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Network Flexibility

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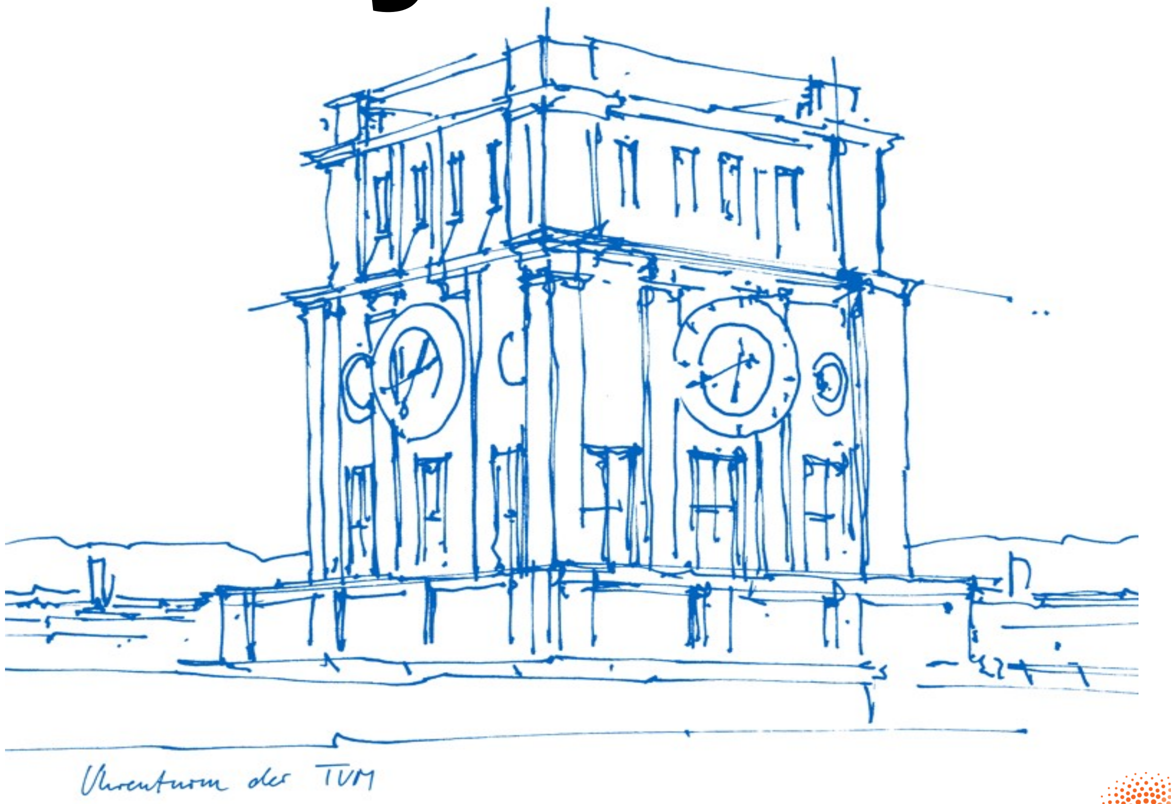

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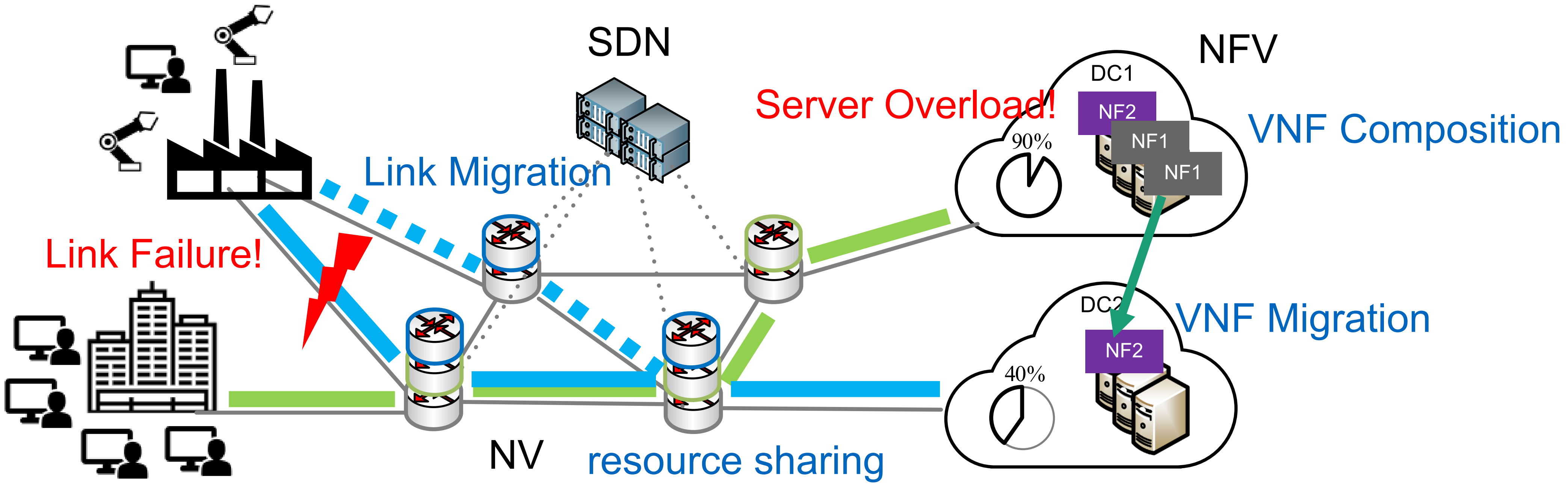
FlexNets

This work is part of a project that has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program grant agreement No 647158 – **FlexNets (2015 – 2020)**.

European Research Council
Established by the European Commission

Softwarized Networking: new way to design and operate networks



- Network Virtualization (NV)
- Network Function Virtualization (NFV)
- Software Defined Networking (SDN)

vast increase in design opportunities:

- performance increase
- cost reduction
- higher ***flexibility***

Outline

- A measure for network flexibility
- A use case (5G RAN function split)

Outline

- A measure for network flexibility (for system comparison)
- A use case (5G RAN function split)

