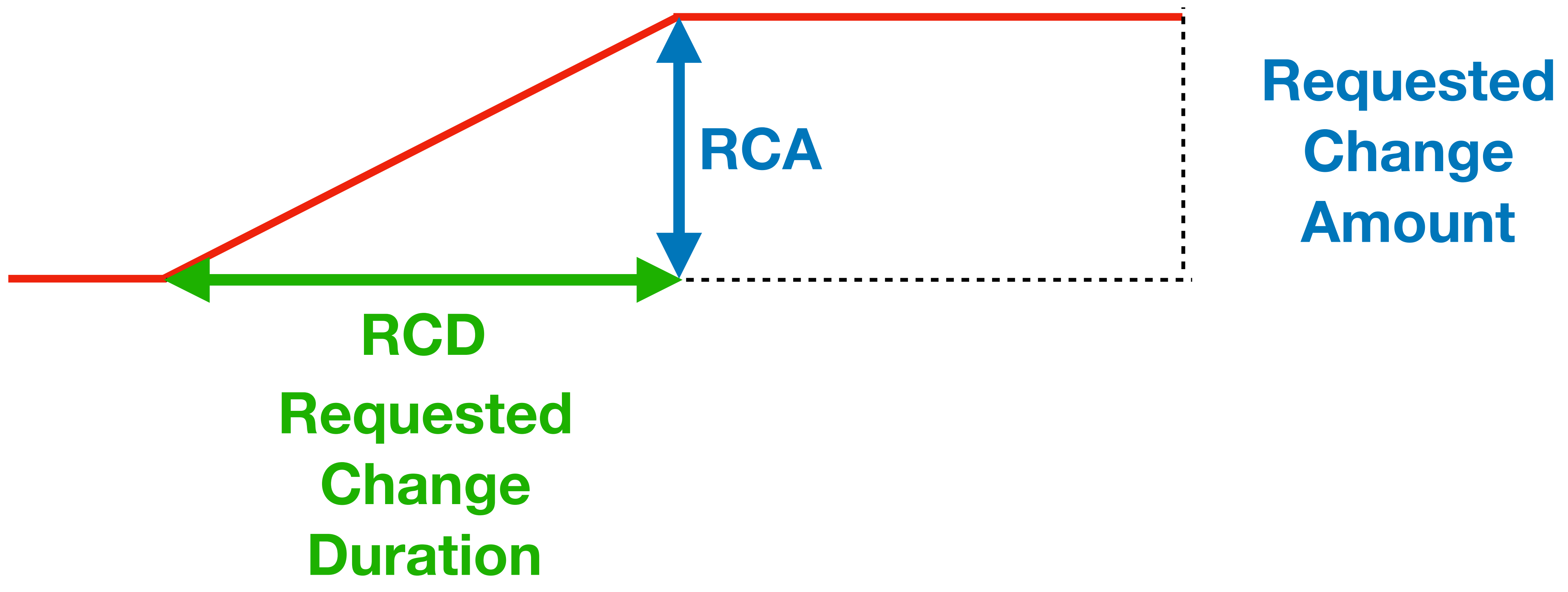

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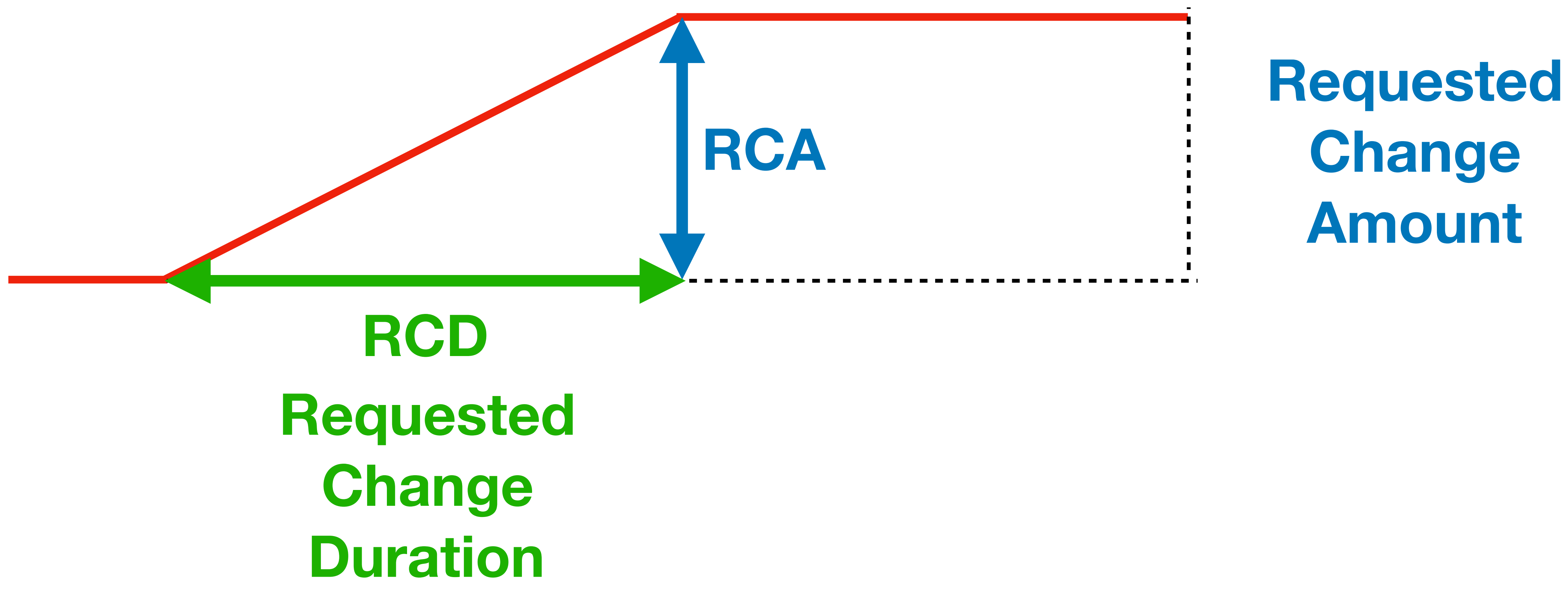

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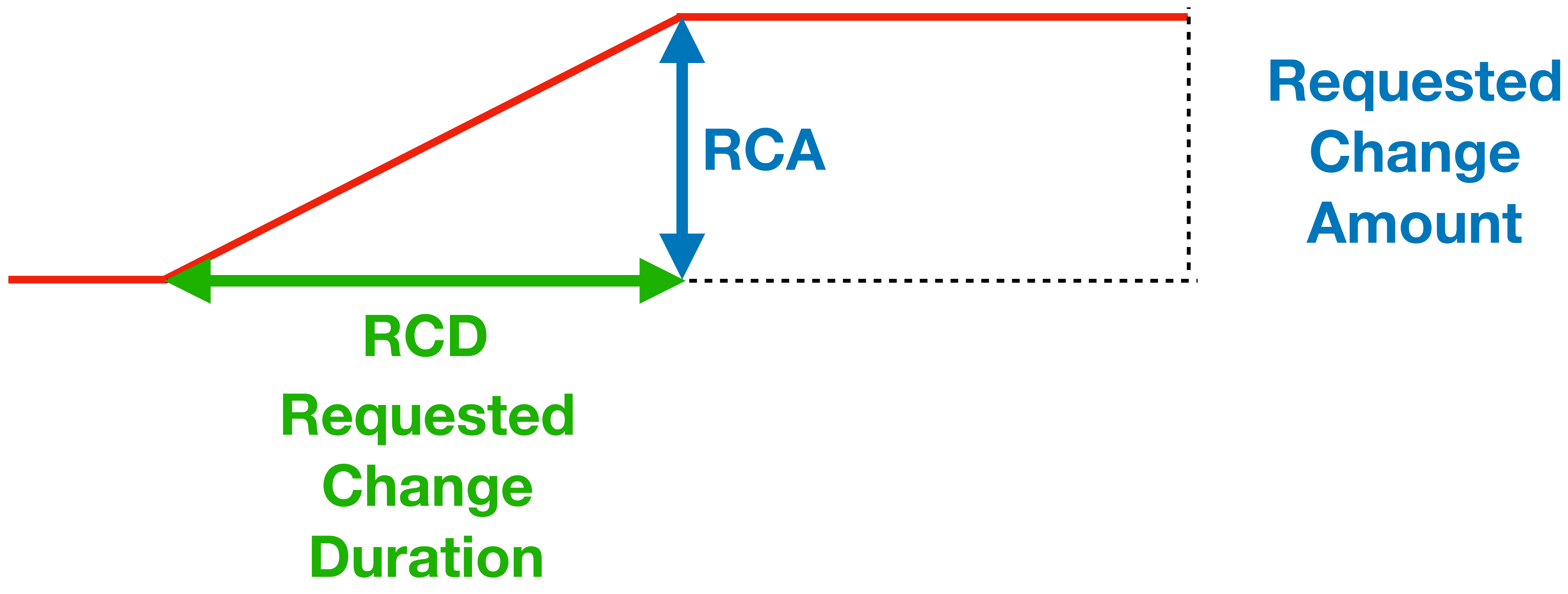

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Wired

Wireless

$$RMSE_i = \sqrt{\frac{1}{T_{trans}} \sum_{t=0}^{T_{trans}} \| y_i^{W}(t) - y_i^{WL}(t) \|^2}$$

