Chair of Communication Networks
Department of Electrical and Computer Engineering
Technical University of Munich

Flexible and Data-Driven Softwarized Networks

Wolfgang Kellerer

Technical University of Munich (TUM), Germany

with Prof. Dr. Peter Babarzci, Dr. Andreas Blenk, Dr. Arsany Basta, Mu He, Patrick Kalmbach, Dr. Markus Klügel, Alberto Martinez Alba, Prof. Dr. Martin Reisslein, Prof. Dr. Stefan Schmid, Johannes Zerwas

NetSoft 2020, Ghent, Belgium, July 2, 2020

Based on work published in W. Kellerer, et al. *Adaptable and Data-Driven Softwarized Networks: Review, Opportunities and Challenges*. In Proc. of the IEEE, Vol 107, No 4. 2019.

www.networkflexibility.org

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)**.

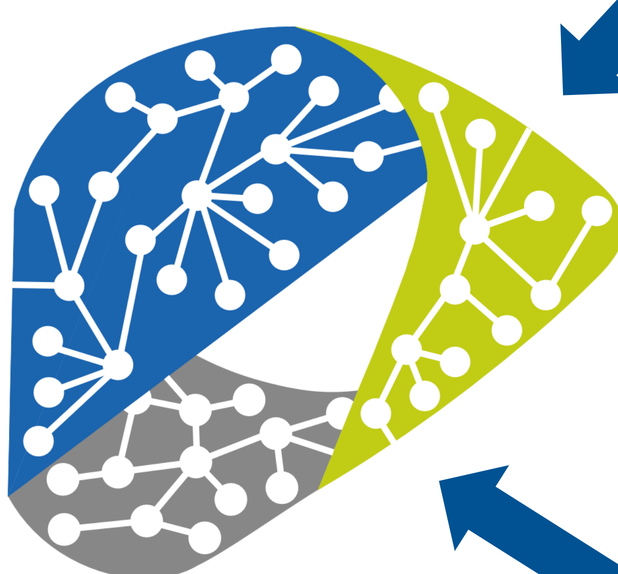
European Research Council
Established by the European Commission

Need for Flexible Network Adaptation

software
updates

all universities
do online
streaming

mega
events



overnight
popular app

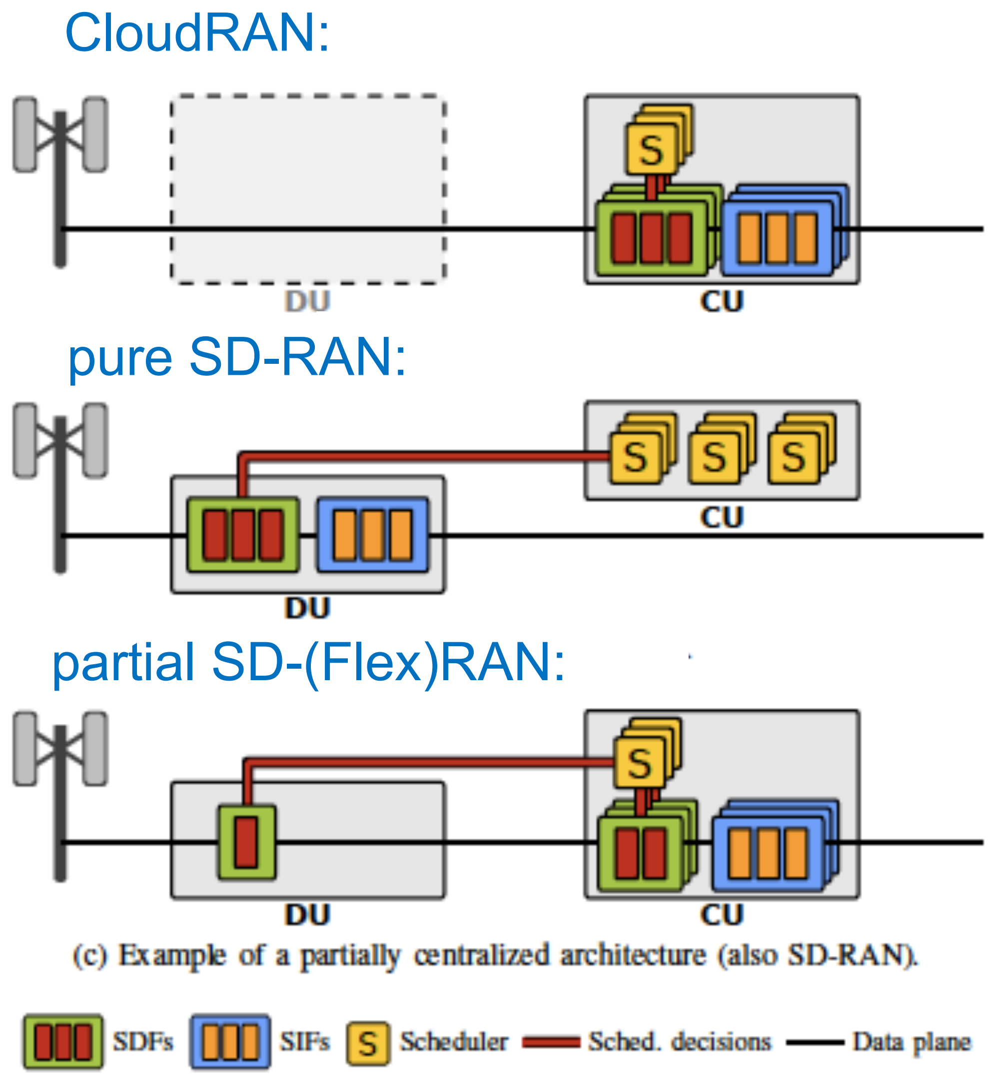
content source
suddenly switches
to home office

to react to dynamic events network as a critical infrastructure
has to <u>adapt</u> to new contexts