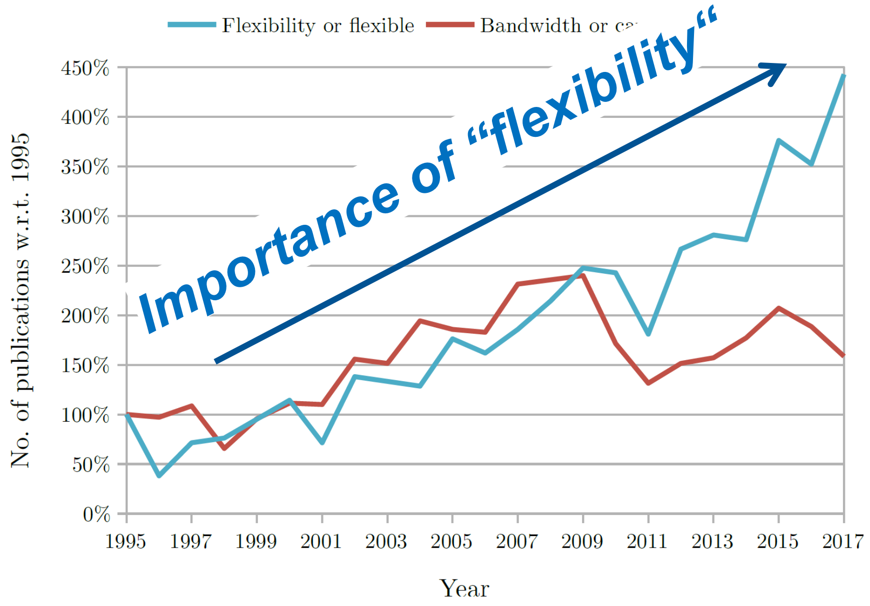
Network Flexibility

so far only qualitative

- **Flexibility is often a key argument for technology selection**

Recent survey [1] on 5G technology

reports
“flexible and scalable network”
as the top motivation
for technology investment
of 297 companies.



Evolution of the # of public. containing ”flexible” or ”flexibility” compared with those cont. ”bandwidth” or ”capacity” in 4 major IEEE public., normed to 1995.

[1] Sdxcentral. Carriers 5G Plans are Rooted in SDN/NFV, says Ixia Survey. [Online]. Available: https://www.sdxcentral.com/articles/news/carriers-5g-plans-rooted-sdnnfv-says-ixia-survey/2017/09/?c action=related articles

A common understanding is missing
We lack a quantitative measure for network flexibility

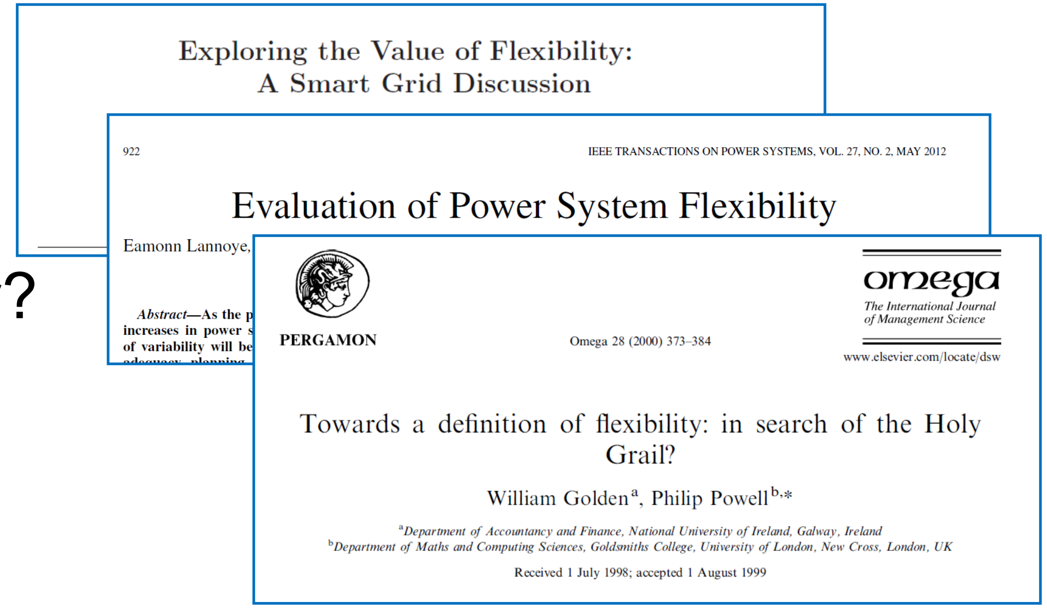
M. He, et al. *Flexibility in Softwarized Networks: Classifications and Research Challenges*. IEEE Communication Surveys & Tutorials, 2019.

Network Flexibility

so far only qualitative

- **Flexibility is often a key argument for technology selection**

- What is ***network flexibility*** ?
- Are we 100% flexible already (e.g. with NFV)?
- What is an optimal network design for flexibility?


Exploring the Value of Flexibility:
A Smart Grid Discussion

922 IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 27, NO. 2, MAY 2012

Evaluation of Power System Flexibility

Eamonn Lannoye,

PERGAMON Omega 28 (2000) 373–384 omega The International Journal of Management Science www.elsevier.com/locate/dsw

Towards a definition of flexibility: in search of the Holy Grail?

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Received 1 July 1998; accepted 1 August 1999

- We propose a quantitative measure for network flexibility
  - Quantify the benefit of flexibility
  - Compare different systems / algorithms
  - Design for flexibility

W. Kellerer, *et al.*, “How to measure network flexibility? A proposal for evaluating softwarized networks,” *IEEE Communications Magazine*, 2018.

A Measure for Network Flexibility

- Evaluation of network systems today
  – Maximize an objective, e.g., throughput or availability or Minimize e.g., cost, latency

- Flexible systems keep future options open
- **Flexibility measure**:
  how good can different implementations **adapt** to future challenges?
- Adaptation: **time** and **cost** are significant constraints

Network **flexibility** = ability to support *adaptation requests (challenges)* (e.g., new requirements or traffic patterns) in a *timely* and *efficient* manner

www.networkflexibility.org

W. Kellerer, *et al.*, "How to measure network flexibility? A proposal for evaluating softwarized networks," *IEEE Communications Magazine*, 2018.

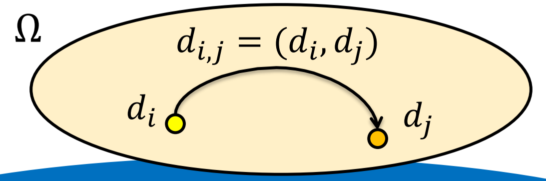
Measuring Network Flexibility (our proposal)

(comparing network designs)

- Input: System with Objective and Constraints T, C
- Input: Request set $\boldsymbol{D} = \{d_{i,j} \dots\}$ with $d_{i,j} \in \Omega \times \Omega$