Transient

Problem Formulation

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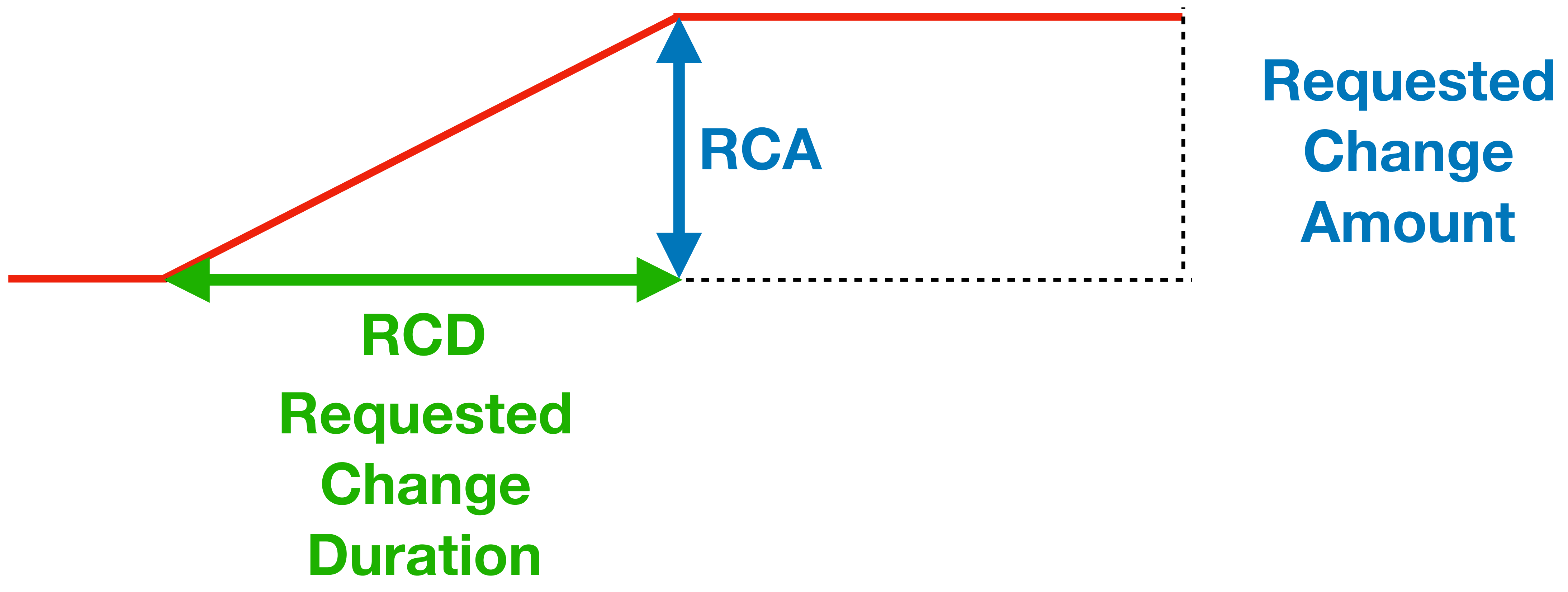

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Wired Wireless

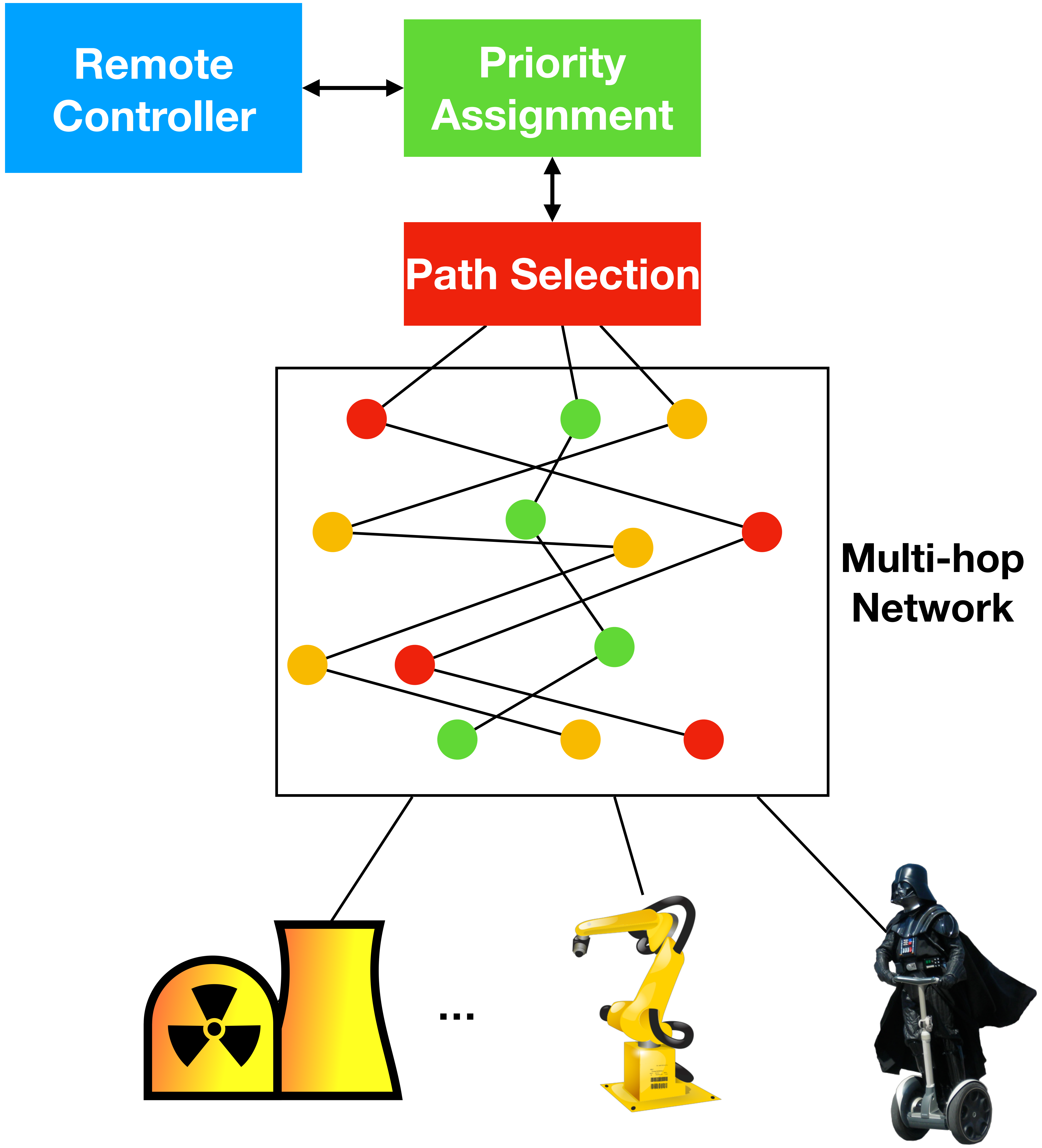
$$RMSE_i = \sqrt{\frac{1}{T_{trans}} \sum_{t=0}^{T_{trans}} \|y_i^{W}(t) - y_i^{WL}(t)\|^2}$$

Transient

$\forall i \in$ **Physical Systems**

Solution: Dynamic Packet Priority Assignment

- **Priority Assignment**
  - Static heuristic (baseline)
  - Dynamic heuristic
  - PID Dynamic heuristic
- **Path Selection**
  - Network Path Quality Determination

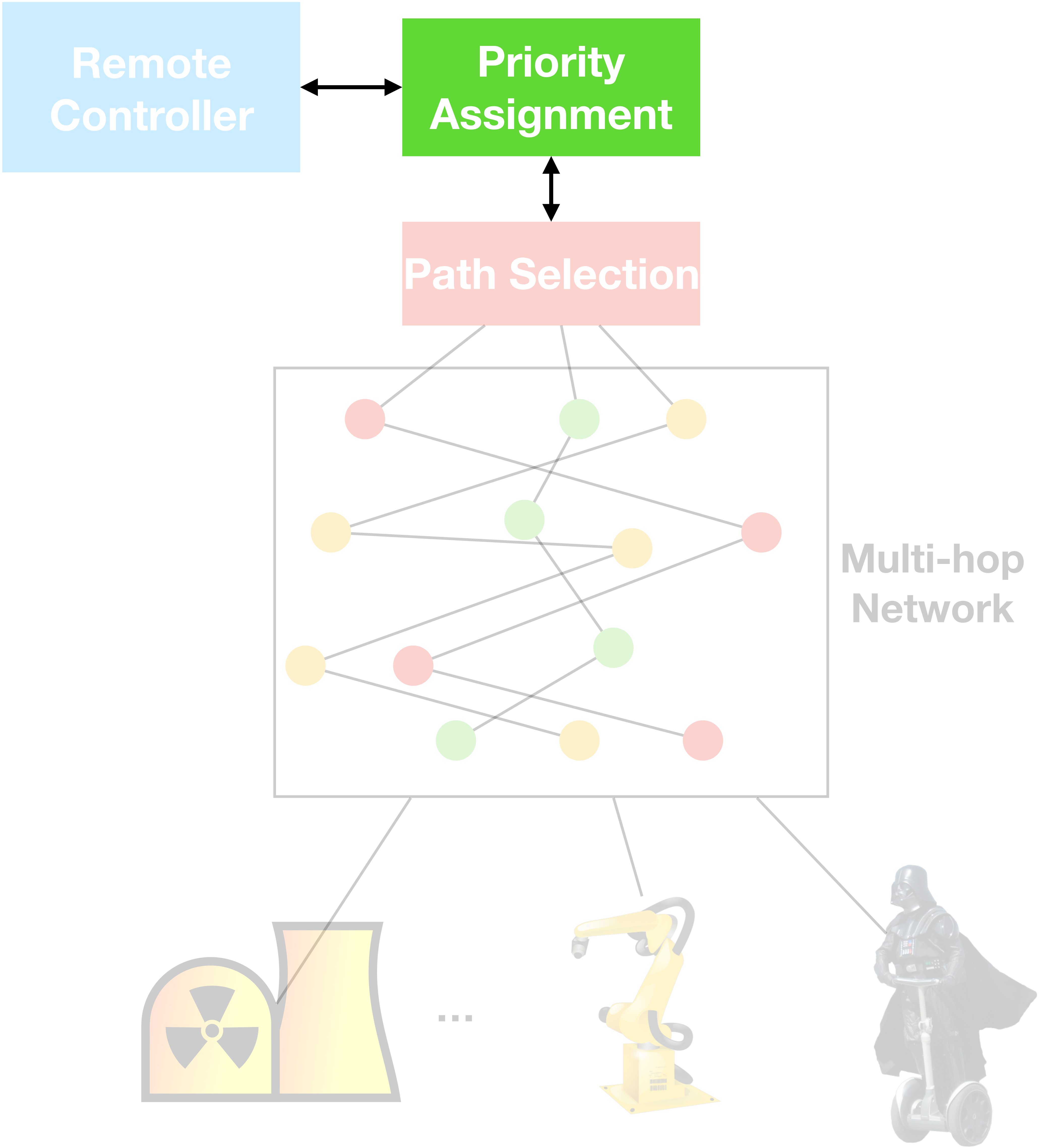


Static Heuristic - Baseline

- Offline analysis
  - Assuming no packet loss
  - For different requested changes in demand
- For all PS *i* compute

$$rRMSE_i(T_{sim}) = \sqrt{\frac{1}{T_{sim}} \sum_{j=0}^{T_{sim}} \|r_i(j) - y_i(j)\|^2}$$