Flexible network adaptation example

- Radio Access Network plus SDN/NFV
  → SD-(Flex) RAN

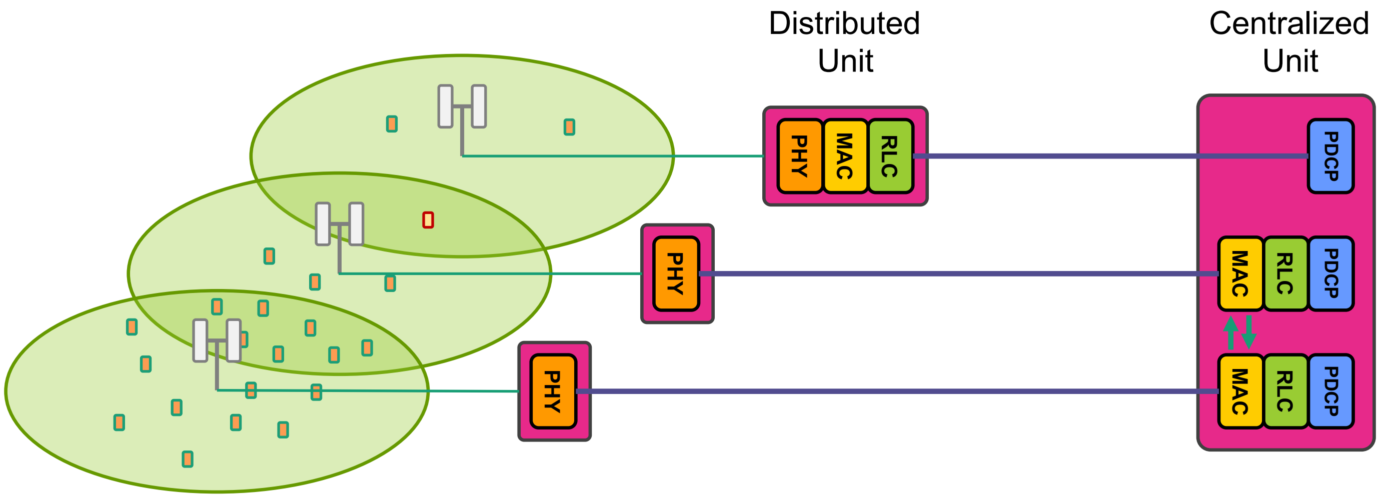
- Dynamic allocation of RAN functions across fixed function split boundaries addressing
  - user densities
  - resource availability



(c) Example of a partially centralized architecture (also SD-RAN).