1. Initialize $\Sigma \coloneqq 0$
2. FOR k = 1:K
   a. Challenge state change
      $d_{i,j}(t'): d(t'-1) = d_i \rightarrow d(t') = d_j,\ d_i \neq d_j$
   b. Observe τ_k and c_k
   c. If $\tau_k \leq T$ and $c_k \leq C$: $\Sigma \coloneqq \Sigma + 1$
3. END
4. $\varphi(T, C) \coloneqq \Sigma / K$

adaptation time threshold (T) and cost budget (C)



challenges: request sequence demanding to adapt

For each challenge: check if system can adapt and record time and cost

count successes

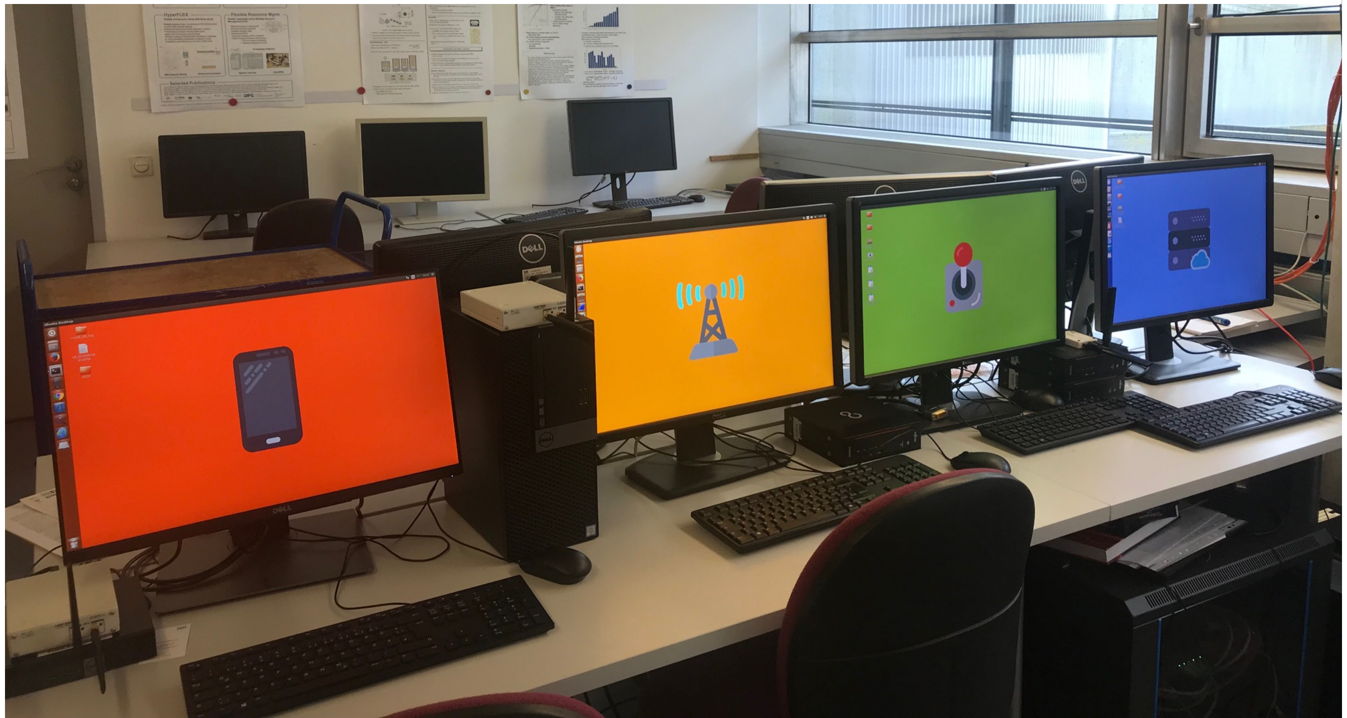
Flexibility
(a success rate)

$$\varphi(T, C) = \frac{|\text{supported requests within constraints } (T, C)|}{|\text{number of requests}|}$$

M. Klügel, M. He, W. Kellerer, P. Babarczi: *A Mathematical Measure for Flexibility in Communication Networks*. **IFIP NETWORKING 2019** (to appear)

Outline

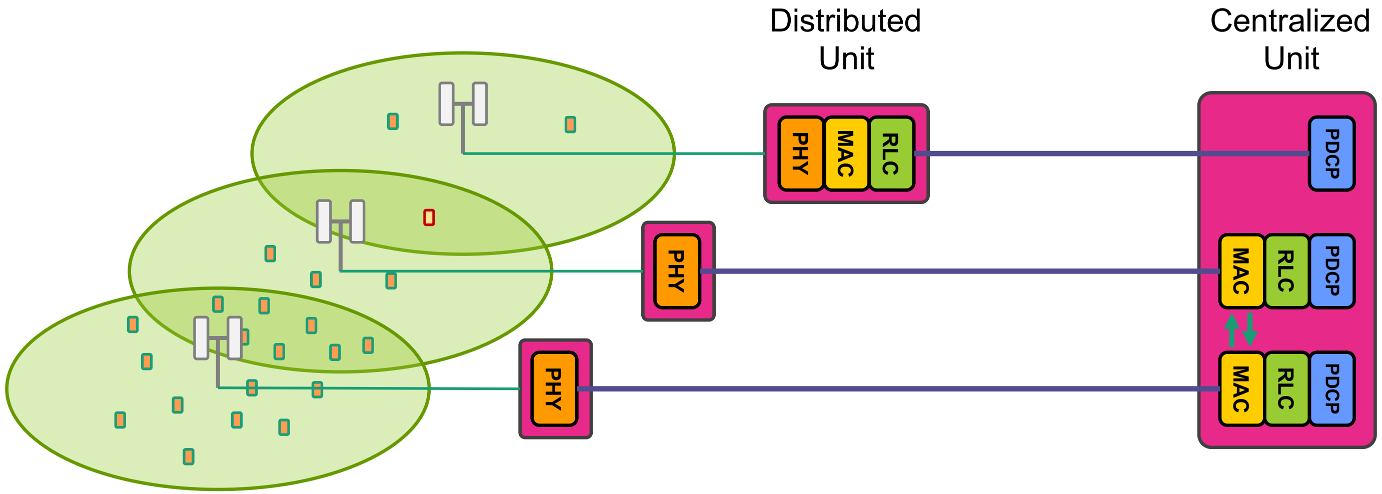
- A measure for network flexibility (for system comparison)
- A use case (5G RAN function split)