- Assign the priorities that minimise the average $rRMSE_i(T_{sim})$
- Do not change the priorities online



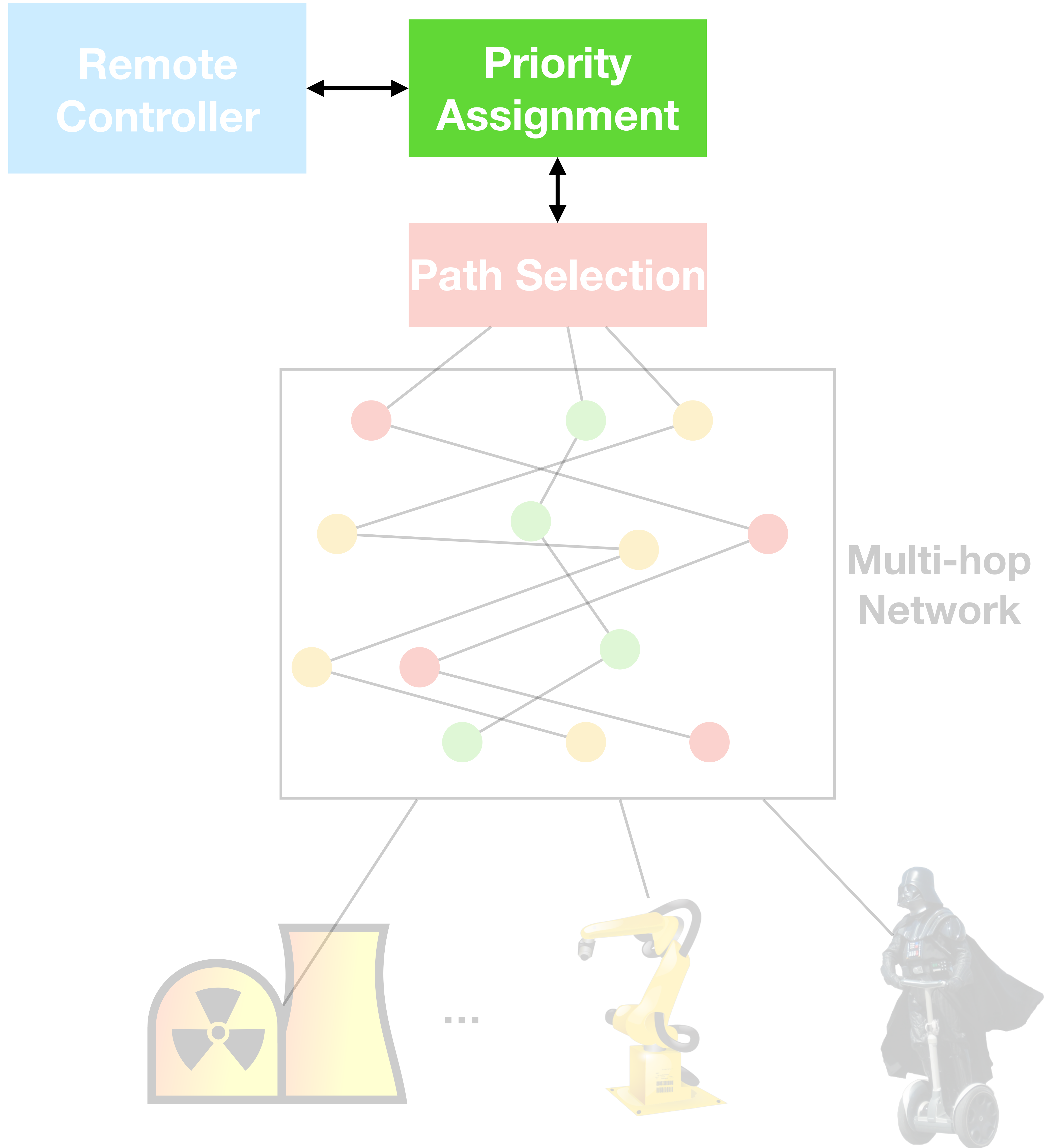
Dynamic Heuristic

- At every time t, for all PS *i* compute

$$rRMSE_i(t) = \sqrt{\frac{1}{t}\sum_{j=0}^{t} \|r_i(j) - y_i(j)\|^2}$$

- Sort the PS *i* by $rRMSE_i(t)$

- Assign the highest priority to the PS with highest value of $rRMSE_i(t)$



PID Dynamic Heuristic

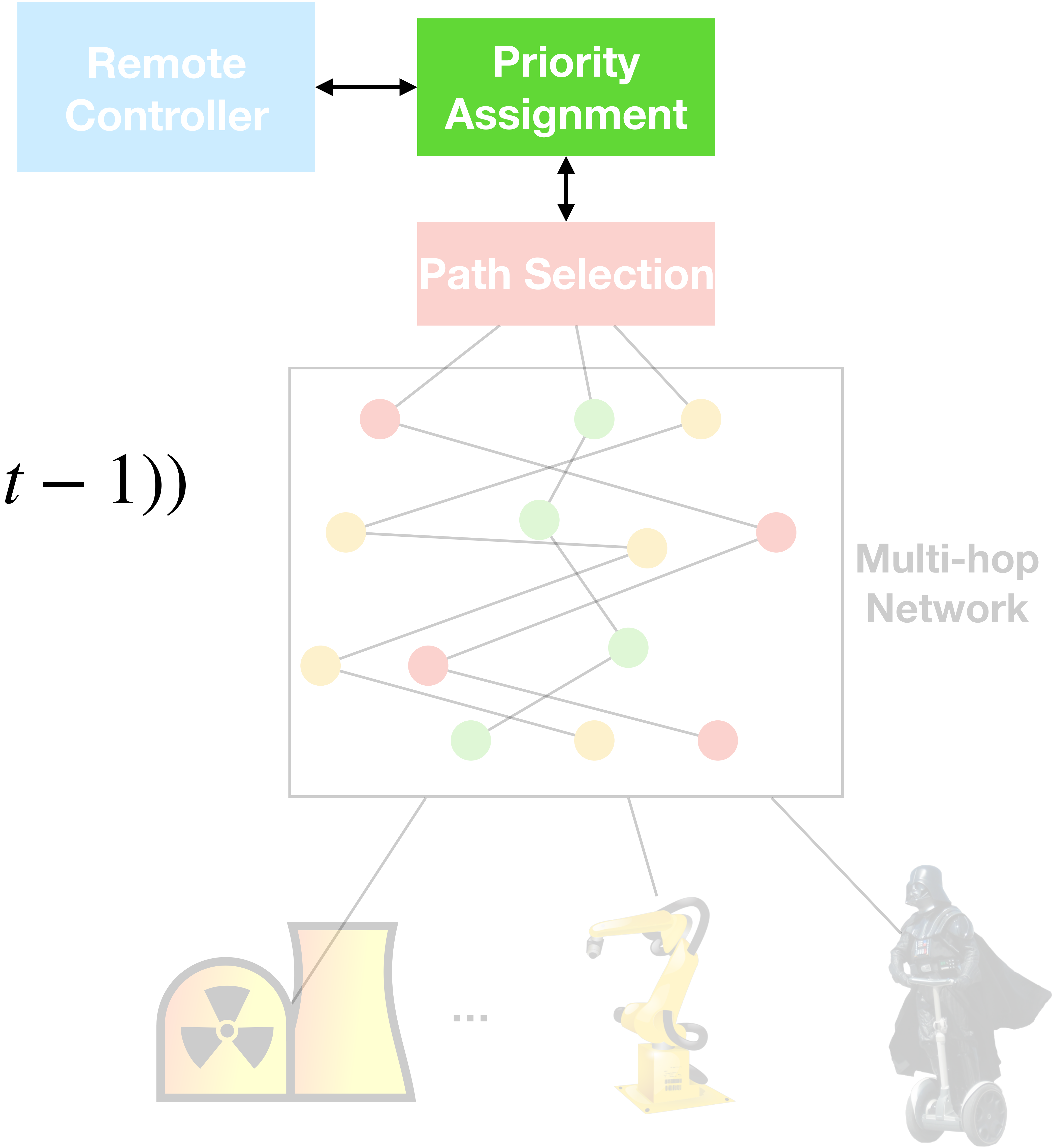
- We define the tracking error as

$$e_i(t) = |r_i(t) - y_i(t)|$$

- The priority for every PS *i* is computed as

$$\pi_i(t) = K_P\left(e_i(t) + \frac{\lambda}{t}\sum_{i=1}^{t} e_i(t)\right) + K_D\left(e_i(t) - e_i(t-1)\right)$$

- strange formula, isn't it?
    - It is a **PID controller**!