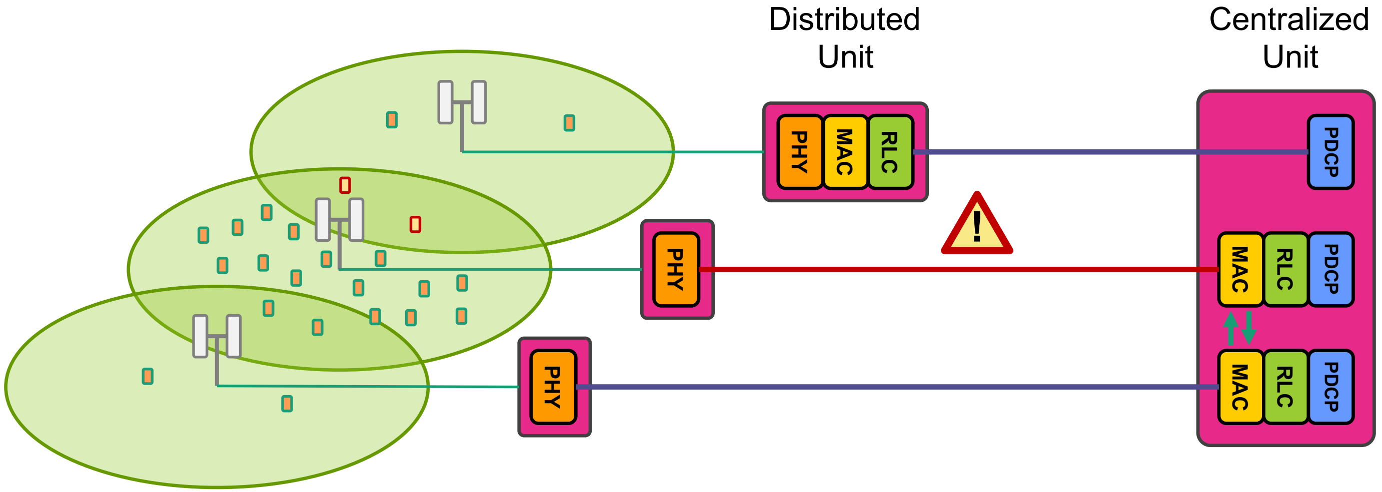
Fixed 5G Function Split

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



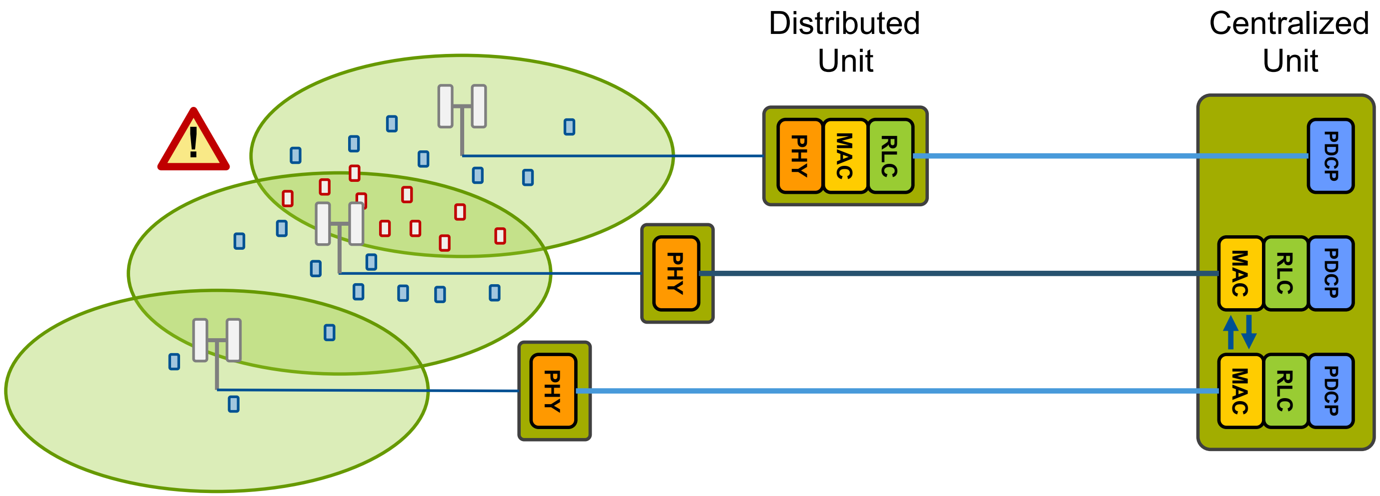
Fixed 5G Function Split

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



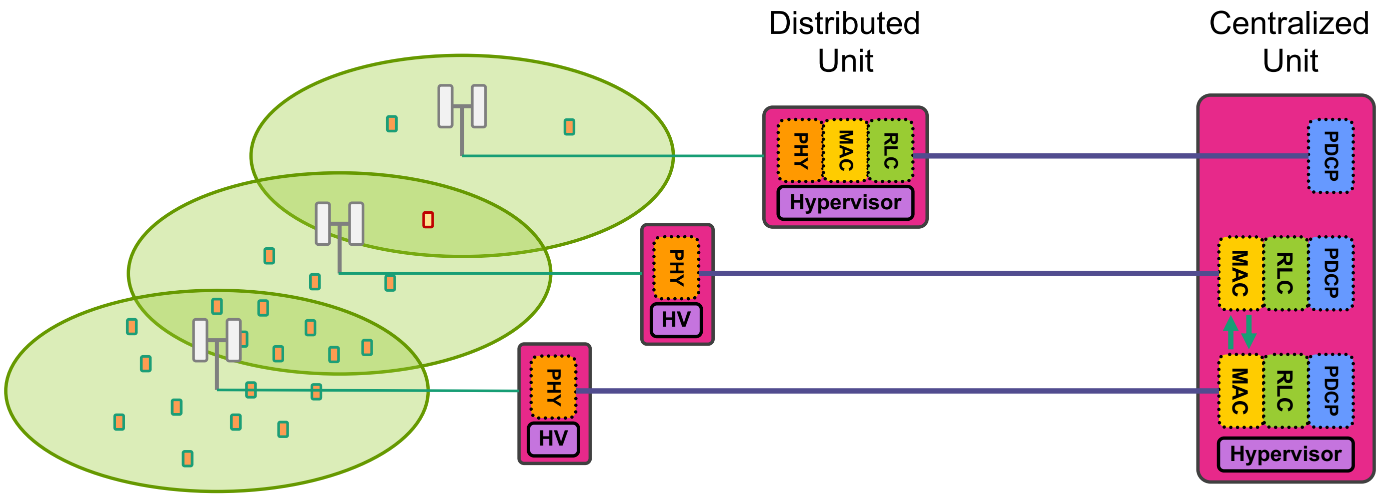
Fixed 5G Function Split

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