Based on a full Proof-of-Concept implementation at TUM

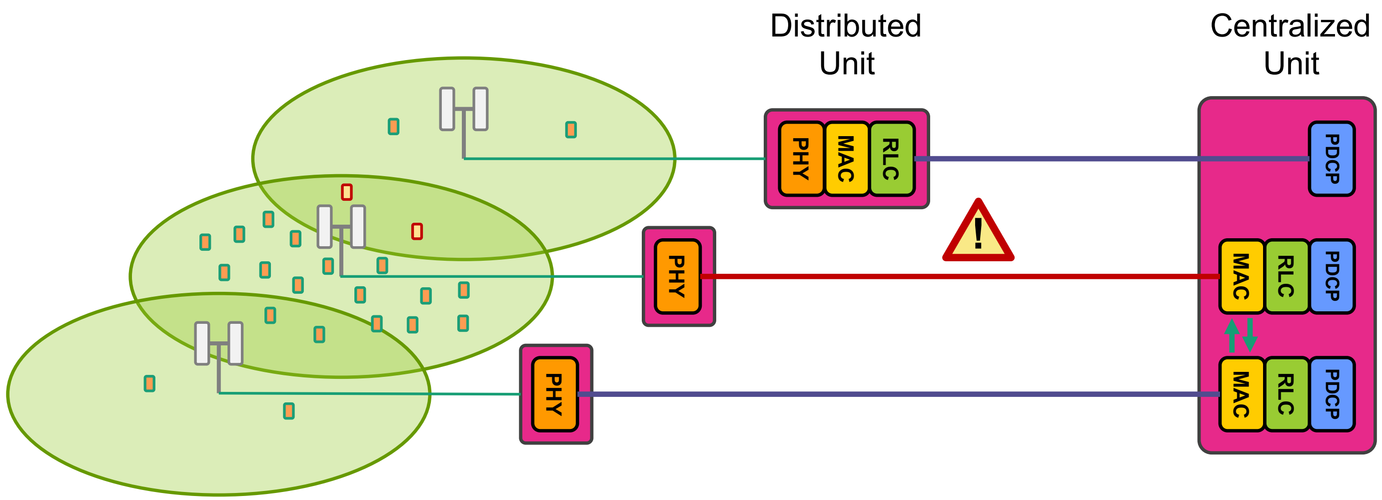
Fixed 5G Function Split

- Function split implemented on dedicated hardware
- Difficult to update
- Deviations from expected distribution of users lead to



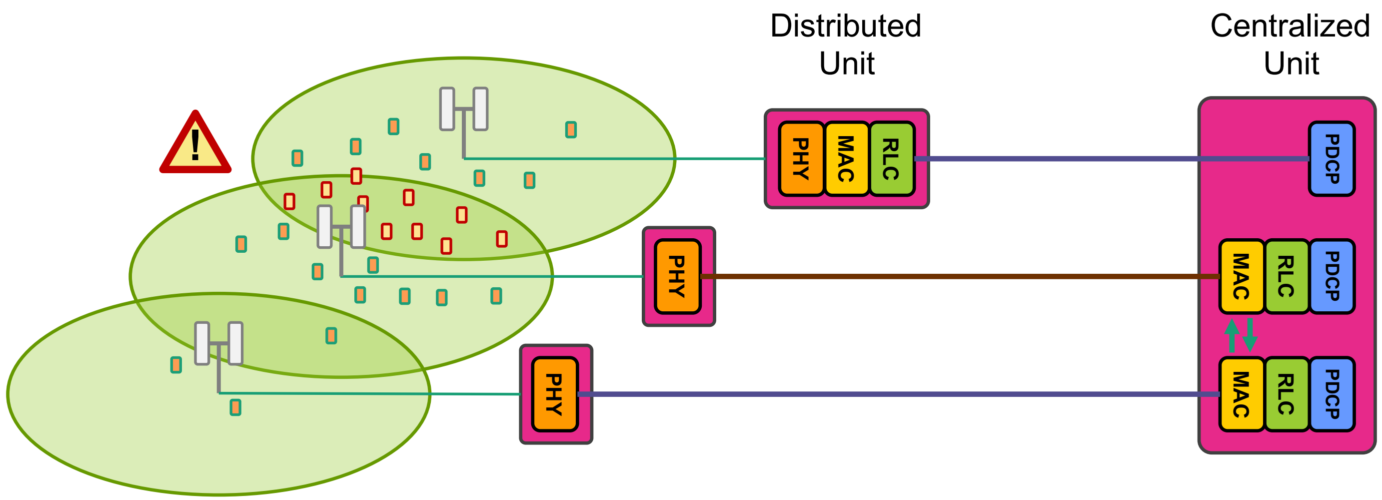
Fixed 5G Function Split

- Function split implemented on dedicated hardware
- Difficult to update
- Deviations from expected distribution of users lead to
  - Network congestion



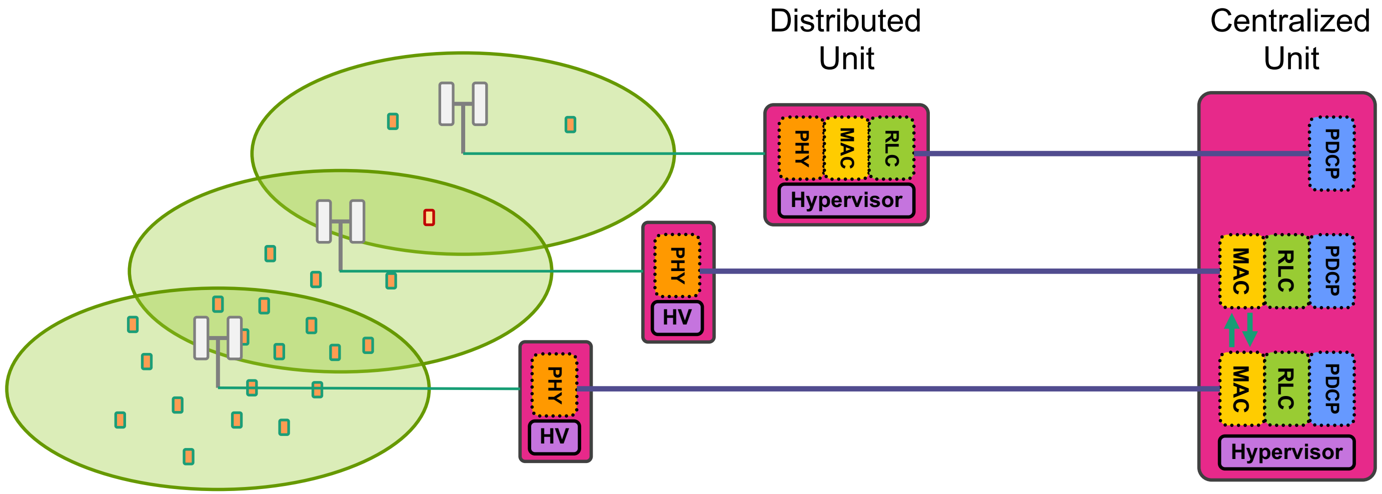
Fixed 5G Function Split

- Function split implemented on dedicated hardware
- Difficult to update
- Deviations from expected distribution of users lead to
  - Network congestion
  - Unmanaged interference