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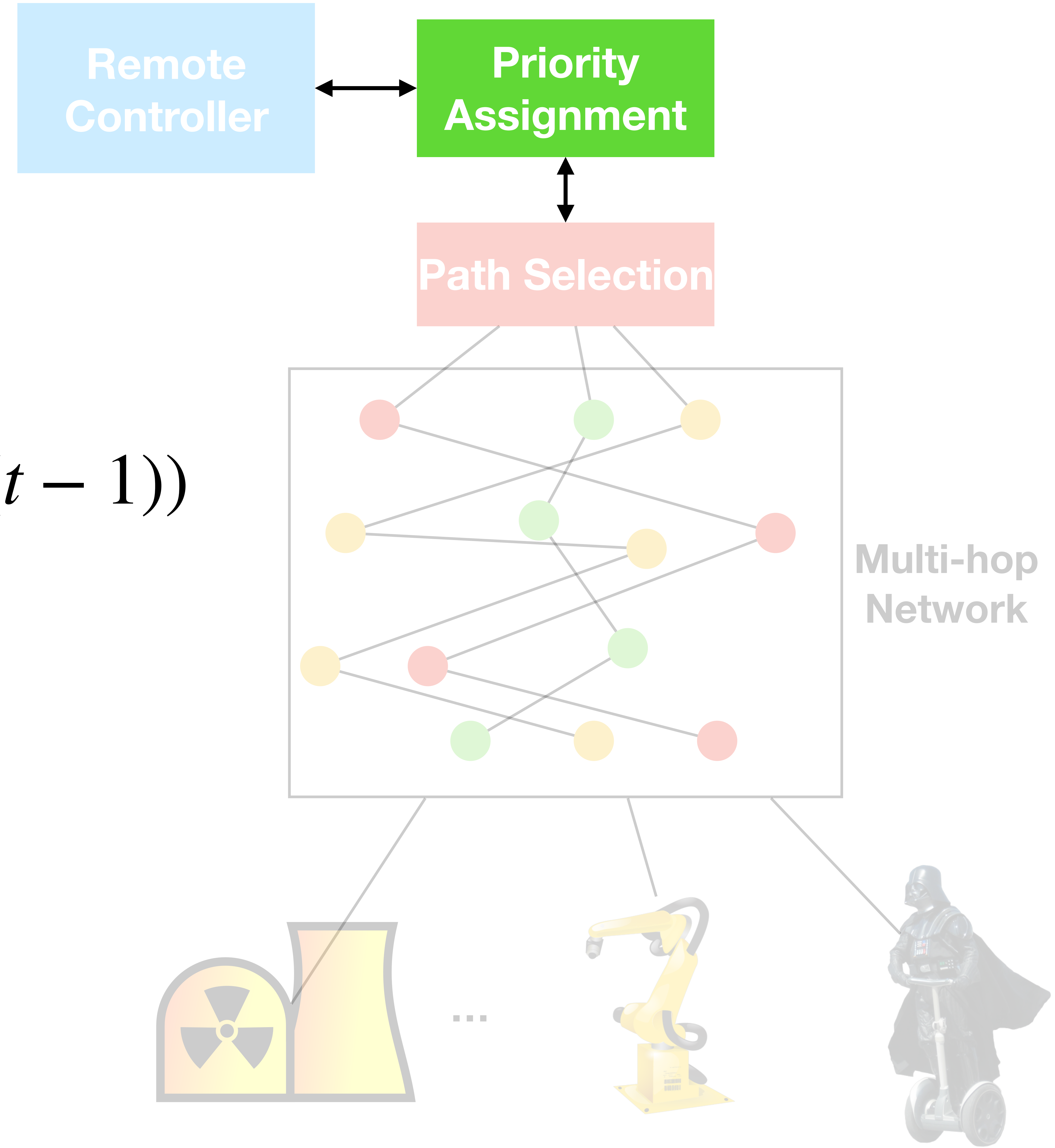
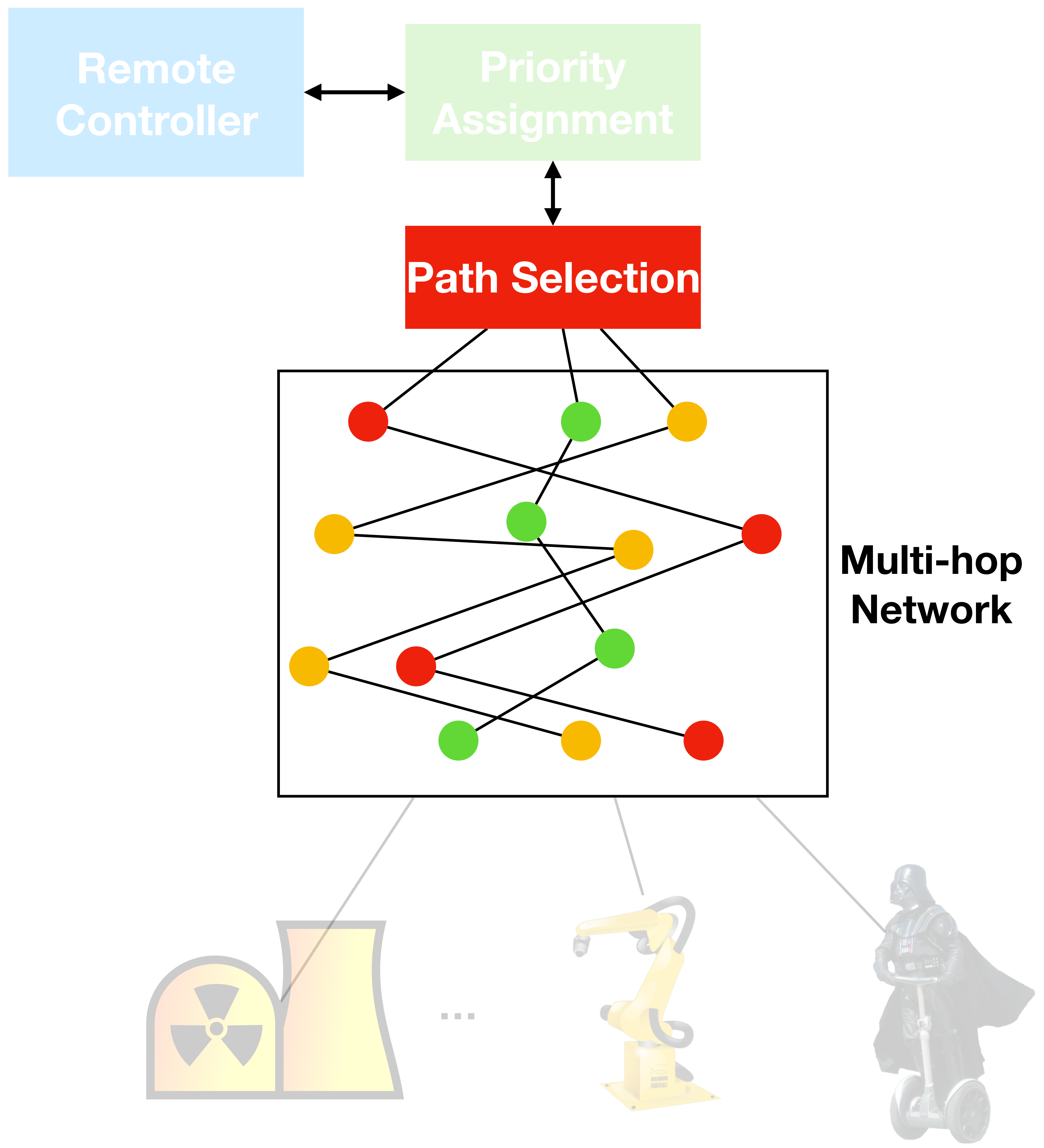


The Path Quality Model: PQModel

- After we determine the priority of the measurement packets
- Includes
  - Network delay
  - Network reliability
- We compute the path quality for all the paths as

