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From Network Flexibility to Network Digital Twins

Prof. Dr.-Ing. Wolfgang Kellerer

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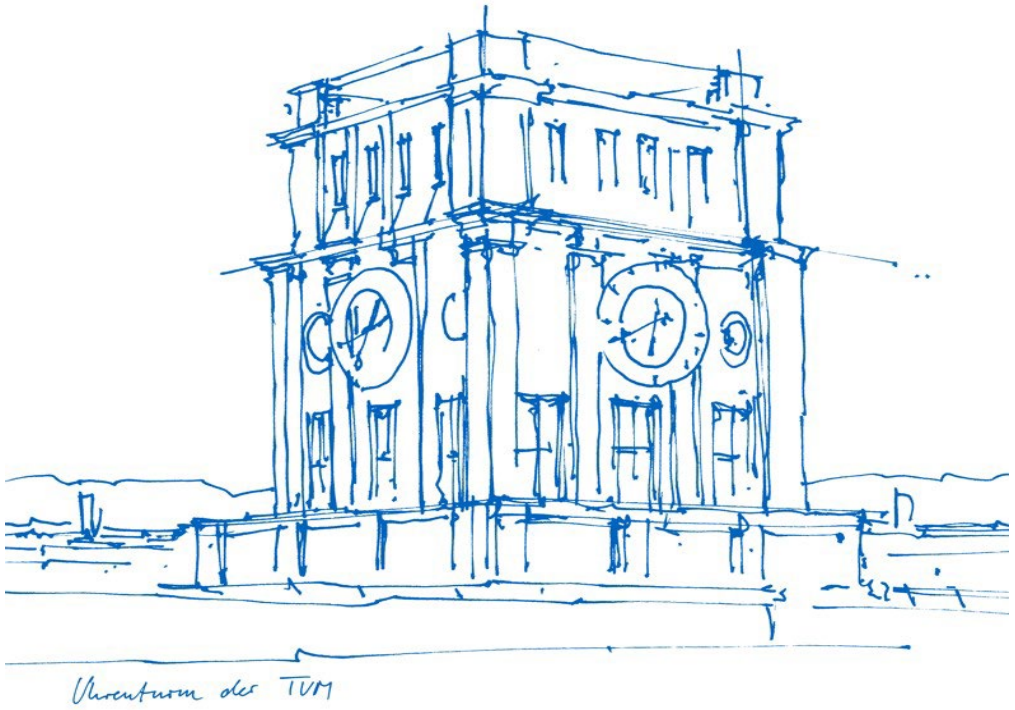

This work receives financial support by the Federal Ministry of Education and Research of Germany (BMBF) in the programme of "Souverän. Digital. Vernetzt." joint project 6G-life, project identification number 16KISK002, and the Bavarian Ministry of Economic Affairs, Regional Development and Energy as part of the project "6G Future Lab Bavaria" and "5G Testbed" and "6G und Quantentechnologie", and the German Research Foundation (DFG), grant number: 316878574.

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DFG Deutsche Forschungsgemeinschaft

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6G-life

What do Flexibility and Network Digital Twins have to do with O-RAN?

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… a lot !

What do Flexibility and Network Digital Twins have to do with O-RAN?

O-RAN

- extends Software-Defined Networking → Software-Defined RAN
- offers new, open interfaces in RAN, multi-vendor concepts, programmability
  dynamic adaptation → unprecedented **flexibility**
- increases … complexity

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who shall manage this?

- autonomous network management – *the holy grail*

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- autonomous network management – *the holy grail*

too risky?

- *twin your network* → **Network Digital Twins**

This talk …

- will raise the challenge of network flexibility,
- introduce the role of Network Digital Twins for autonomous network management, and
- how AI/ML may lead to a solution

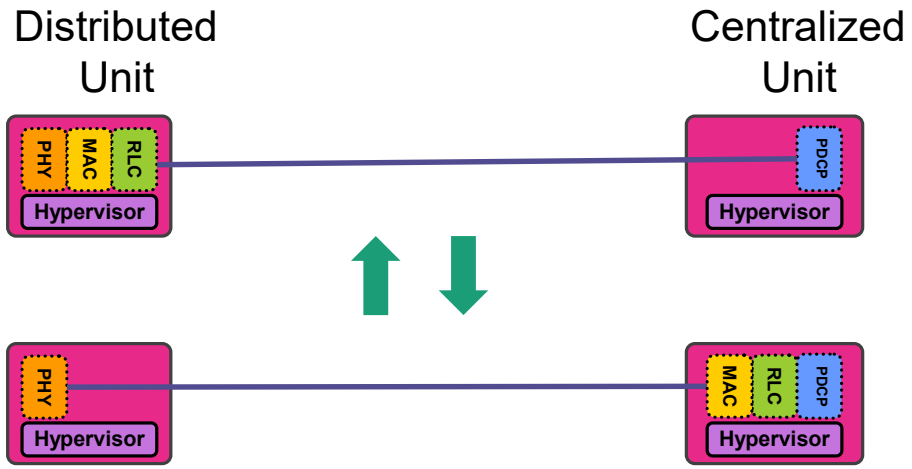
based on SD-X and Kubernetes examples

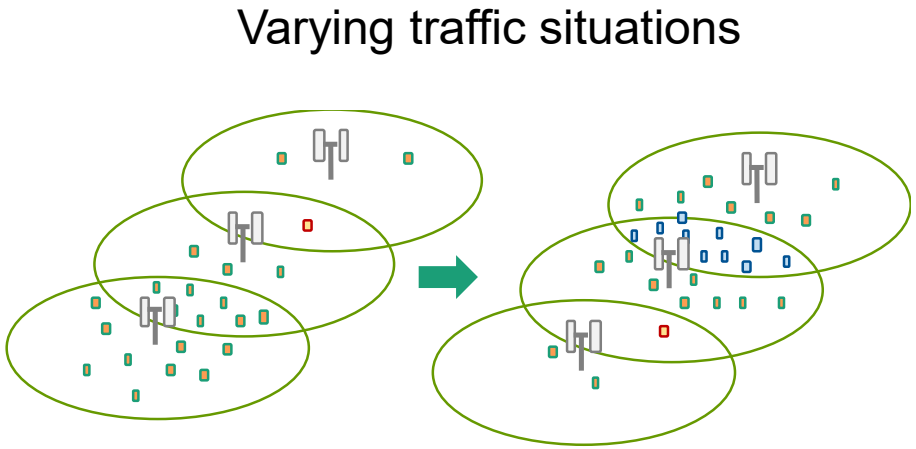
Use Case for Network Flexibility – Function Splits