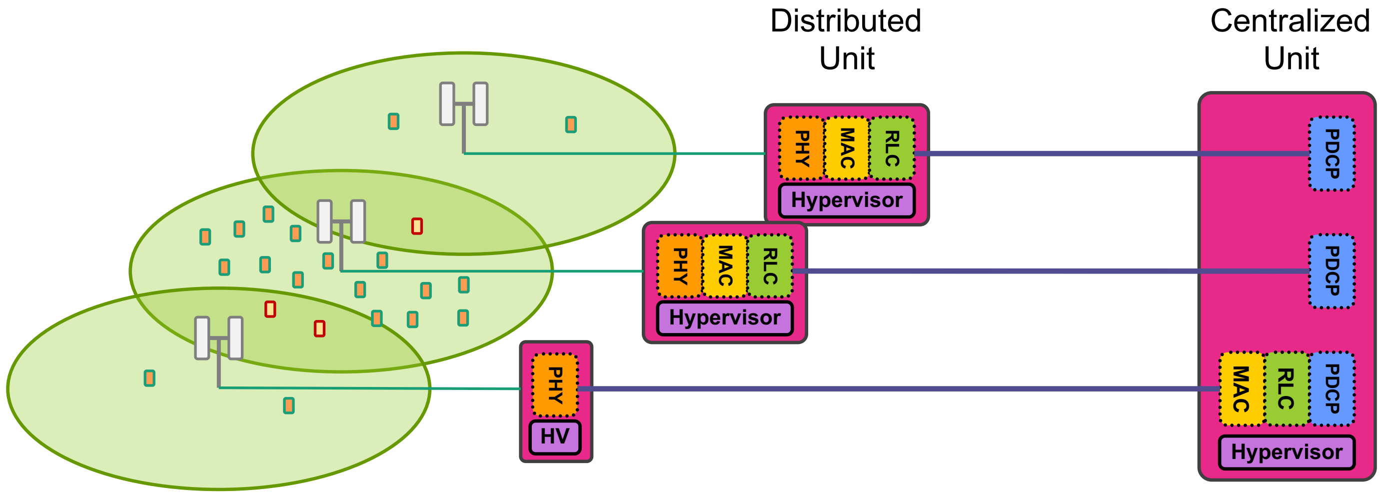
NFV-based 5G+ Function Split

- Functions are softwarized and implemented on off-the-shelf hardware
- Simple to deploy and update



NFV-based 5G+ Function Split

- Functions are softwarized and implemented on off-the-shelf hardware
- Simple to deploy and update
- Functions can be migrated to adapt to network changes



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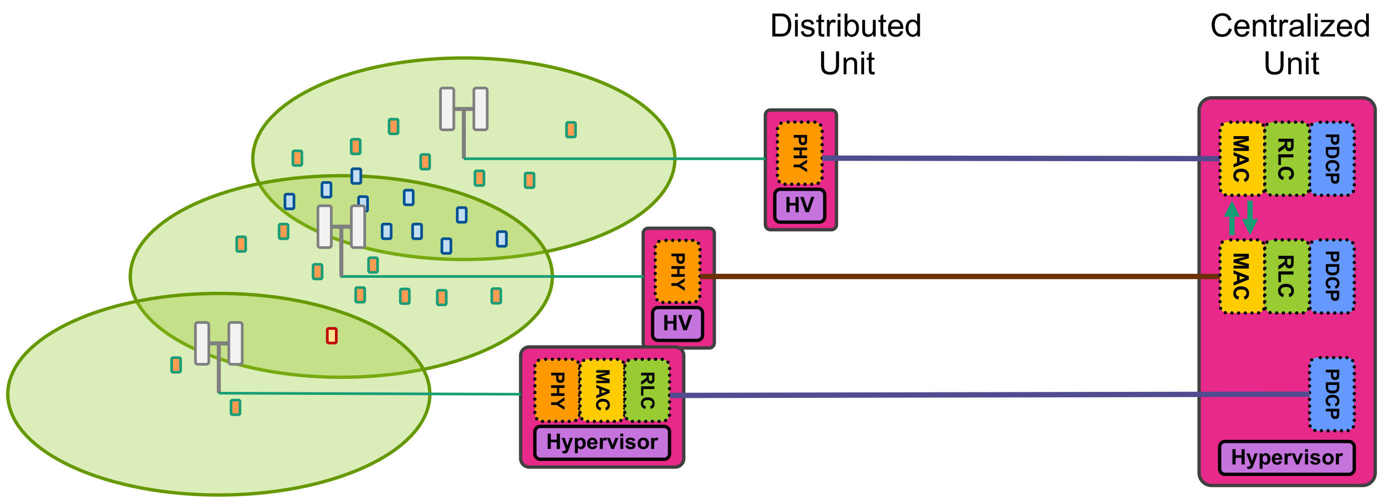
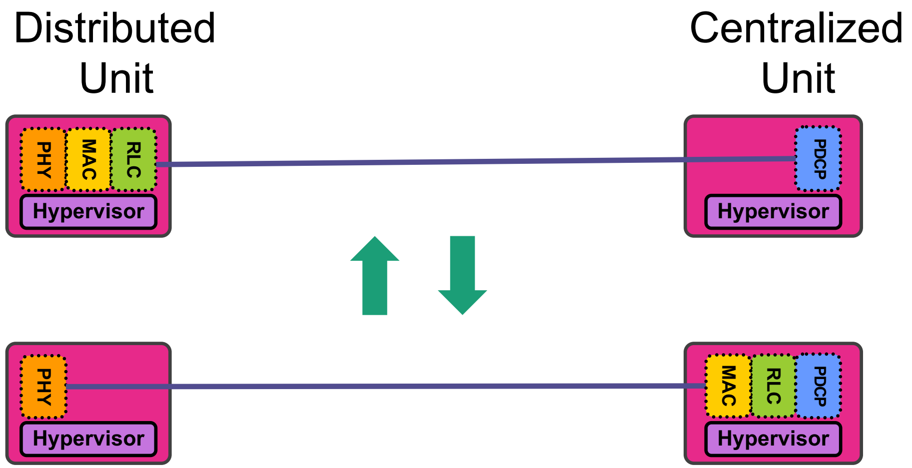


NFV-based 5G+ Function Split Use Case: **Focus on Adaptation**

- Use case: PHY-MAC split and RLC-PDCP split (for this example)
- Adaptation: dynamic migration between the two split options
- Constraints (for measuring flexibility)
  - Time T to complete function migration
    - If too high (e.g. higher than the scheduling interval) ⇒ Packet losses and latency
  - Cost C required to perform the adaptation
    - Packet losses
    - Computational cost
    - Power consumption

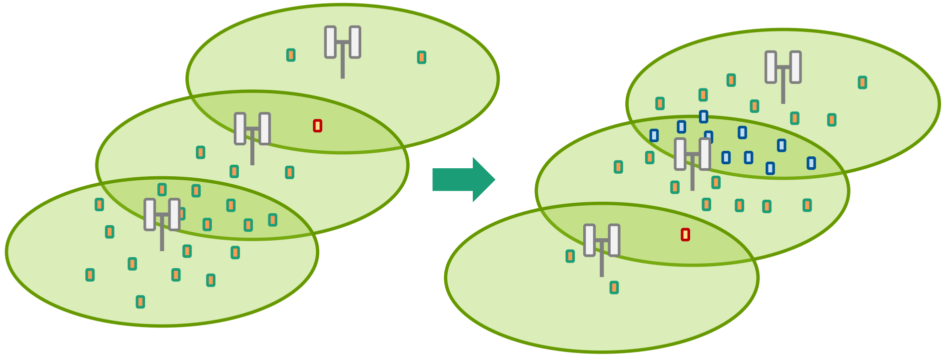


NFV-based 5G+ Function Split: **Flexibility Measure**

- **Objective:** maximize data rate for all UEs
- **Topology:** 18 DUs and 1 CU
  - The CU can implement up to 4 MAC-PHY DUs
- **Challenges:** change in the UEs distribution
- **Successful adaptation:** reach 80% of the data rate of the optimal configuration within T ms with cost C packet losses