$$PQ = D_{net} + \alpha \, n_{loss} \, \Delta_{csp}$$



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End-to-end delay

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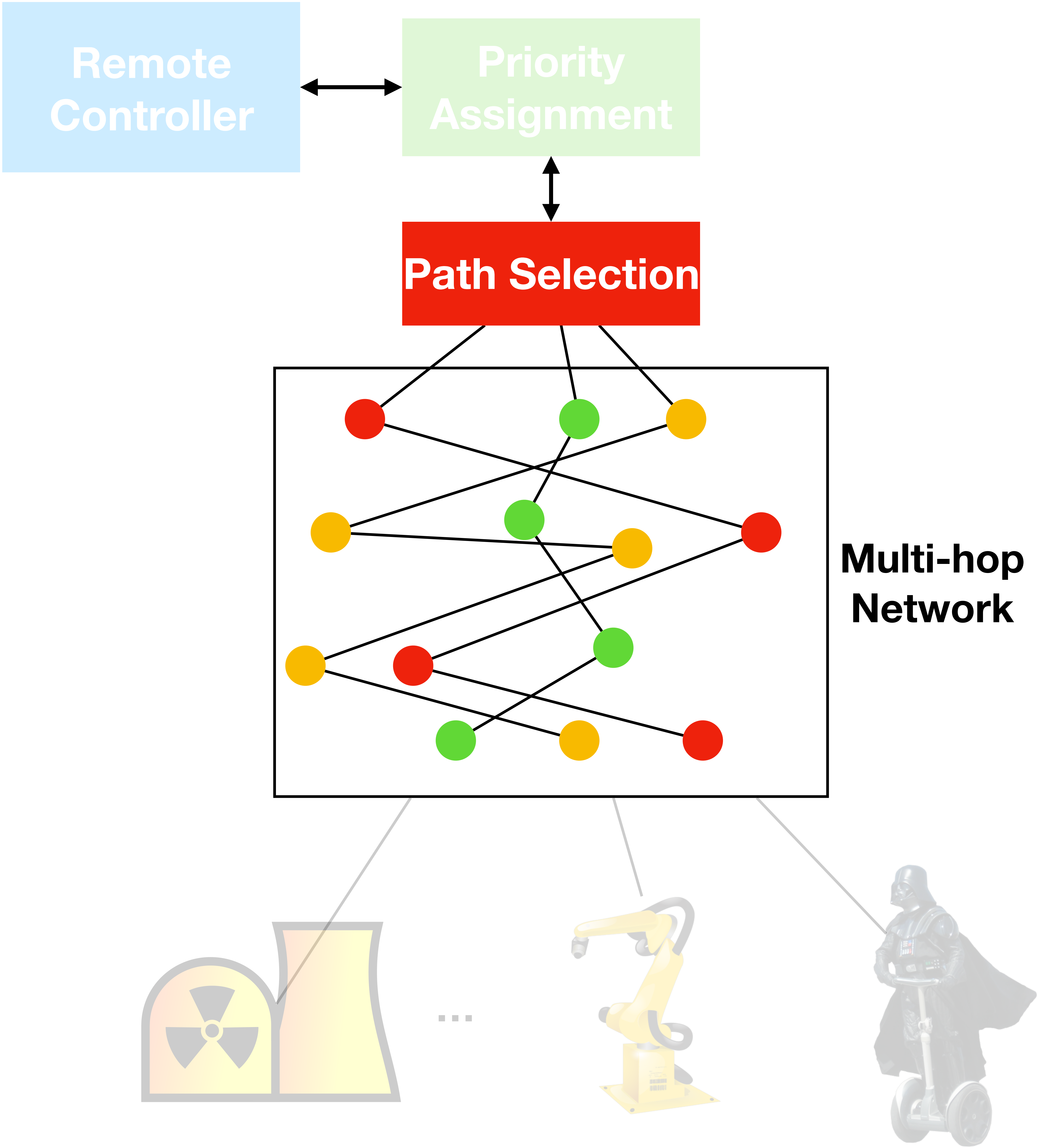

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End-to-end delay **Control Sampling Period**

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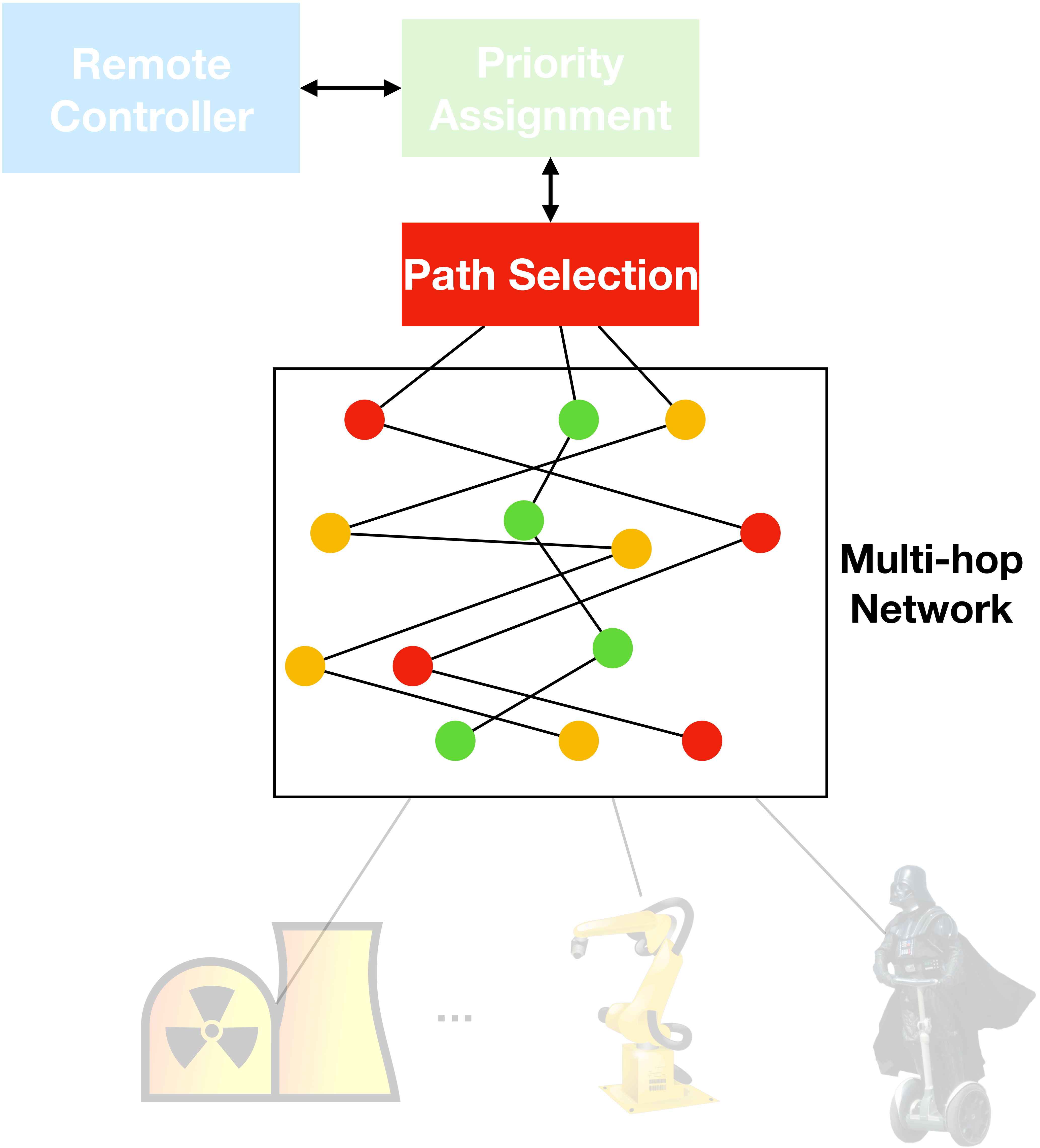

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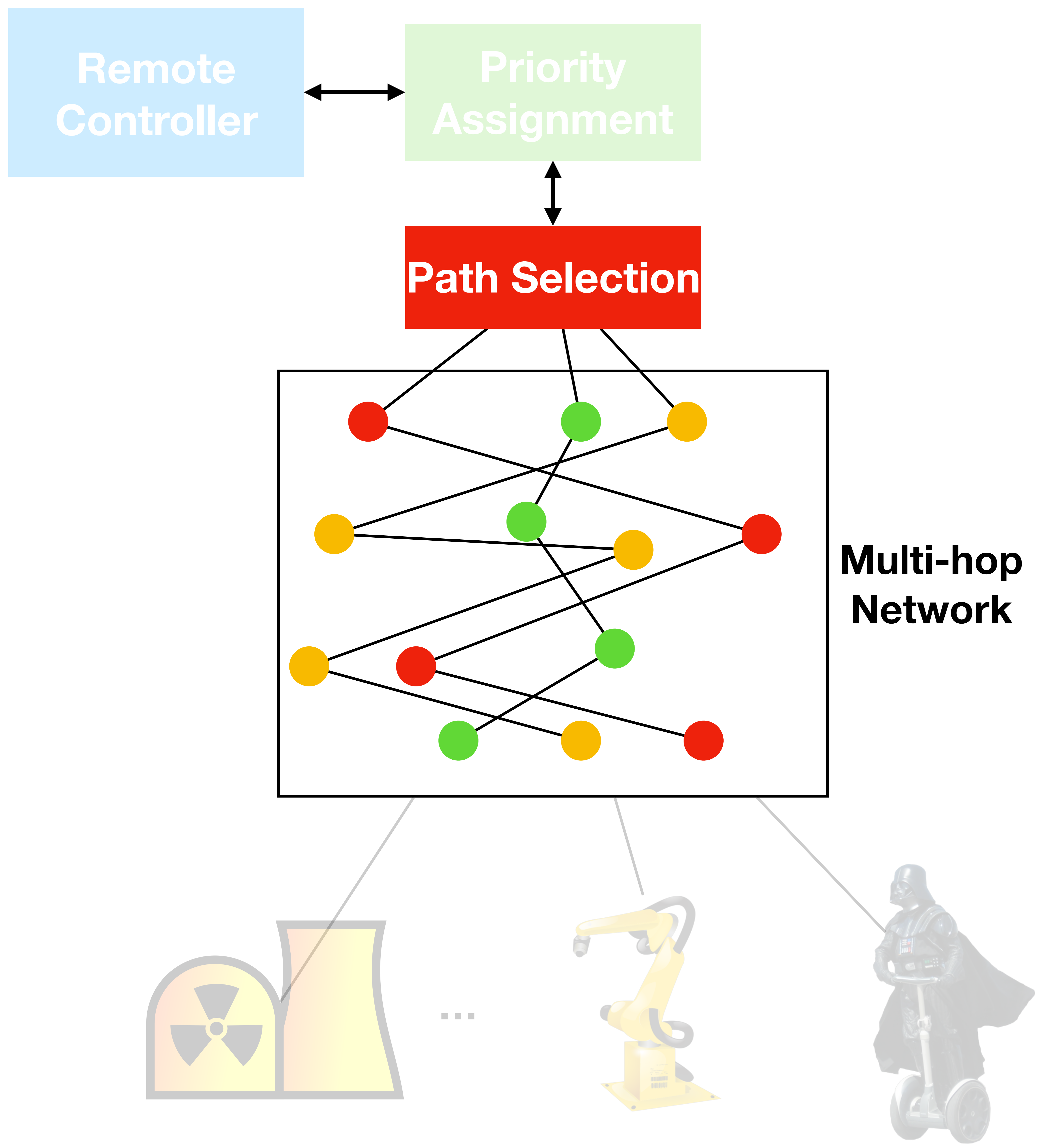
Consecutive Packet losses