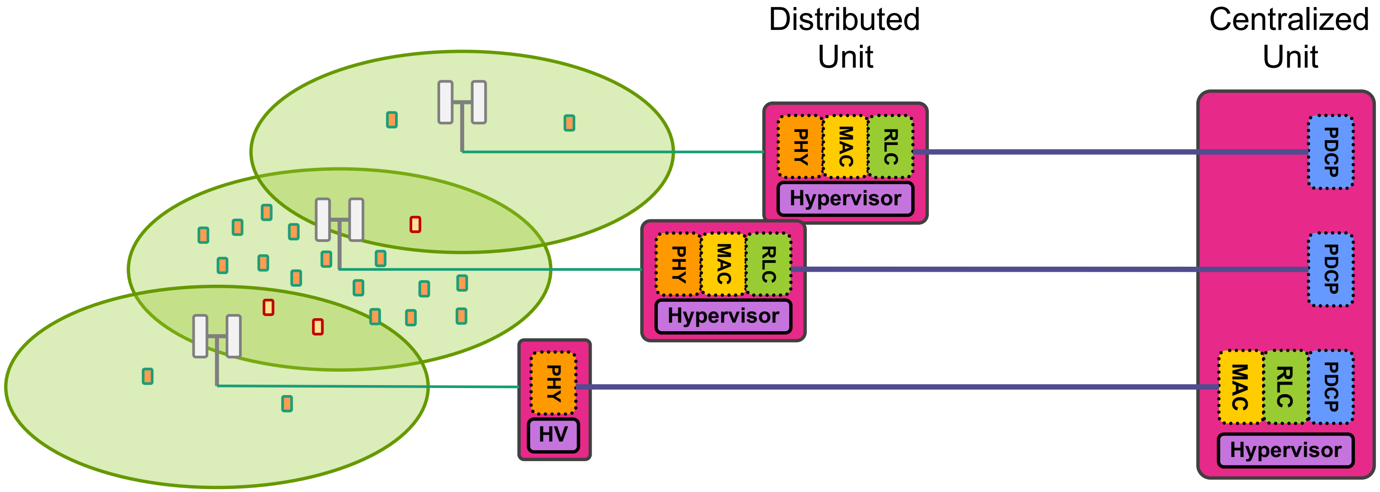
NFV-based 5G+ Function Split

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



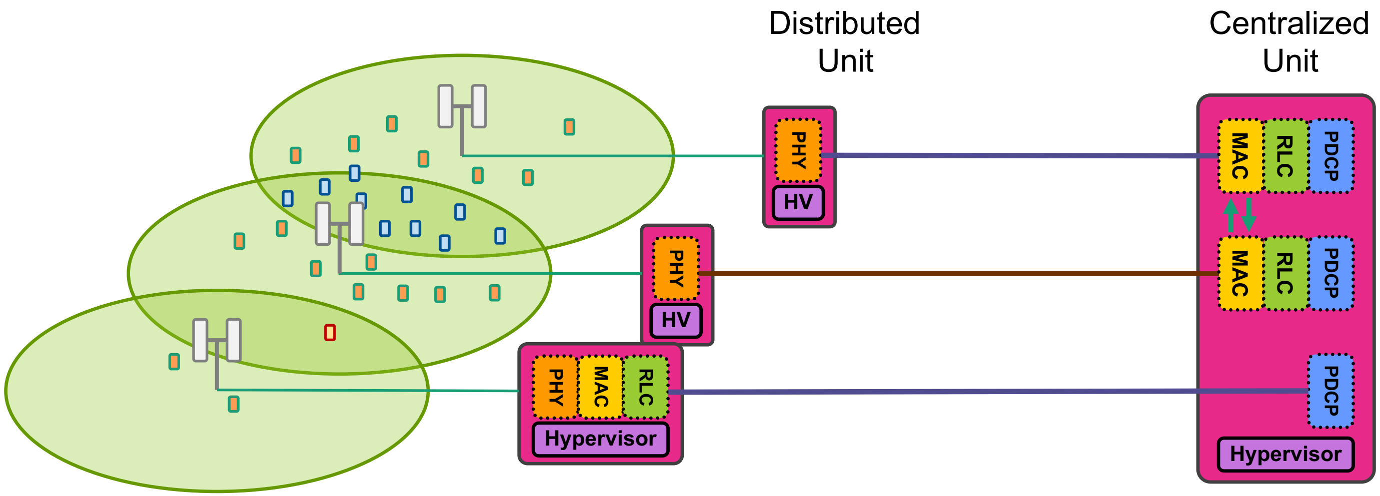
NFV-based 5G+ Function Split

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

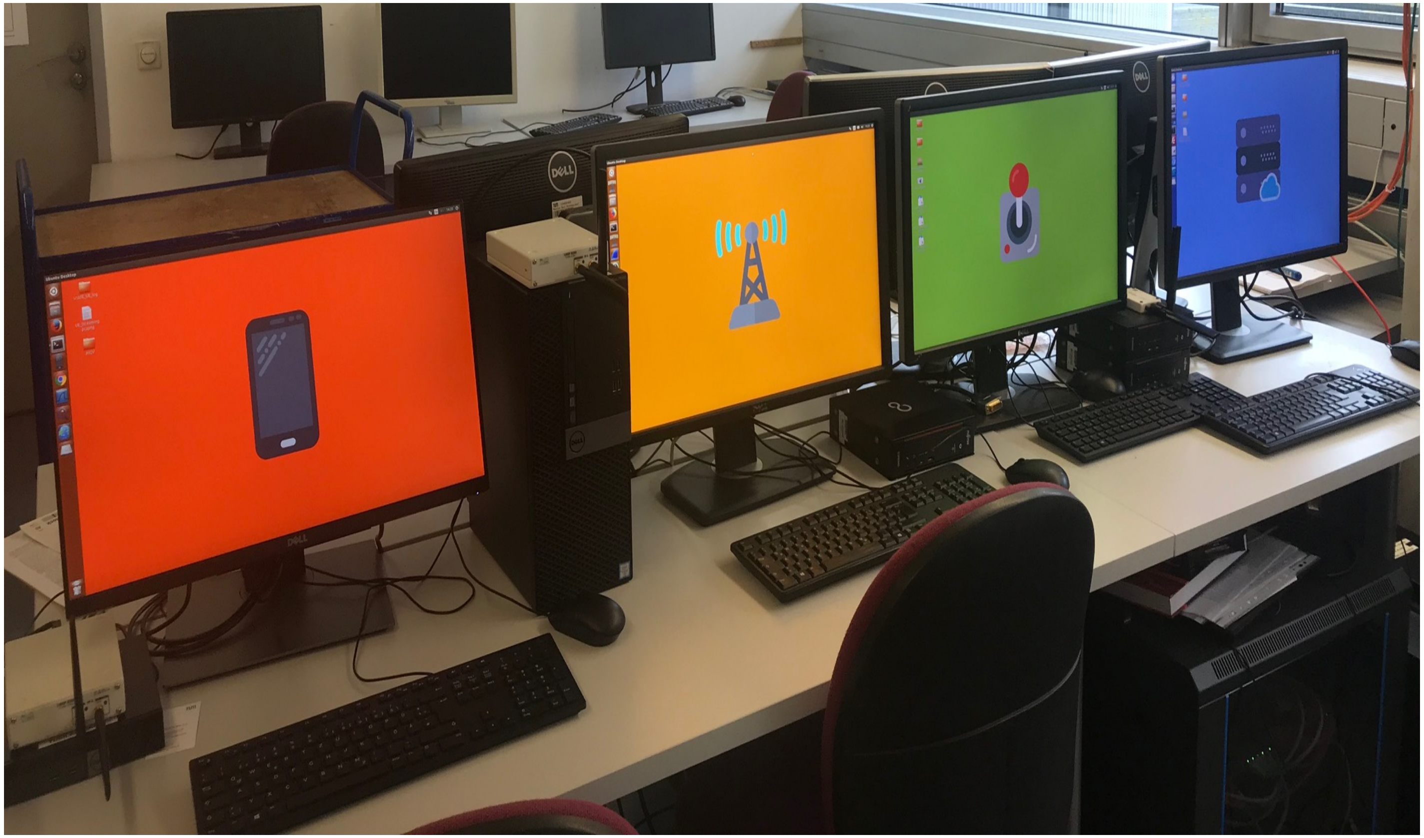


NFV-based 5G+ Function Split