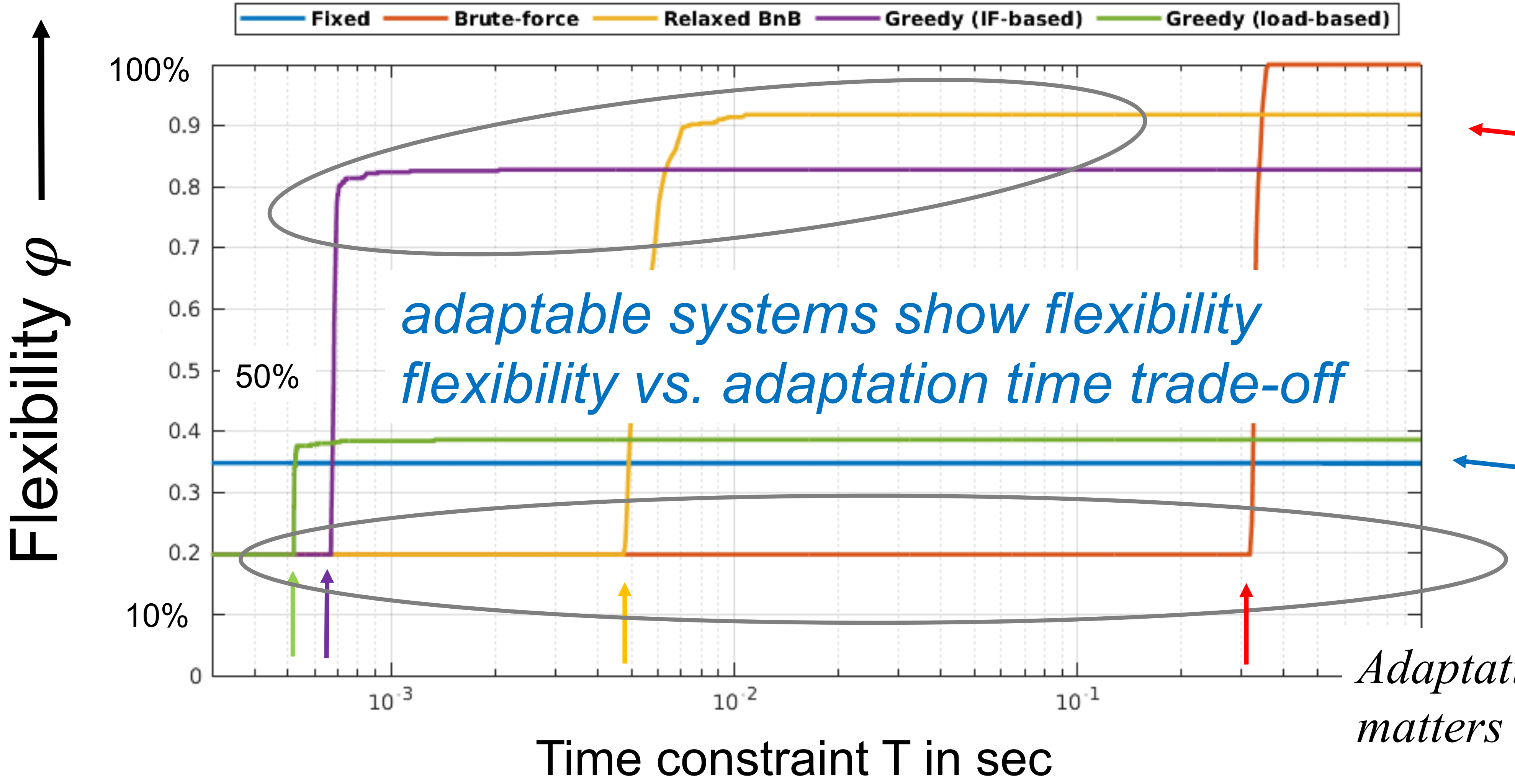
- **Systems under comparison:**
  - Fixed functional split

  NFV-based functional split:
  - Greedy algorithms (load-based)
  - Greedy algorithm (IF-based)
  - Lagrangian-relaxed BnB (branch-and-bound)
  - Brute-force search



NFV-based 5G+ Function Split: **Flexibility Measure Results**

- Flexibility measure $$\varphi = \frac{\text{successful adaptations given } T \text{ and } c}{\text{all challenges}}$$ for $C \rightarrow \infty$