- Fixed function split configuration vs.
- Dynamic migration (between the PHY-MAC split and RLC-PDCP split)

Measure for Network Flexibility: $\varphi = \frac{\text{successful (re−)configurations given } T \text{ and } C}{\text{all demands}}$

T reaction time constraint
C adaptation cost constraint

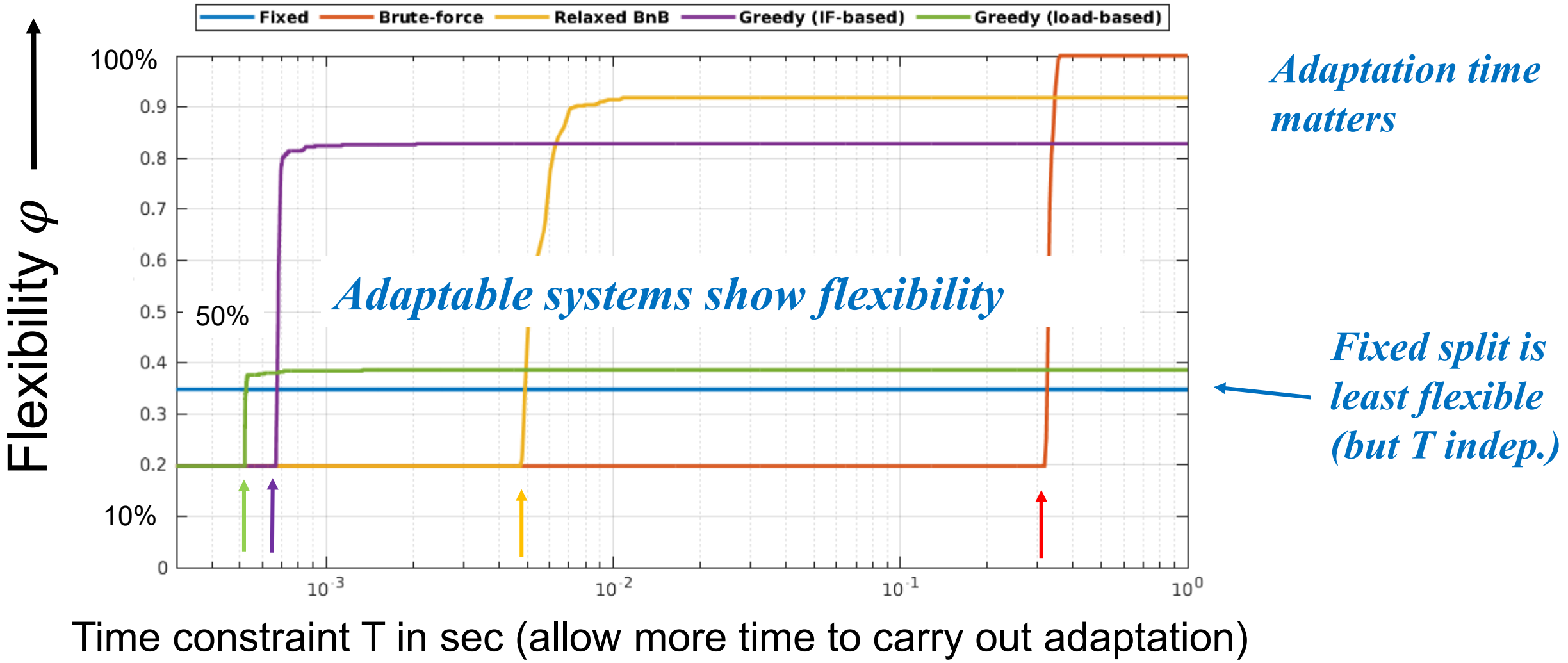




A. Martínez Alba, P. Babarczi, A. Blenk, M. He, P. Krämer, J. Zerwas, and W. Kellerer.
"Modeling the Cost of Flexibility in Communication Networks". *IEEE Conference on Computer Communications, INFOCOM* 2021.

Use Case for Network Flexibility – Function Splits

- Comparison of different adaptation algorithms



Conclusion 1

- **we can measure network flexibility**
- **(adaptation) time matters**

www.networkflexibility.org

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W. Kellerer, P. Kalmbach, A. Blenk, A. Basta, M. Reisslein, S. Schmid:
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What if the time is (too) short?

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What if the time is (too) short?

… in highly dynamic systems such as (Open-)RAN?