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

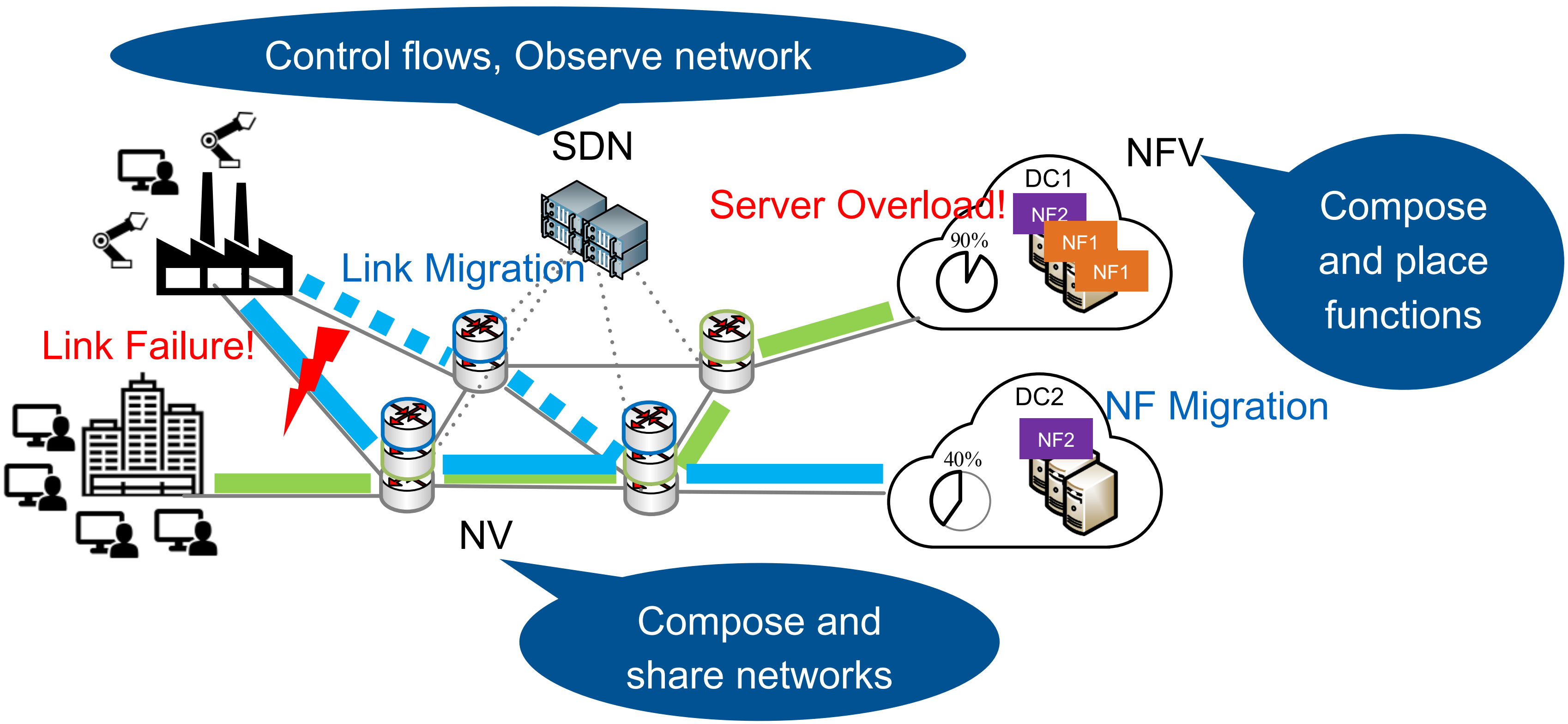


Based on a full Proof-of-Concept implementation at TUM



Martínez Alba, Alberto; Gómez Velásquez, Jorge Humberto; Kellerer, Wolfgang:
An adaptive functional split in 5G networks.
2019 IEEE INFOCOM WKSHPS - 3rd Workshop on Flexible and Agile Networks: 5G and Beyond