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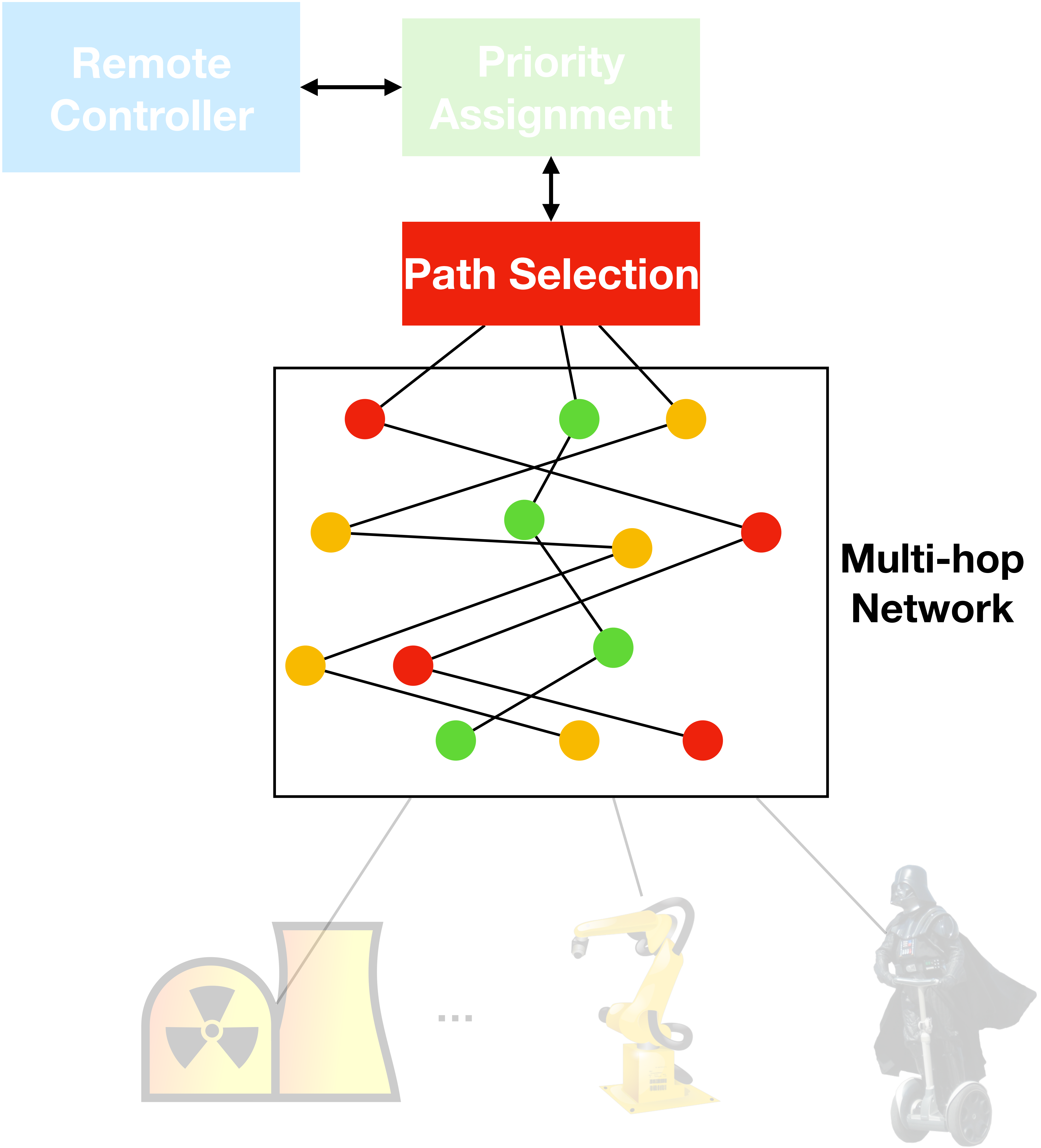
Design parameter **Consecutive Packet losses**



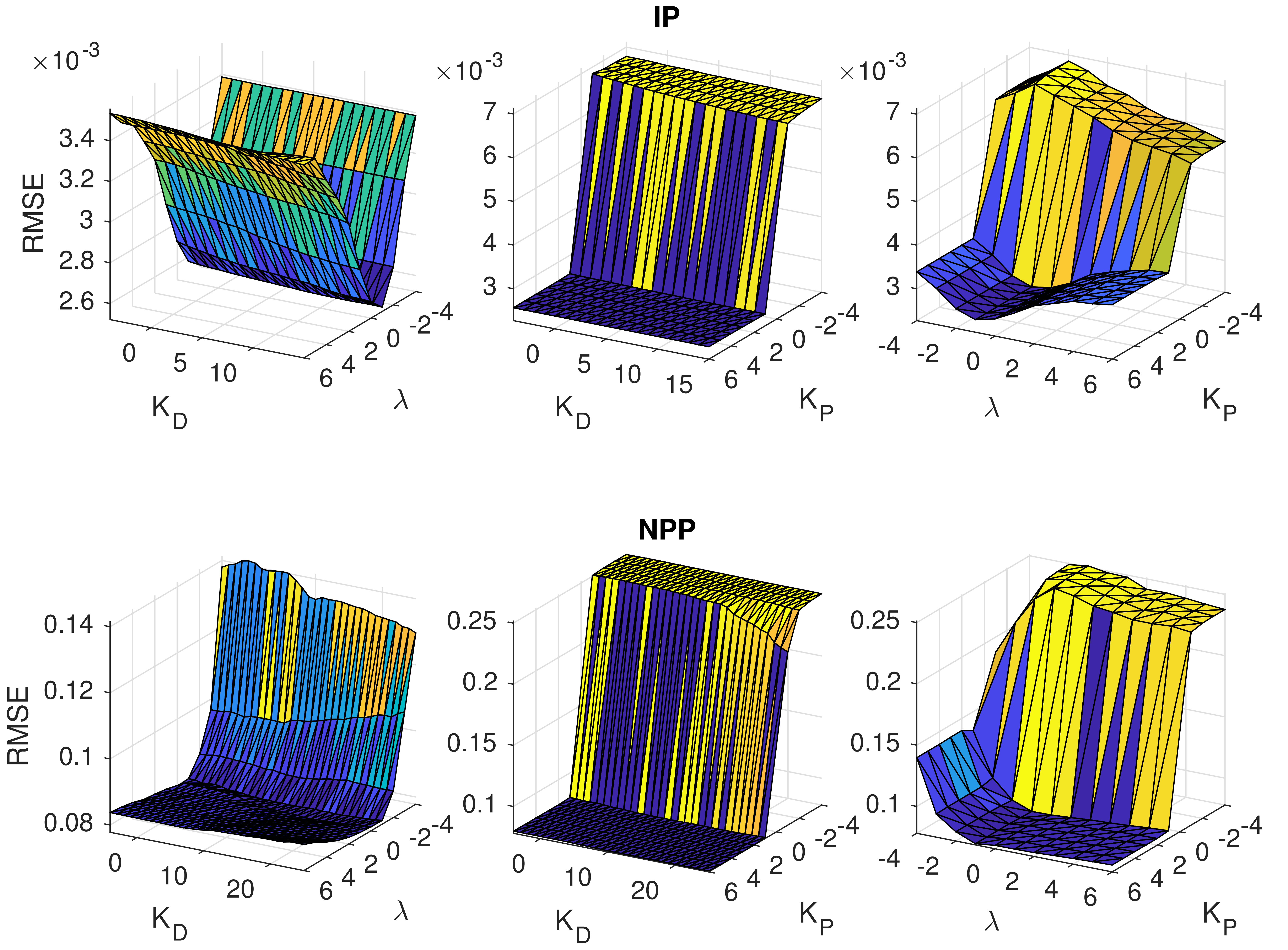
Case studies

x3 

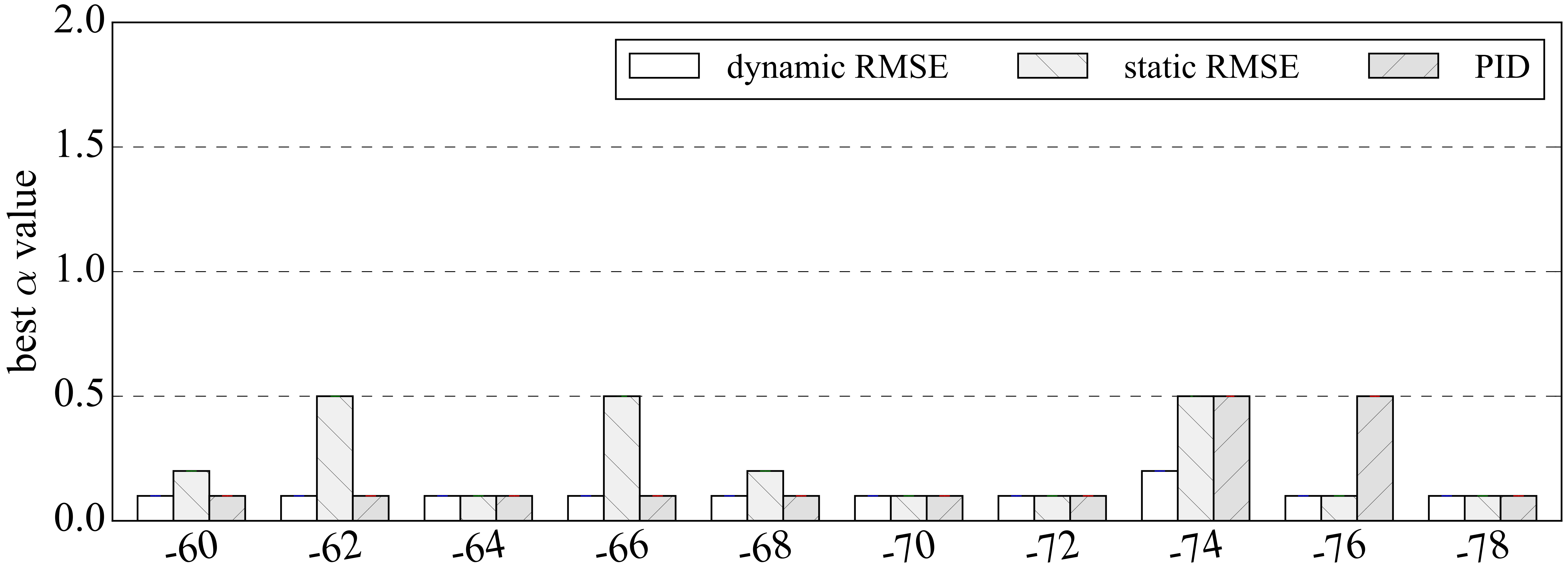
x3 

Parameters	Inverted Pendula (IP)	Nuclear Power Plant (NPP)	
Sampling period Ts	0.01s	0.1s	
Simulation time Tsim	100s	300s	
RCA	$(6 + 4l)$ meters	$(2 + 2l)$ MWatts	$l=0,\dots,4$
RCD	$5j$ seconds	$15j$ seconds	$j=1,\dots,8$
ST change	[0s, Tsim-RCD]	[0s, Tsim-RCD]	