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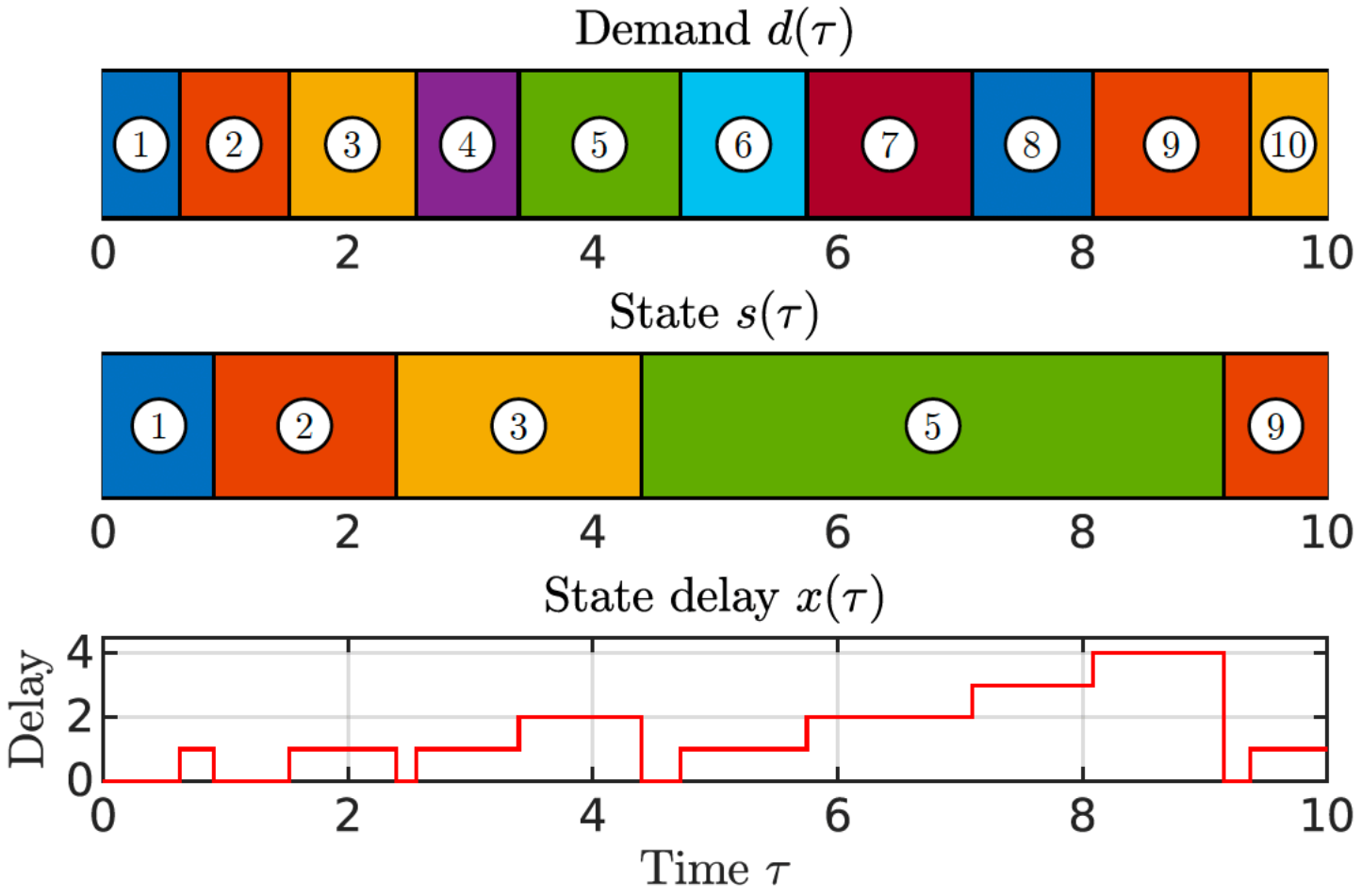
Reacting to a demand takes time



Demands (for possible re-configuration)

Actual realized reconfigurations (state changes)

Delay between demand occurence and reconfiguration completed

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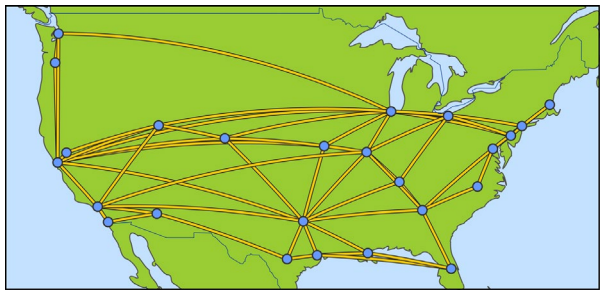
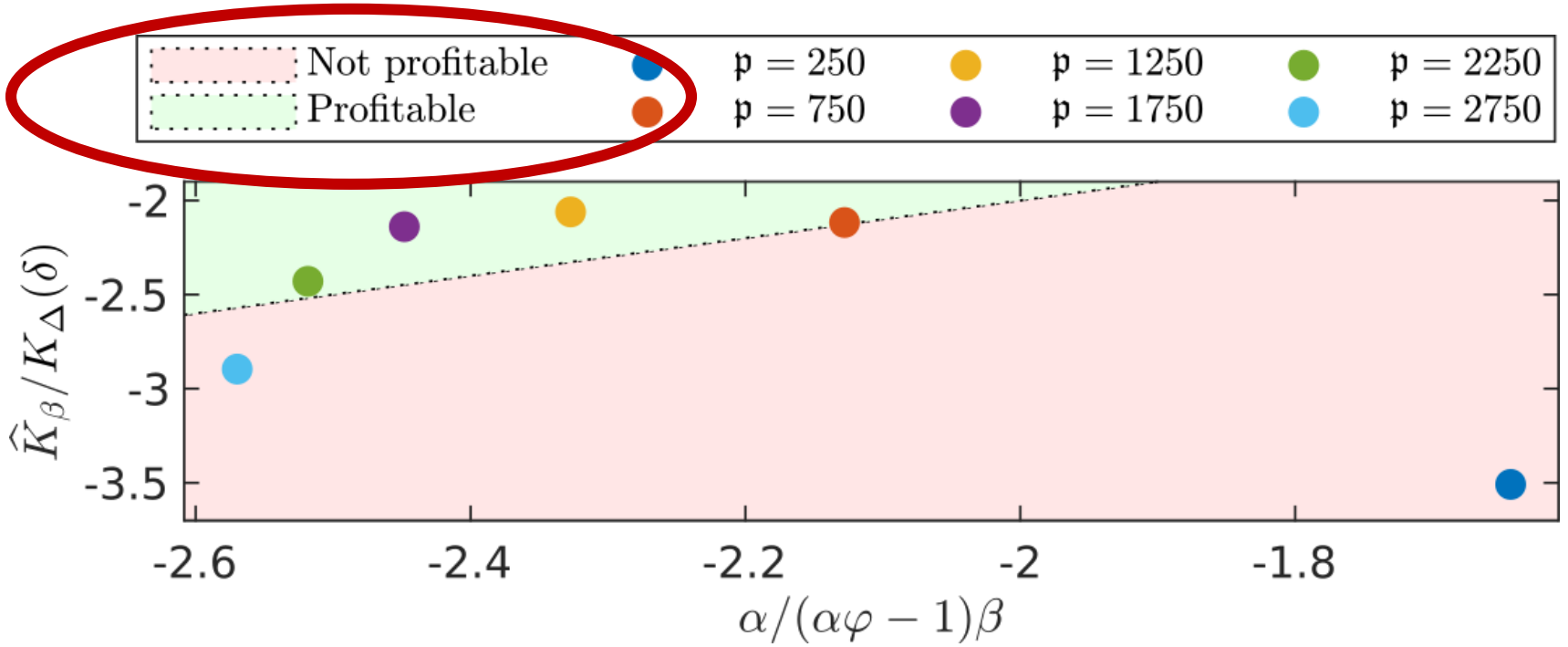
Some reconfigurations might not be feasible (not profitable)