Flexible network adaptation: Softwarized Networks



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

} enablers for **flexible adaptation**

<u>Flexible</u> adaptation

- Network systems today: max. throughput or min. latency
- Flexible systems keep future options open
  → <u>flexibility as an objective</u>

- Flexibility can **measure** how good different implementations can **adapt** to future challenges?
  - **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

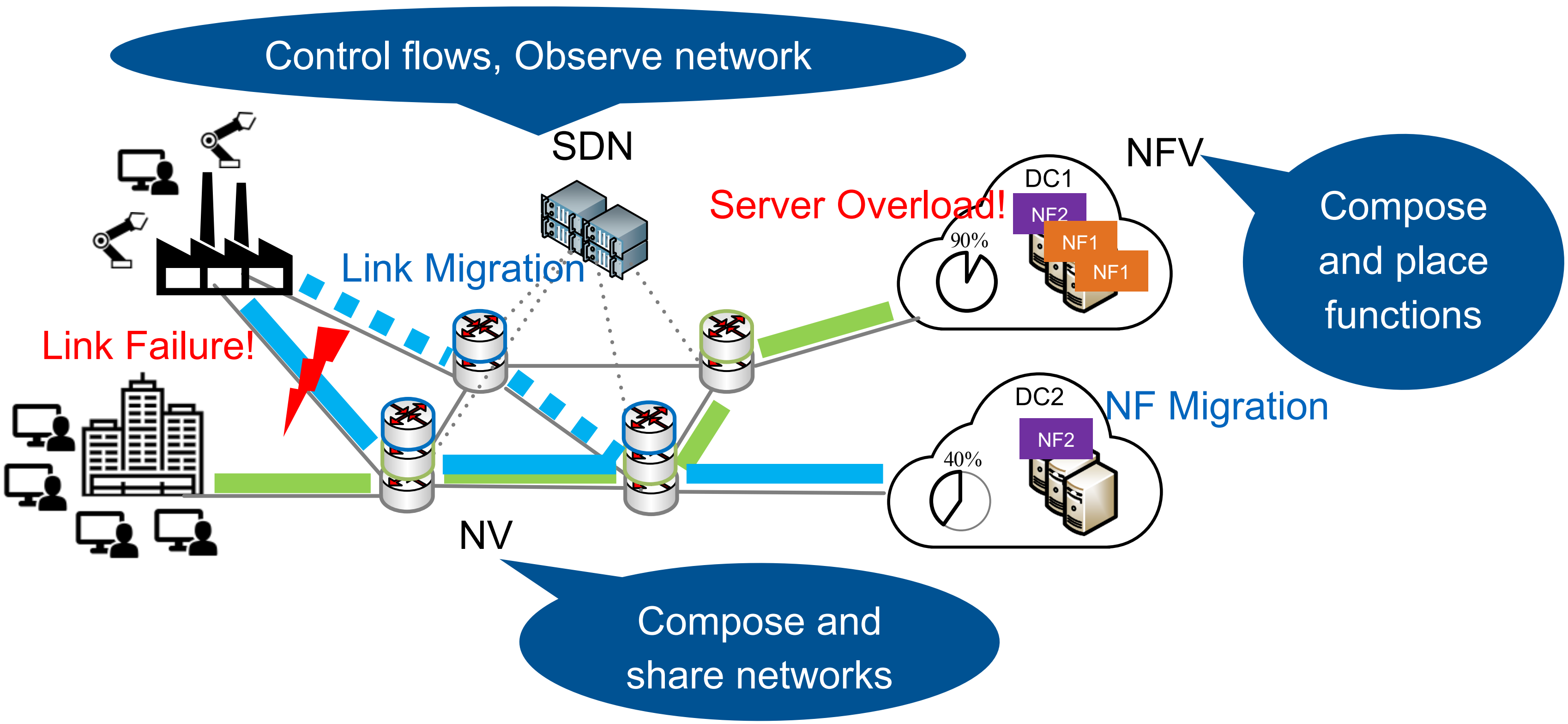
www.networkflexibility.org

www.networkflexibility.org

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

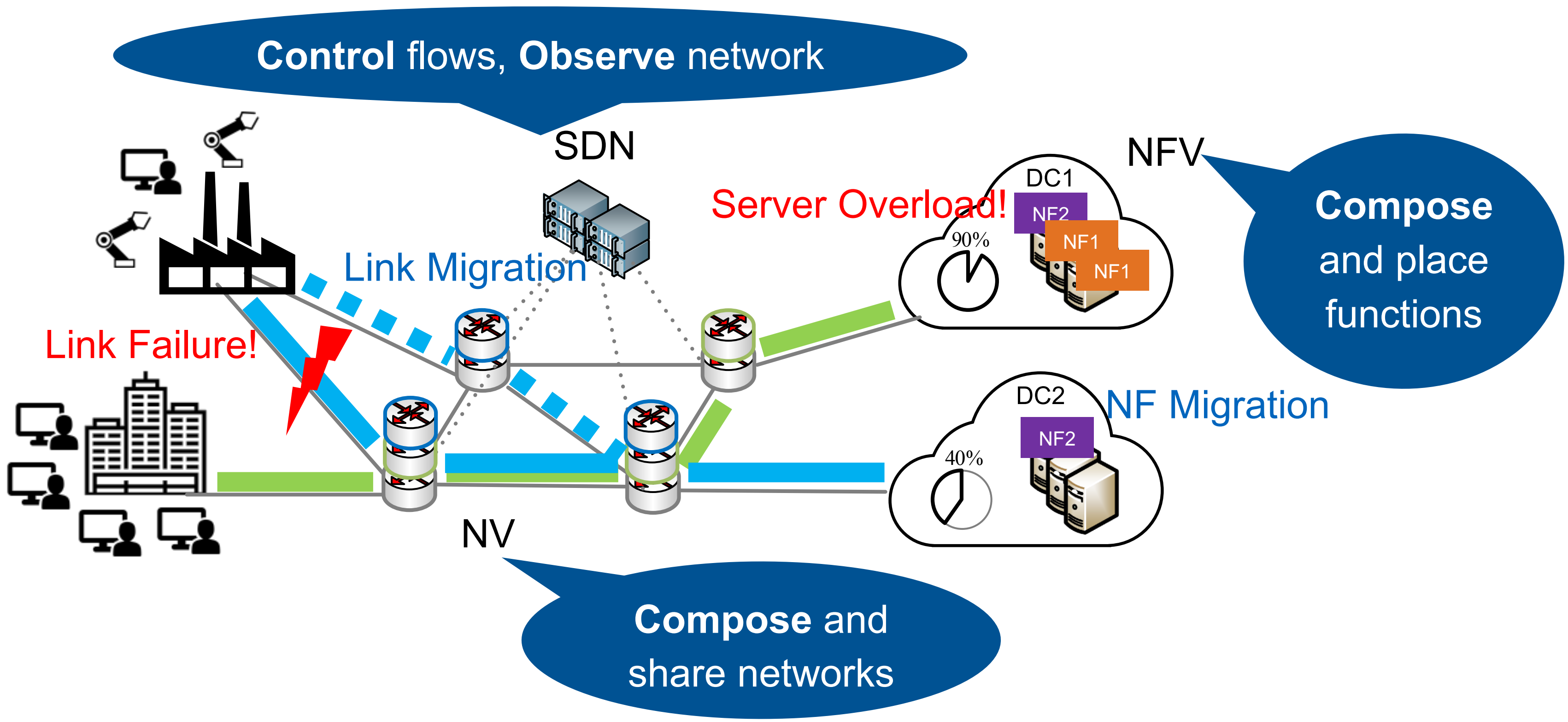
FlexNets

3 phases of network adaptation



Adaptation: (1) Detection – (2) Decision – (3) Execution

3 functional primitives by softwarized networks