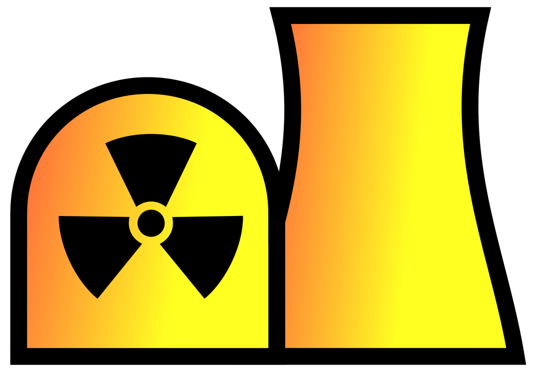
PID Tuning

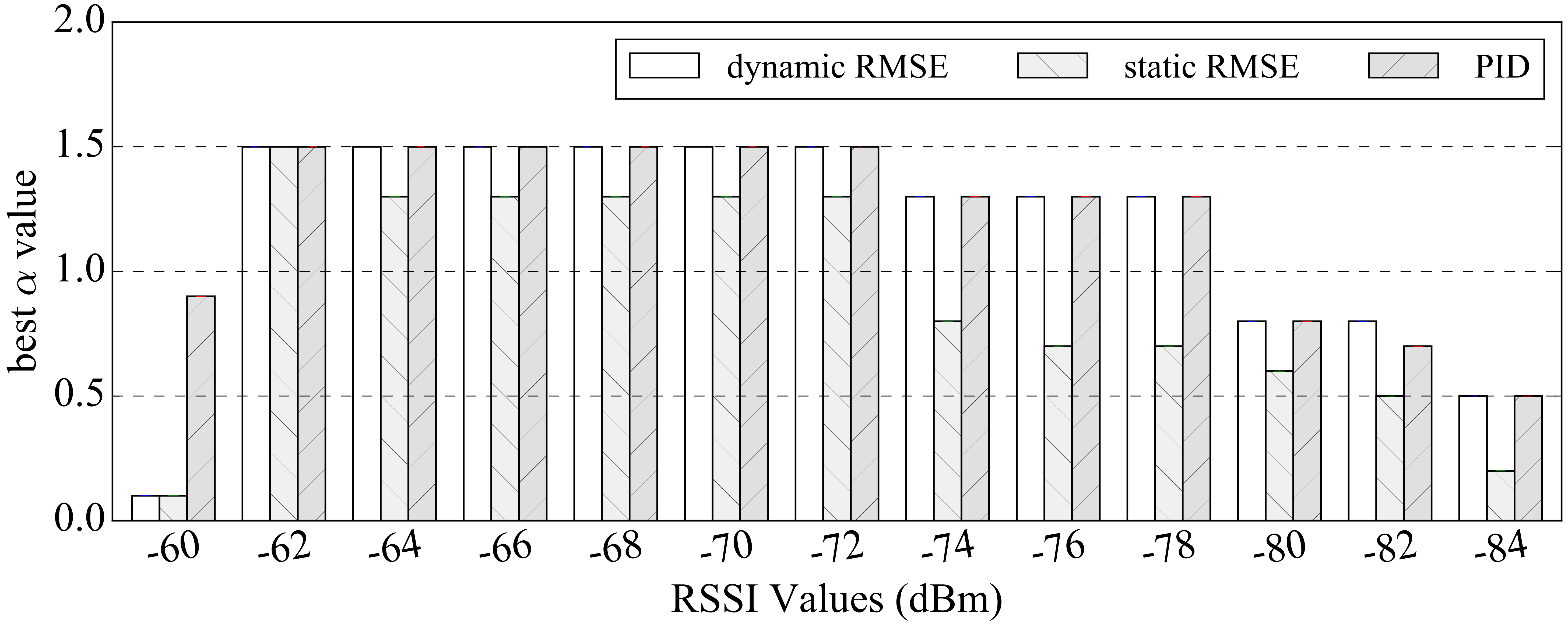


α Tuning



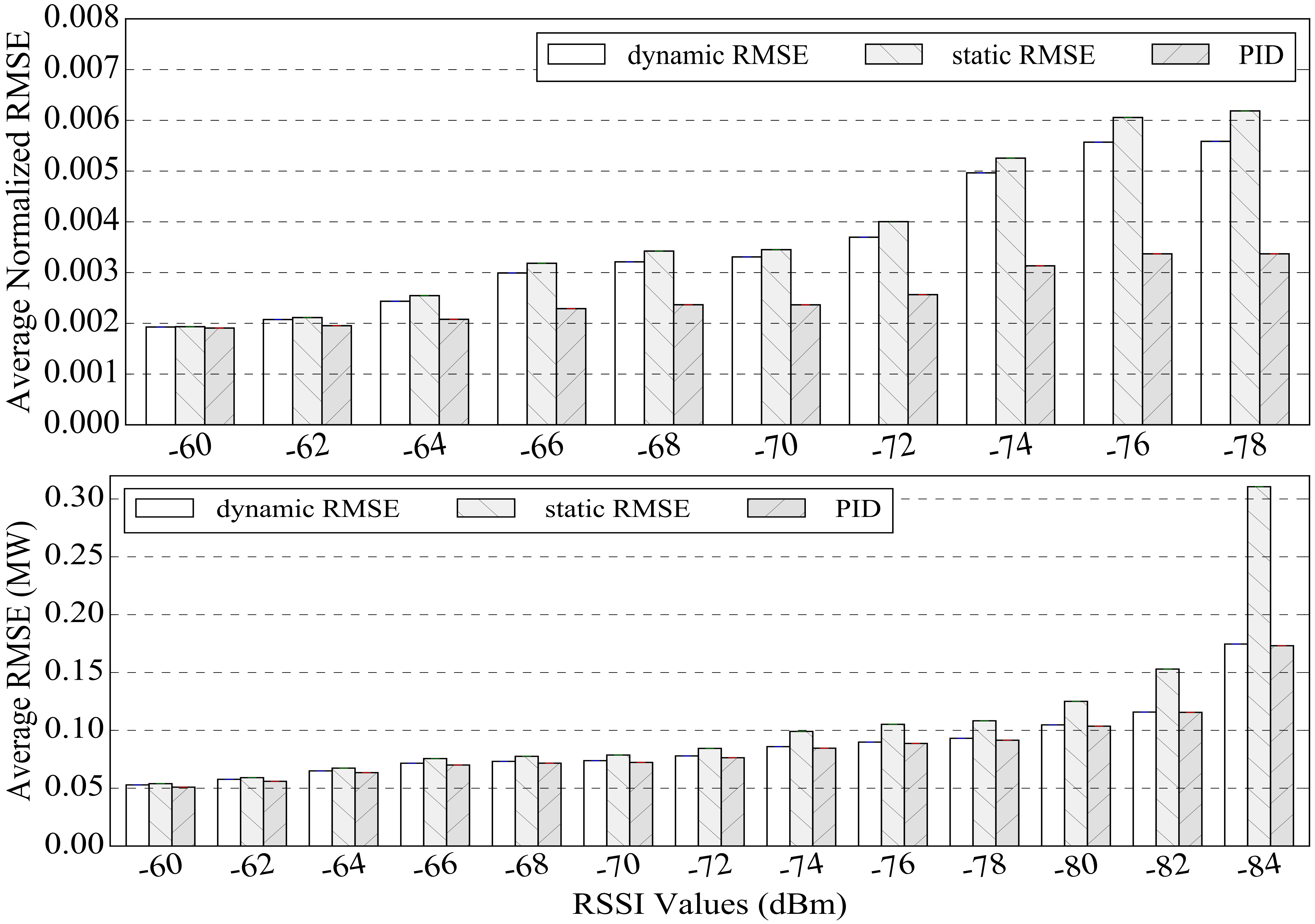
The IP is more sensitive to large delays