- Use case: dynamic flow allocation in SDN network
  - Possible initial populations for a GA: $\mathfrak{p}$={250, 750, 1250, 1750, 2250, 2750}
  - Which initial population values of this Genetic Alg. lead to profitable networks?





normalized representation of demand parameters and flexibility measure

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Conclusion 2

- **Reacting to a demand takes time and cost**
- **Carefully consider which re-configuration to apply**

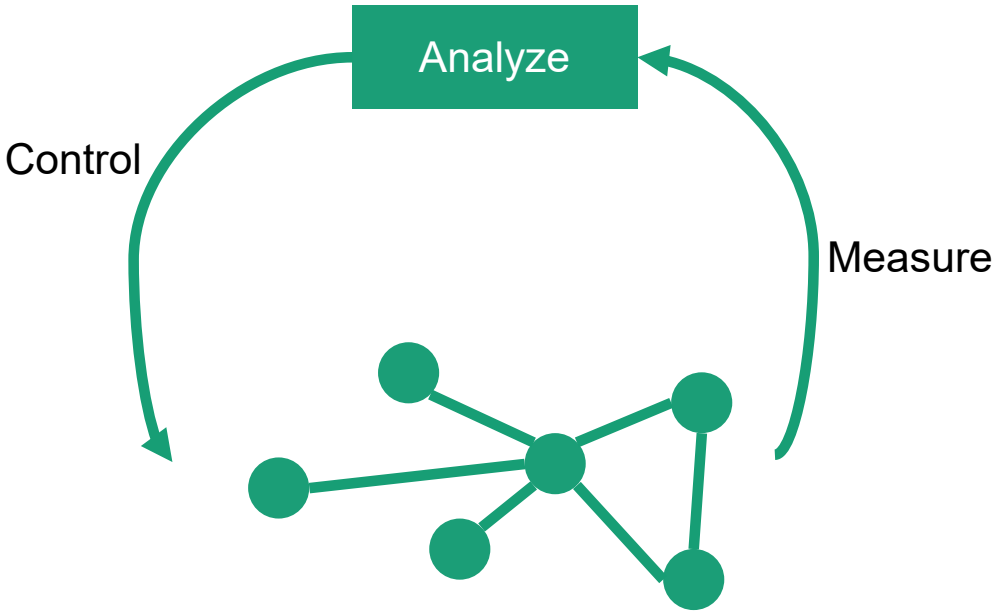
Conclusion 2

- Reacting to a demand takes time and cost
- Carefully consider which re-configuration to apply

Can we automate this?

Towards Autonomous Networks

- Network Managers' all-time Dream:
  lean back and watch!



Towards Autonomous Networks

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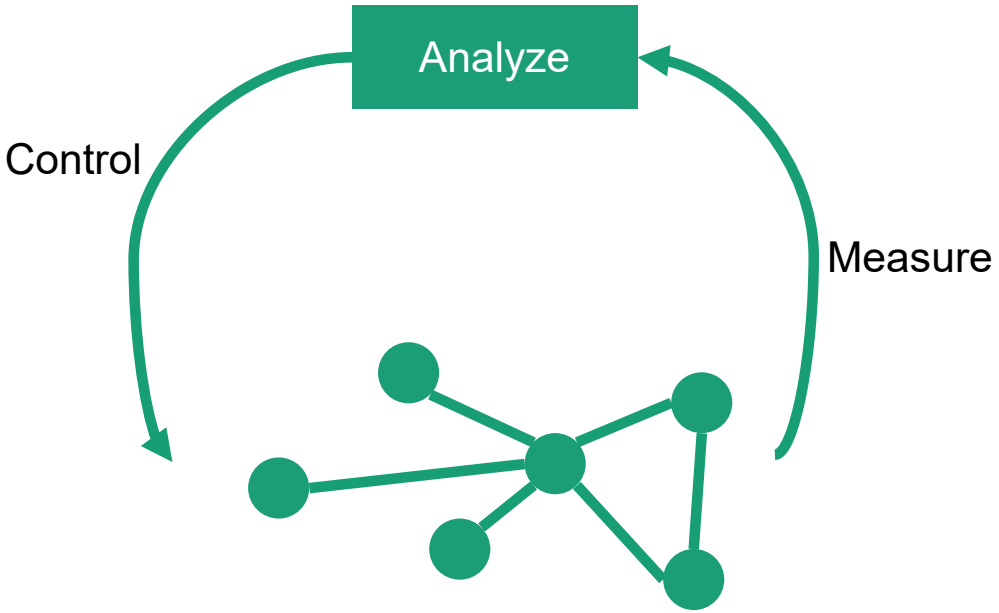
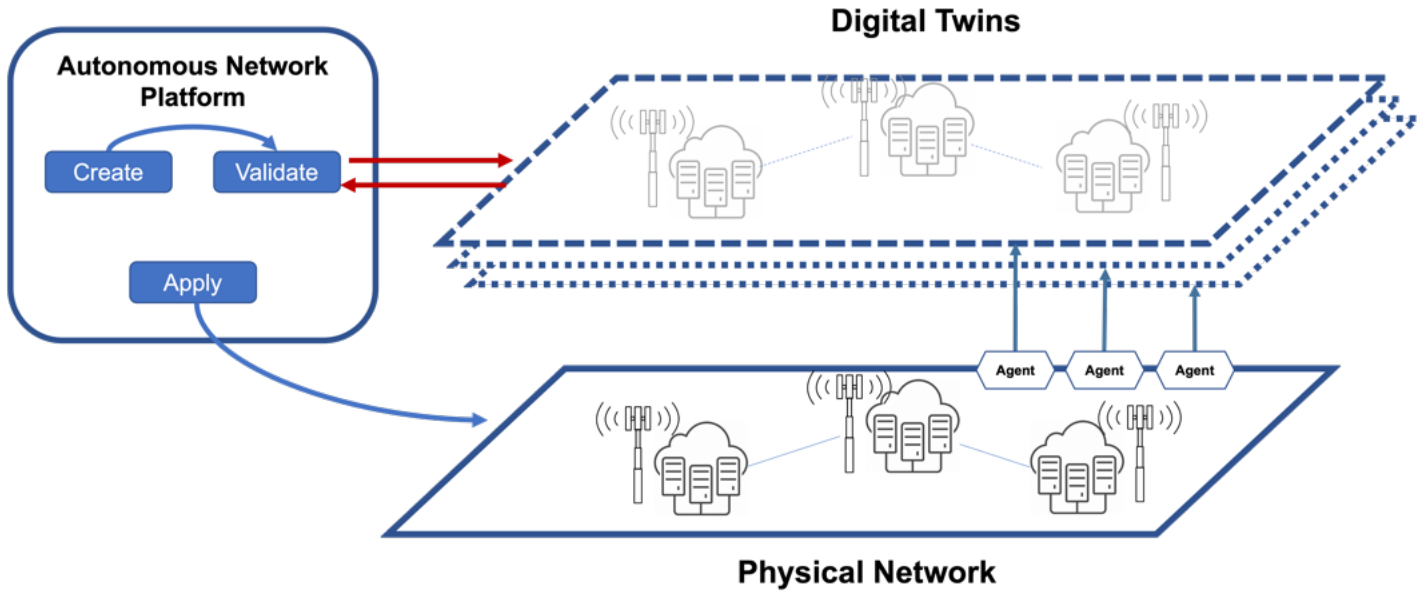