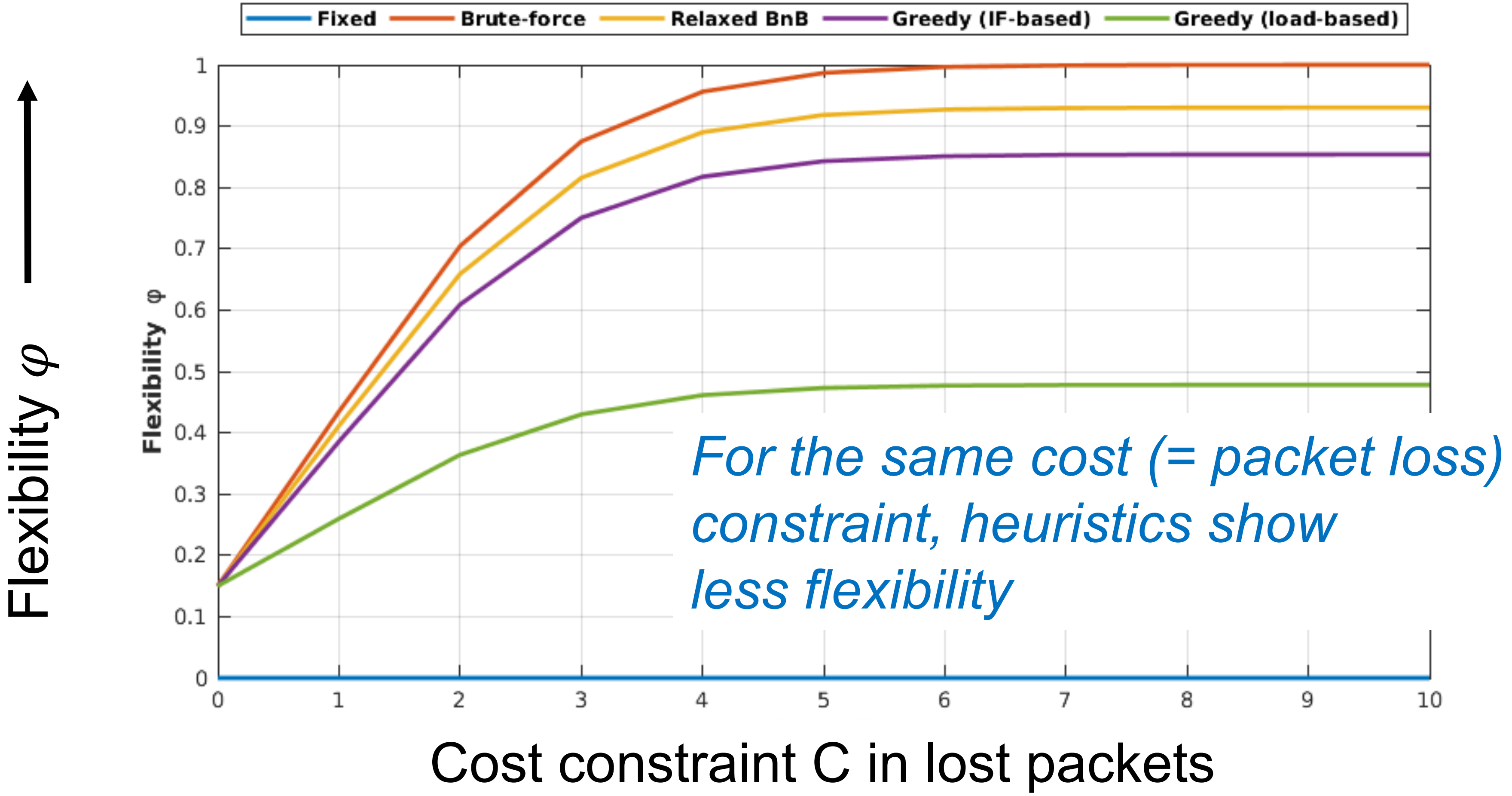
Simple (faster) algorithms do not reach high flexibility

Fixed split is least flexible (and T indep.)

Adaptation time matters

NFV-based 5G+ Function Split: **Flexibility Measure → Cost**

- Here: Cost C = number of packets lost during adaptation (= addtl. cost for adapt.)
- for $T \rightarrow \infty$



Summary

- Softwarized Networks provide flexible network adaptation
- Flexibility needs to be quantified (→ measure)
  - to compare flexible systems
  - to explicitly design for flexibility
- Proposed flexibility measure takes time and cost explicitly into account

more on networkflexibility.org

References

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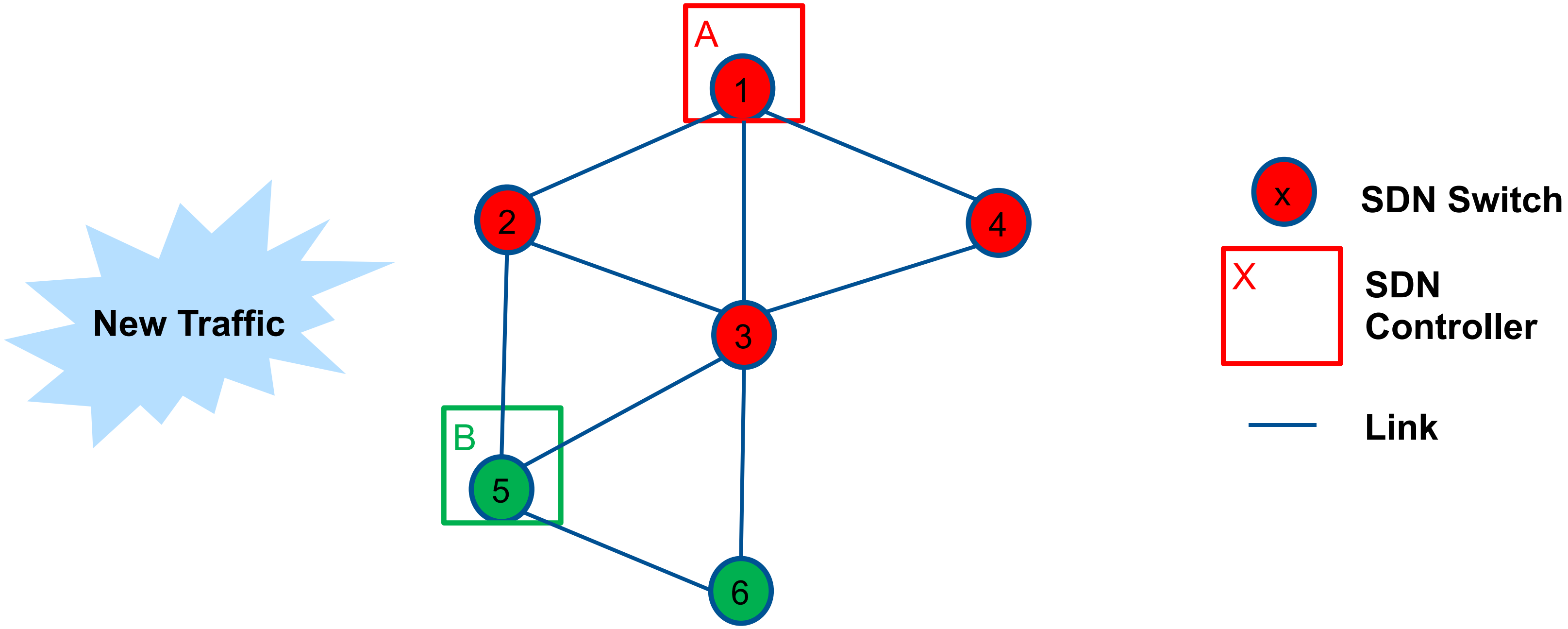
W. Kellerer, A. Basta, A. Blenk, *Using a Flexibility Measure for Network Design Space Analysis of SDN and NFV*, **IEEE INFOCOM Workshop**, SWFAN'16, SF, USA, April 2016.

A. Martínez Alba, J. Gómez Velásquez, W. Kellerer, *An adaptive functional split in 5G networks*. **IEEE INFOCOM WKSHPS** - 3rd Workshop on Flexible and Agile Networks: 5G and Beyond, Flexnets'19, Paris, France, 2019.