Adaptation: (1) Detection – (2) Decision – (3) Execution

Network Observation (SDN, NFV)

Composition (NFV, NV)

Control (SDN, NV)

Enablers contribute differently to primitives

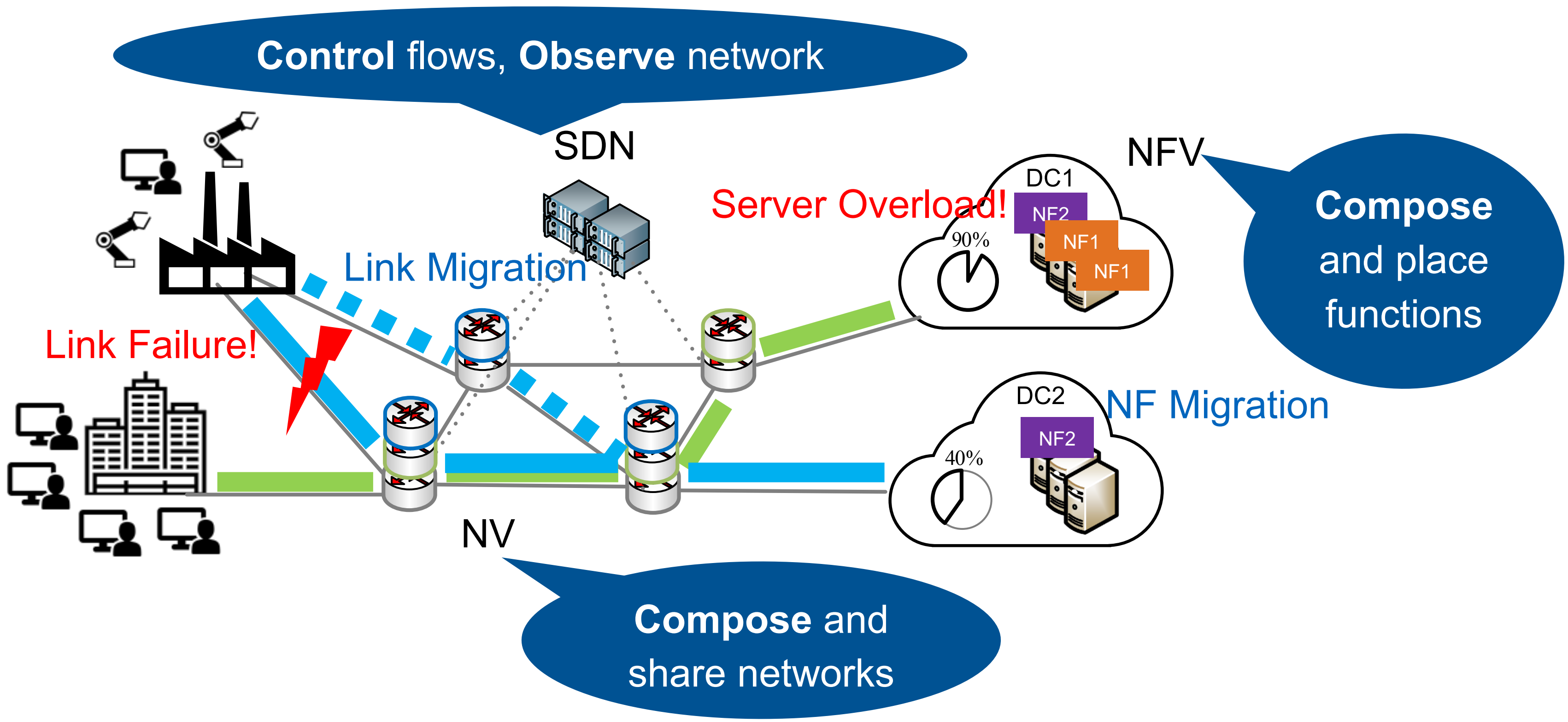
	Enabler(s)		Primitive(s)		
Adaptation	**SDN**	**NFV**	**Obs.**	**Comp.**	**Ctl.**
Monitoring	•	•	•		
Event detection	•	•	•		
Adaptive measurements	•	•	•		
Function configuration		•		•	
Fct. cfg. (push to SDN node)	•			•	•
Fct. res. dimen. (scale)		•		•	
Add/remove f.ct./ctl. (scale)	•	•		•	
Function placement		•		•	
Controller placement	•			•	
Function (de-)composition		•		•	
Function chaining		•	•	•	•
HW / SW configuration	•	•	•	•	•
Flow steering (direct rout.)	•				•
Traffic engineering	•				•
Rule/policy adaptation	•	•		•	•
Consistent network update	•		•		•
Admit and embed services and virtual networks	•	•	•		•