too risky?

Twin your network!



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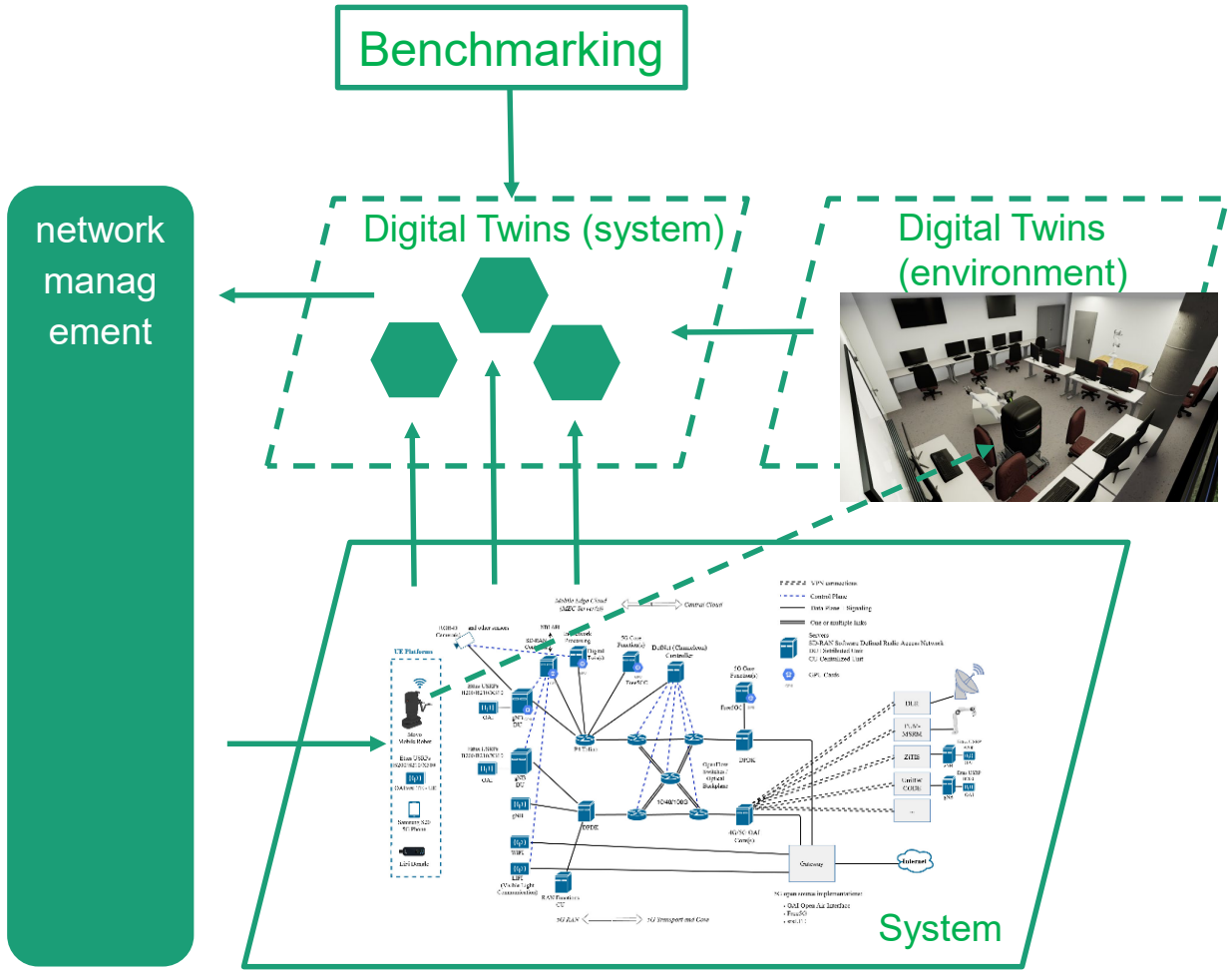
Network Digital Twins

- Network Digital Twin = synchronized copy of a system (component)
- DTs may get information from DTs representing the environment / channel (sensors, trajectories)
- DTs simulate system behavior to improve the system
- Input to simulation: (autonomous) benchmarking