Case study 1: Dynamic Controller Placement



- Traffic fluctuations require control plane to adapt in order to achieve better control performance → *Dynamic Control Plane*
  - SDN controller migration & SDN switch reassignment

Case Study	Flexibility Aspect	New Request	Flexibility Measure	System Objective	Cost in focus
ynamic SDN roller placement	function placement	new flow arrival (from distribution)	fraction of successful controller placements	control performance: (min. avg. flow setup time)	operation latency (OPEX): avg. flow setup time

Case study 1: Dynamic Controller Placement

Varying traffic flow profiles

max. adaptation time threshold
(will be varied)

$$\varphi_T(S) = \frac{|supported\ requests\ within\ T|}{|given\ new\ requests|}$$

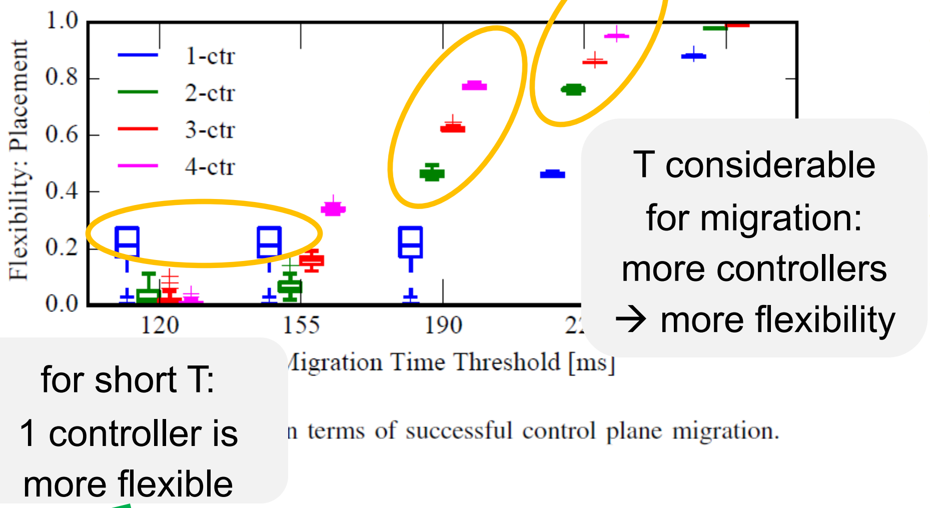
C -> ∞
recorded

SDN controller migration and switch reassignment can be done within T

- Flexibility → Migration Success Ratio
  - Calculate controller migration and switch reassignment time *T_migration*
  - If *T_migration* smaller than T → count as a supported request

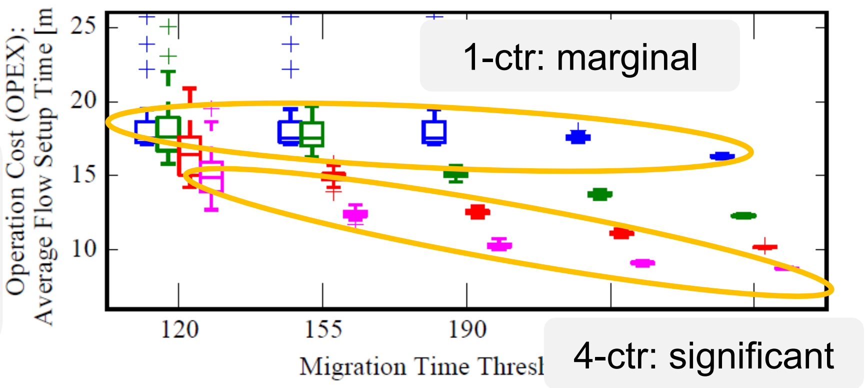
Case study 1: Dynamic Controller Placement

Flexibility



n terms of successful control plane migration.

Cost



(b) Operation cost (OPEX) in terms of the average flow setup time.

intuitive

- **More controllers** (larger migration time threshold) → higher flexibility
- **Single controller** case: more flexible for **tight time threshold** as probability that single controller stays in optimal location is high

unexpected!

- 1 controller → **marginal** performance improvement vs. adaptation T
- 4 controllers → **significant** performance improvement vs. adaptation T
- However, if we consider **all cost factors**, we can reach a trade-off!

M. He, A. Basta, A. Blenk, W. Kellerer, *How Flexible is Dynamic SDN Control Plane?*, IEEE INFOCOM Workshop, SWFAN'17, Atlanta, USA, May 2017.

Case study 2: SDN Resilience

- Flexibility aspect of **flow configuration** for a **resilience** scenario in an SDN network under a given **recovery time** threshold T.
- Objective: system recovery
- Compare 3 systems: 1:1 protection vs 1+1 protection vs restoration
- Flexibility measure: fraction of recoverable failures
- New requests: all possible **single and dual link failures**

Flexibility Aspect	New Request	Flexibility Measure	System Objective	Cost in focus
flow configuration	all possible single and dual failures	fraction of recoverable failures	system recovery: (single and dual failures)	resources overhead (CAPEX): node and link reservation

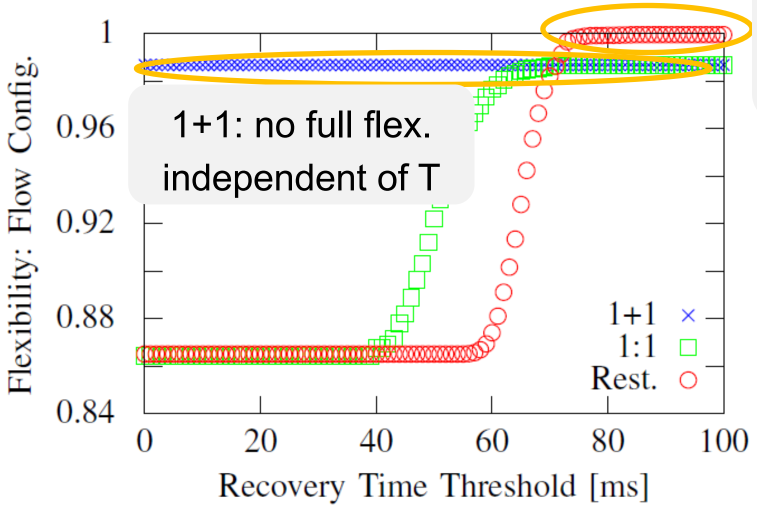
Case study 2: SDN Resilience

- **1:1 protection**
  - primary and backup paths pre-calculated
  - backup path is inactive
  - need switching time between primary and backup in case of a failure

- **1+1 protection**
  - primary and backup paths pre-calculated
  - primary and backup paths are both active
  - recovery time is almost instantaneous!

- **Restoration**
  - no backup path in advance
  - switch detect failure → controller informed → re-routes affected flows
  - recovery time is very critical

Case study 2: SDN Resilience



(a) Flexibility in terms of covered single and dual link failures.

	Resources Cost (CAPEX)	
	Node reservation: Avg. number of flow table entries	Link reservation: Number of required links
1 + 1	11.78	13038
1 : 1	11.78	13038
Rest.	5.05	5400

(b) System resources cost (CAPEX) in terms of nodes and links used for reservation.

intuitive

- 1+1 **can not** reach **full flexibility**
- However, 1+1 is obviously **independent** of **recovery time**
- Restoration can cover **all failures** if given enough recovery time

intuitive

- Protection imposes more than **2x capex overhead** than restoration
- Again, if we consider **all cost factors**, we can reach a trade-off!