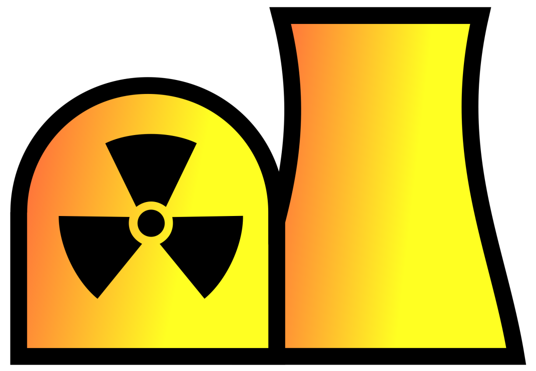




α decreases with high network interference

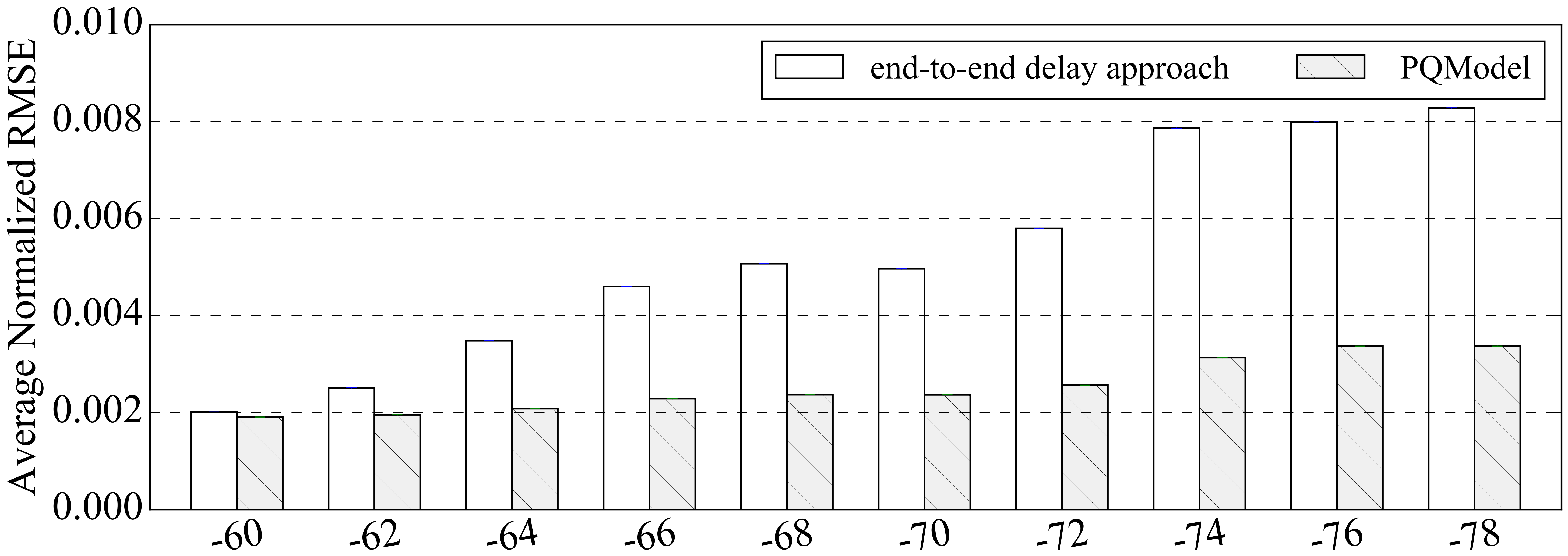
Comparison of the Different Heuristics

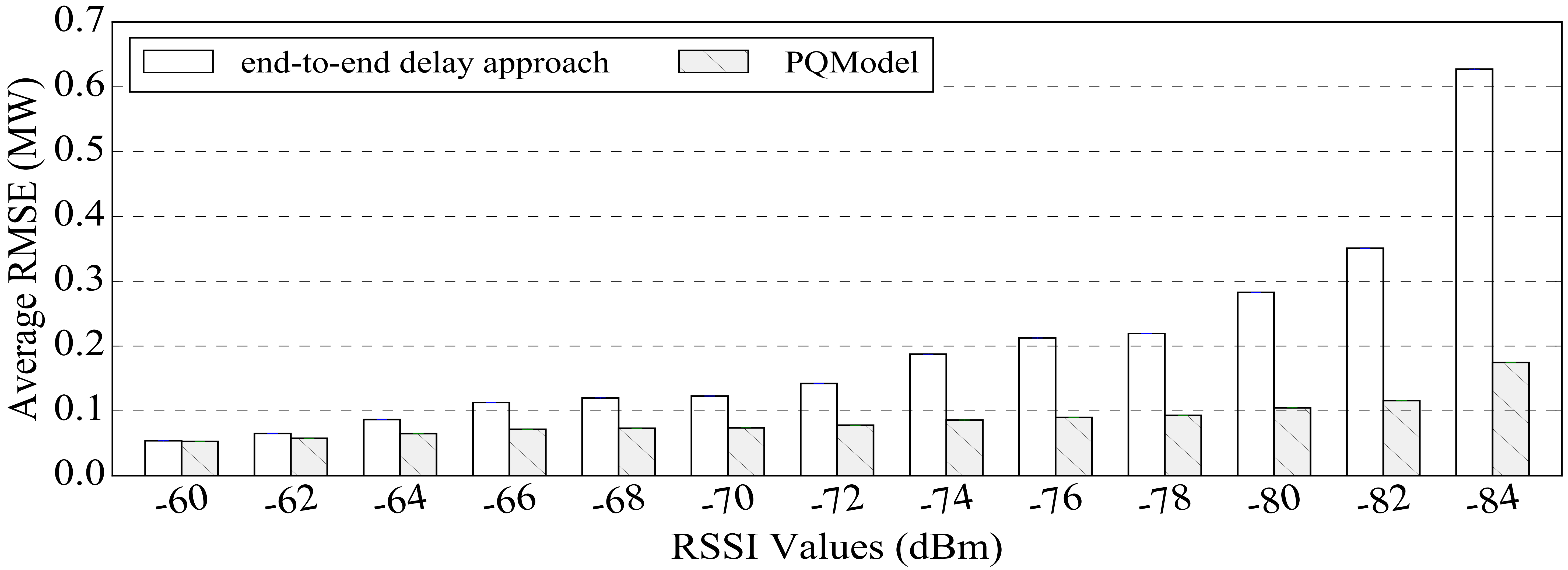




PID provides better and more stable performance

Improvement With PQModel



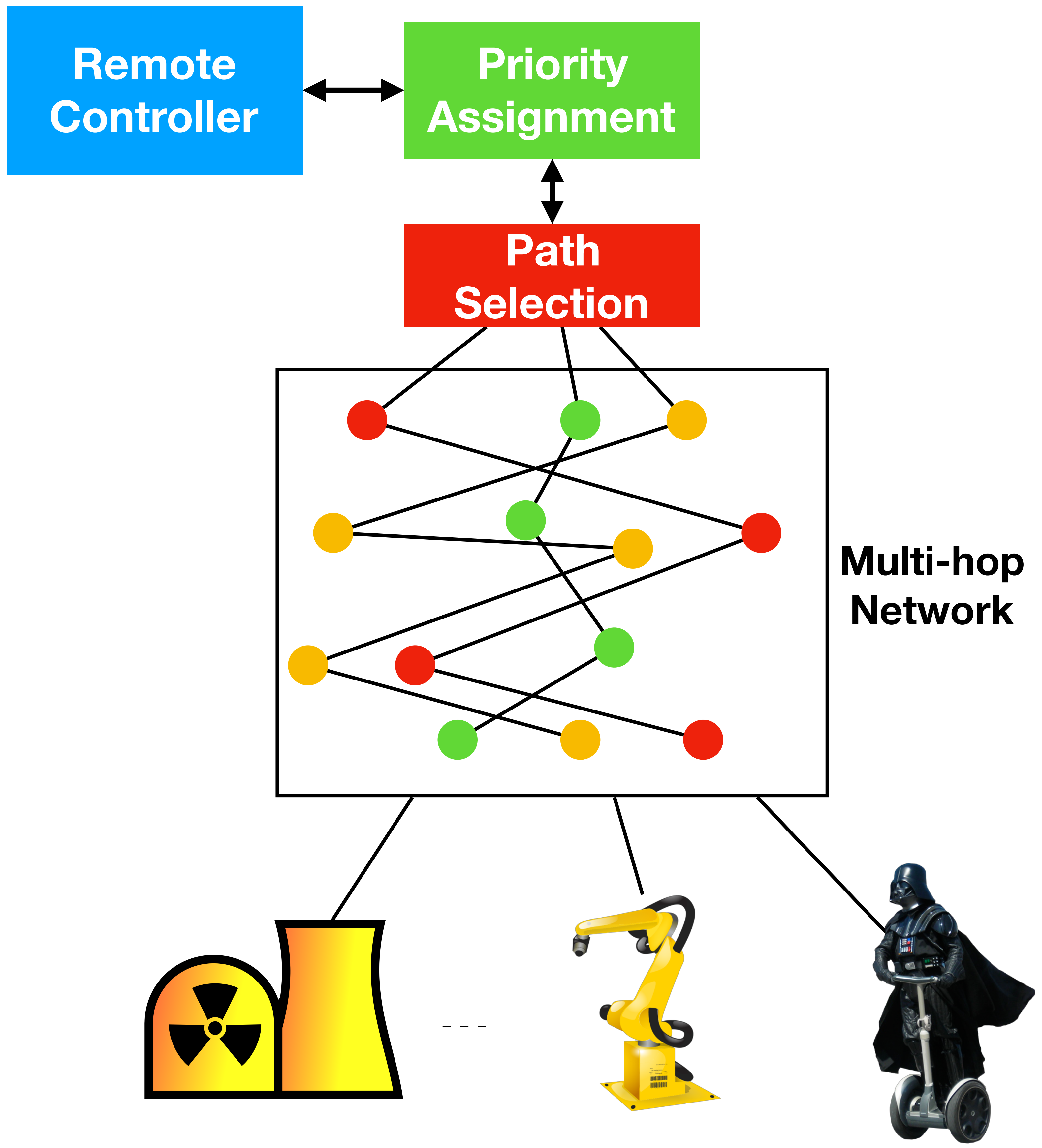


The PQ model outperforms end-to-end approaches

Conclusion

- We explored the interaction between dynamic packet scheduling and the control system performance in WCS
  - Highly nonlinear systems are not heavily explored in the literature
- Three heuristics for packet priority assignment
  - PID: most promising
- Path quality model
  - Tradeoff between delay and reliability

Questions?



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