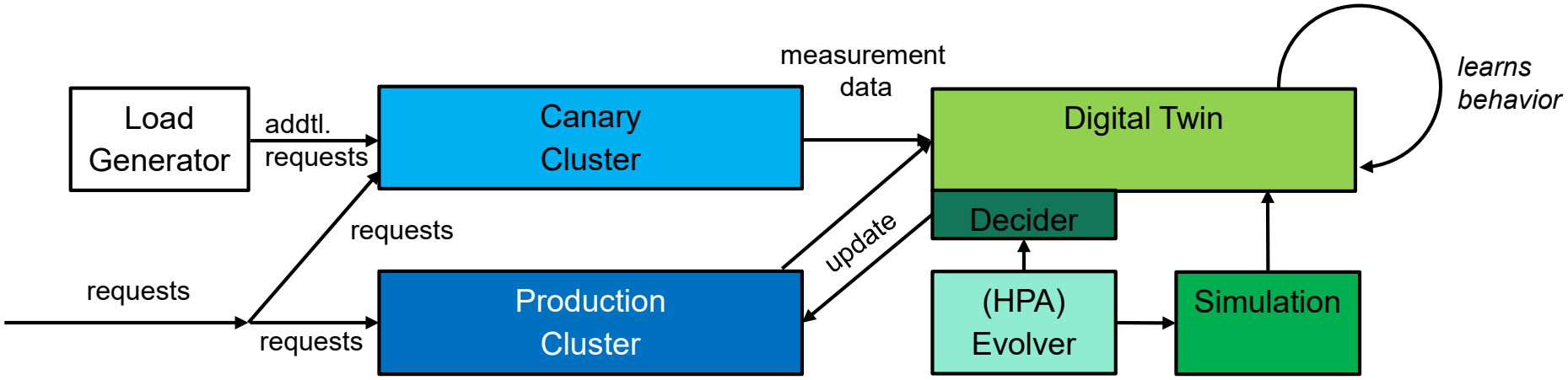
Zerwas, Johannes; Kalmbach, Patrick; Henkel, Laurenz; Retvari, Gabor; Kellerer, Wolfgang; Blenk, Andreas; Schmid, Stefan: NetBOA: Self-Driving Network Benchmarking. ACM SIGCOMM 2019 Workshop on Network Meets AI & ML (NetAI '19), 2019

Our contribution:

KAPETÅNIOS: Automated Kubernetes Adaptation through a Digital Twin

Concept

- self-operating Kubernetes (K8s) cluster
- uses digital twinning and machine learning to
- autonomously adapt its Horizontal Pod Autoscaler (HPA) to workload changes



Johannes Zerwas, Patrick Krämer, Razvan-Mihai Ursu, Navidreza Asadi, Phil Rodgers, Leon Wong, Wolfgang Kellerer
KAPETÅNIOS: Automated Kubernetes Adaptation through a Digital Twin. IEEE Networks of the Future, Ghent, Belgium, 2022.

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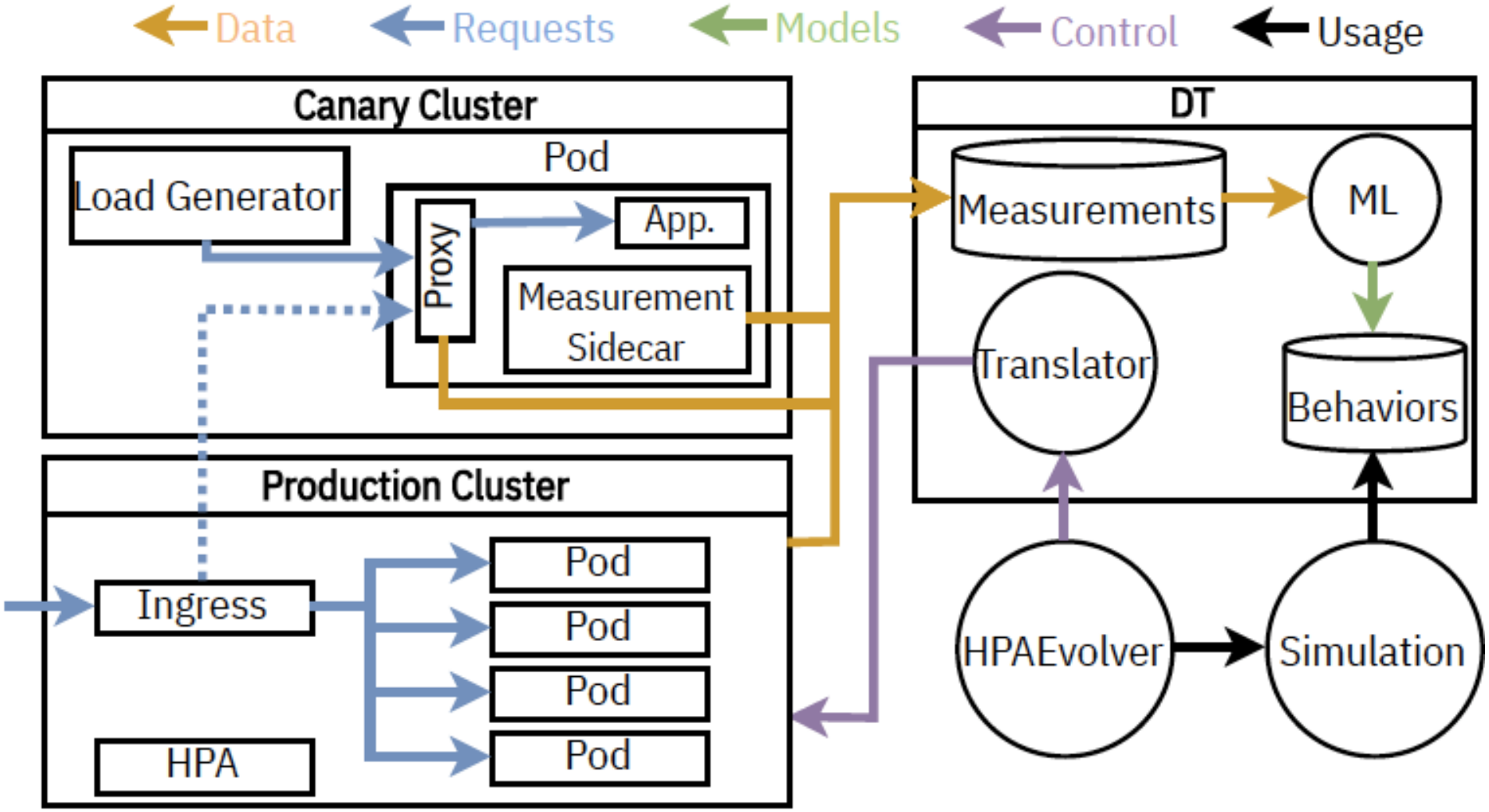

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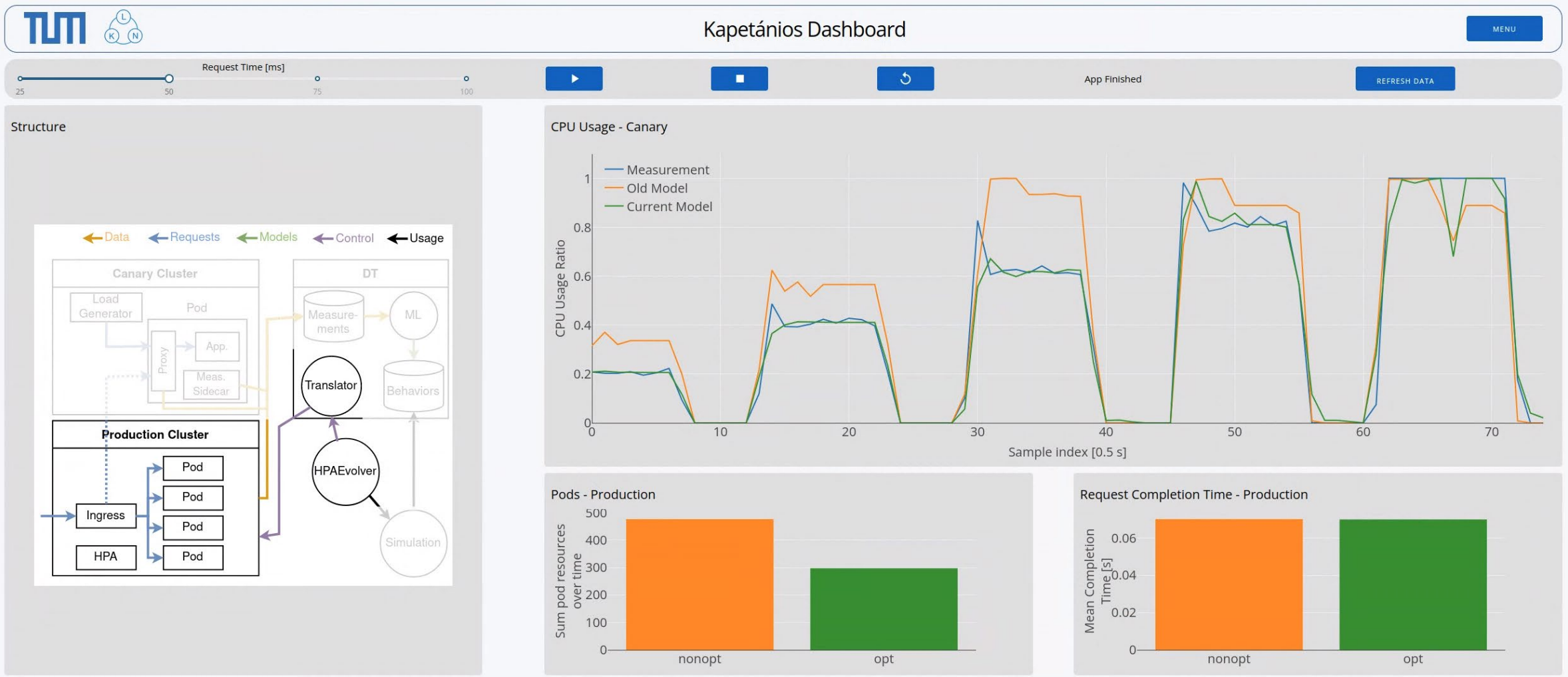

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How to obtain a Network Digital Twin?

… AI/ML may help

R.-M. Ursu, J. Zerwas, P. KrÅNamer, N. Asadi, P. Rodgers, L. Wong, and W. Kellerer, “Towards Digital Network Twins: Can we Machine Learn Network Function Behaviors?” in 2023 IEEE 9th International Conference on Network Softwarization (NetSoft), 2023,

How to obtain a Network Digital Twin?

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- *Can we Machine Learn Network Function Behavior?*

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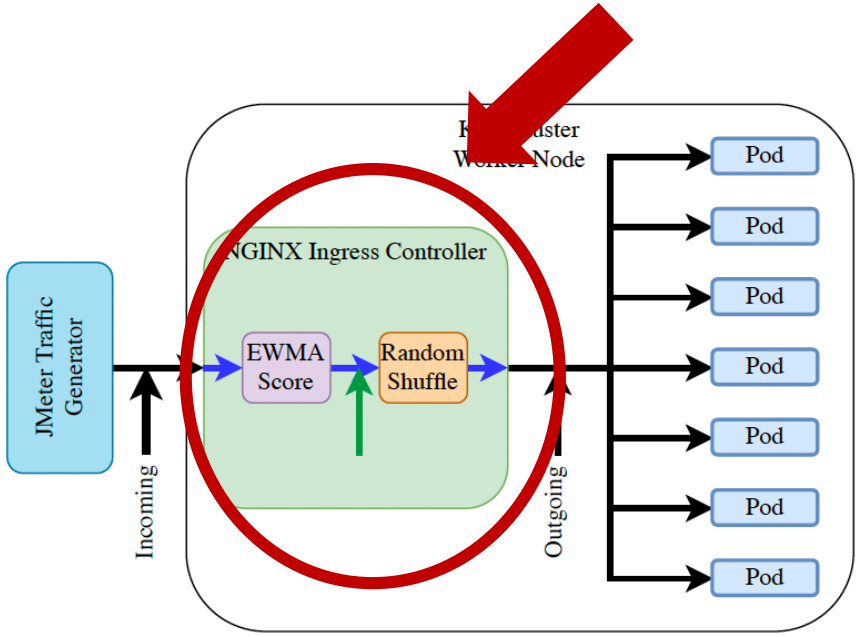
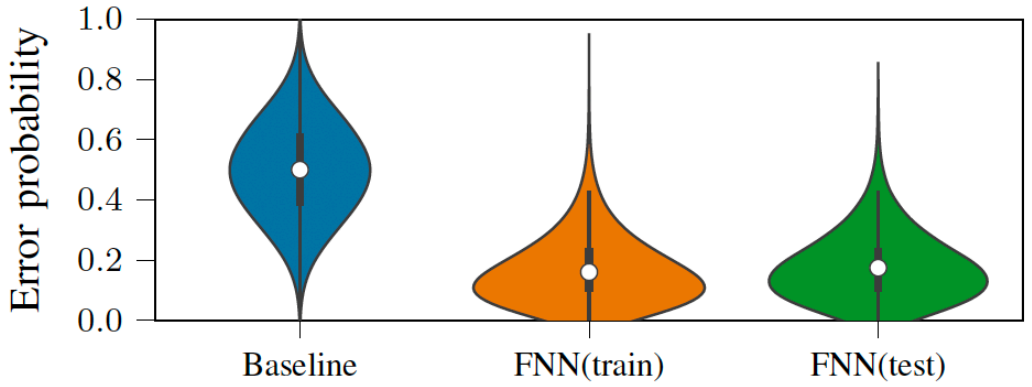
Can we machine learn network Functions Behavior?

Use case: Kubernetes Load Balancer





random decision

learned behavior

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How to obtain a Network Digital Twin?

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- *Can we Machine Learn Network Function Behavior?*
- *Can AI/ML automate learning?*

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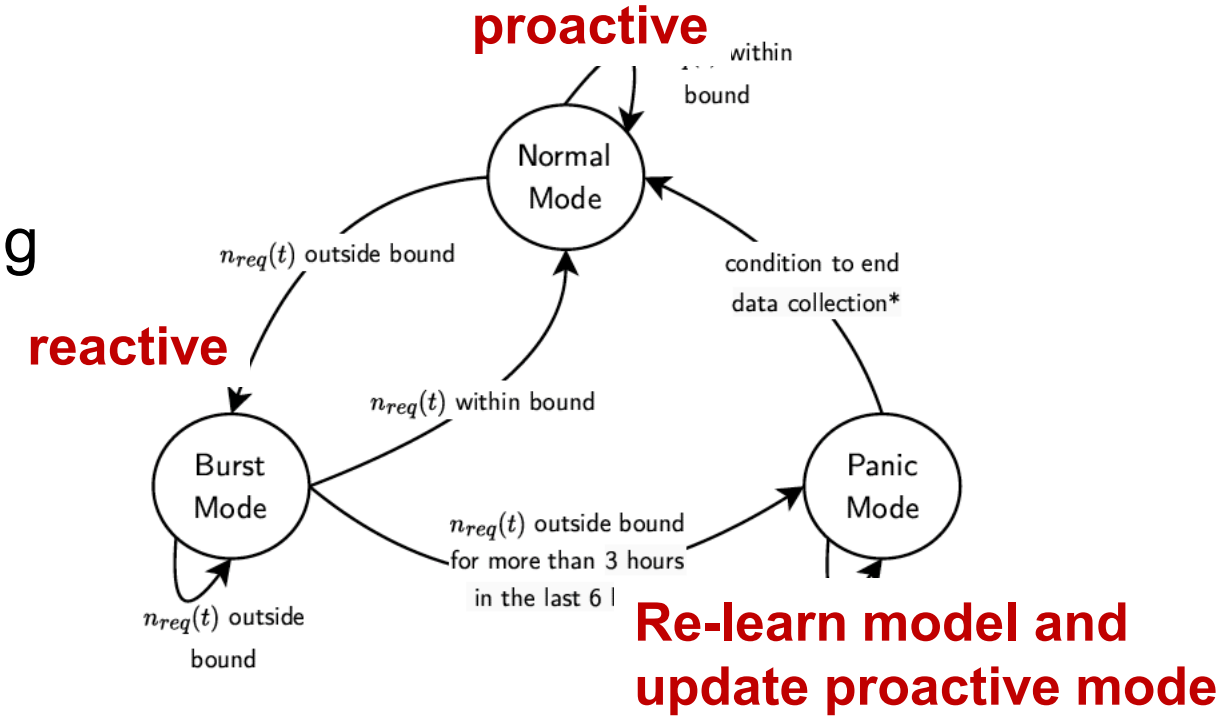
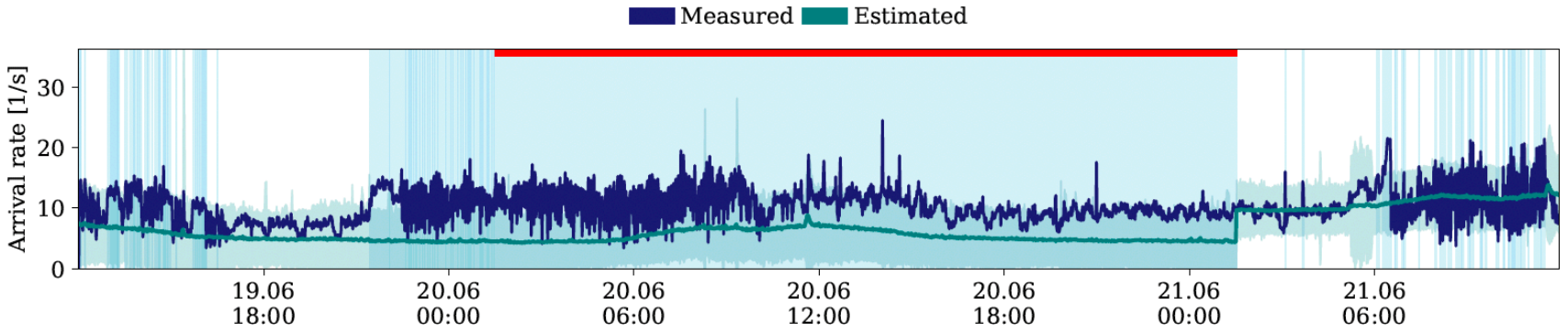
Can AI/ML automate learning?

- Use Case

  HYPA: Hybrid Horizontal Pod Autoscaling with Automated Model Updates





K. Aykurt, R.-M. Ursu, J. Zerwas, P. KrÅNamer, N. Asadi, L. Wong, and W. Kellerer, "HyPA: Hybrid Horizontal Pod Autoscaling with Automated Model Updates," in 2023 IEEE Conference on Network Function Virtualization and Software Defined Networks (NFV-SDN), 2023

Final Conclusion and Lessons Learned

- After SDN in the core, O-RAN provides SD-x based flexibility to the RAN
- We can actually measure such **network flexibility**
- Adaptation time and adaptation cost matter

www.networkflexibility.org

FlexNets

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erc European Research Council Established by the European Commission

- Towards **automated network management**
  we need a playground to decide in runtime, which reconfigurations to apply (feasible, profitable)

- **Network Digital Twins** provide a solution
- We provide Kapetanios
- We show that NDTs can be learned (instead of complex modeling)

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Rakuten Mobile

6G-life

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