data collection

compose, configure, Place, migrate, chain

flow steering, traffic engineering

Adaptation phases meet functional primitives



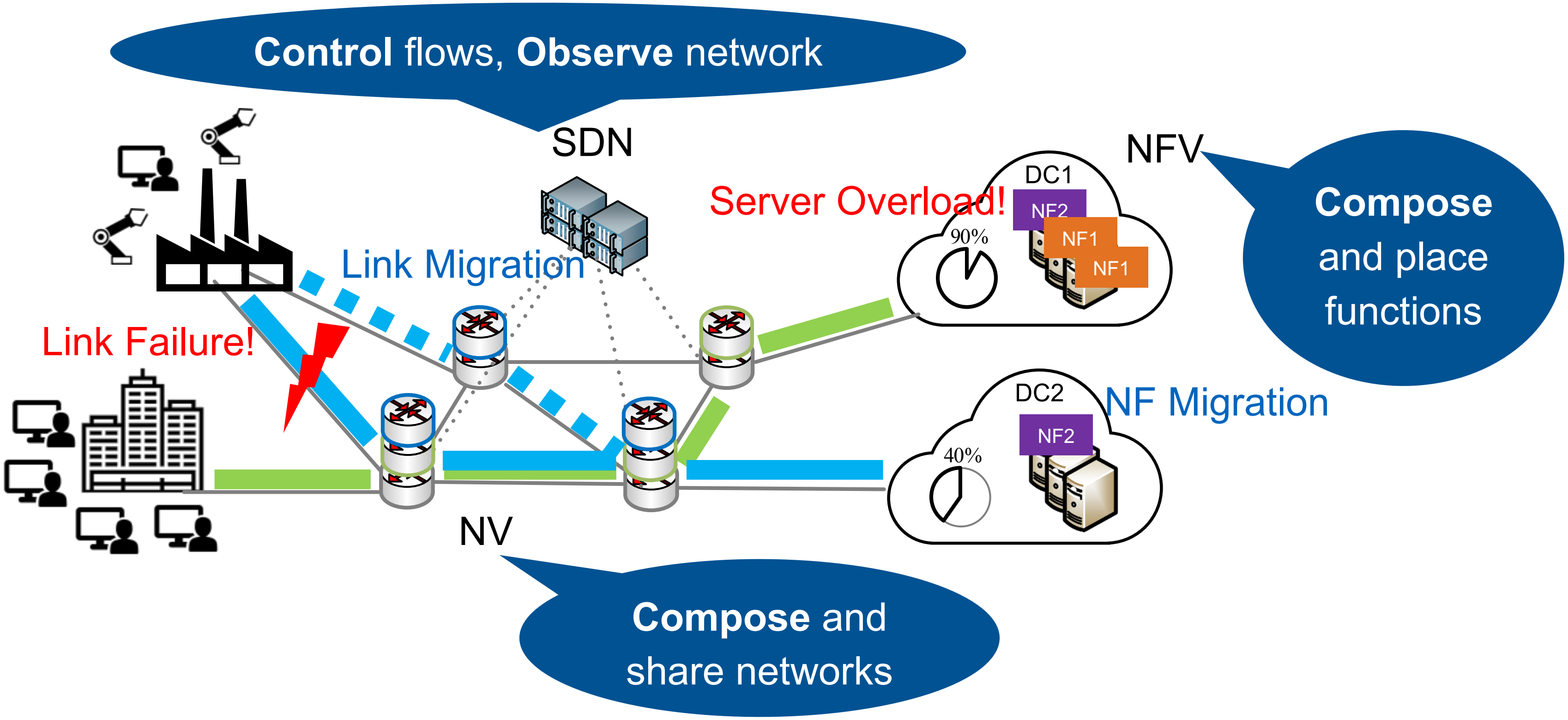
Adaptation: (1) Detection – (2) Decision – (3) Execution

Network Observation (SDN, NFV)

Composition (NFV, NV)

Control (SDN, NV)

Adaptation phases meet functional primitives



Adaptation: (1) Detection – (2) Decision – (3) Execution

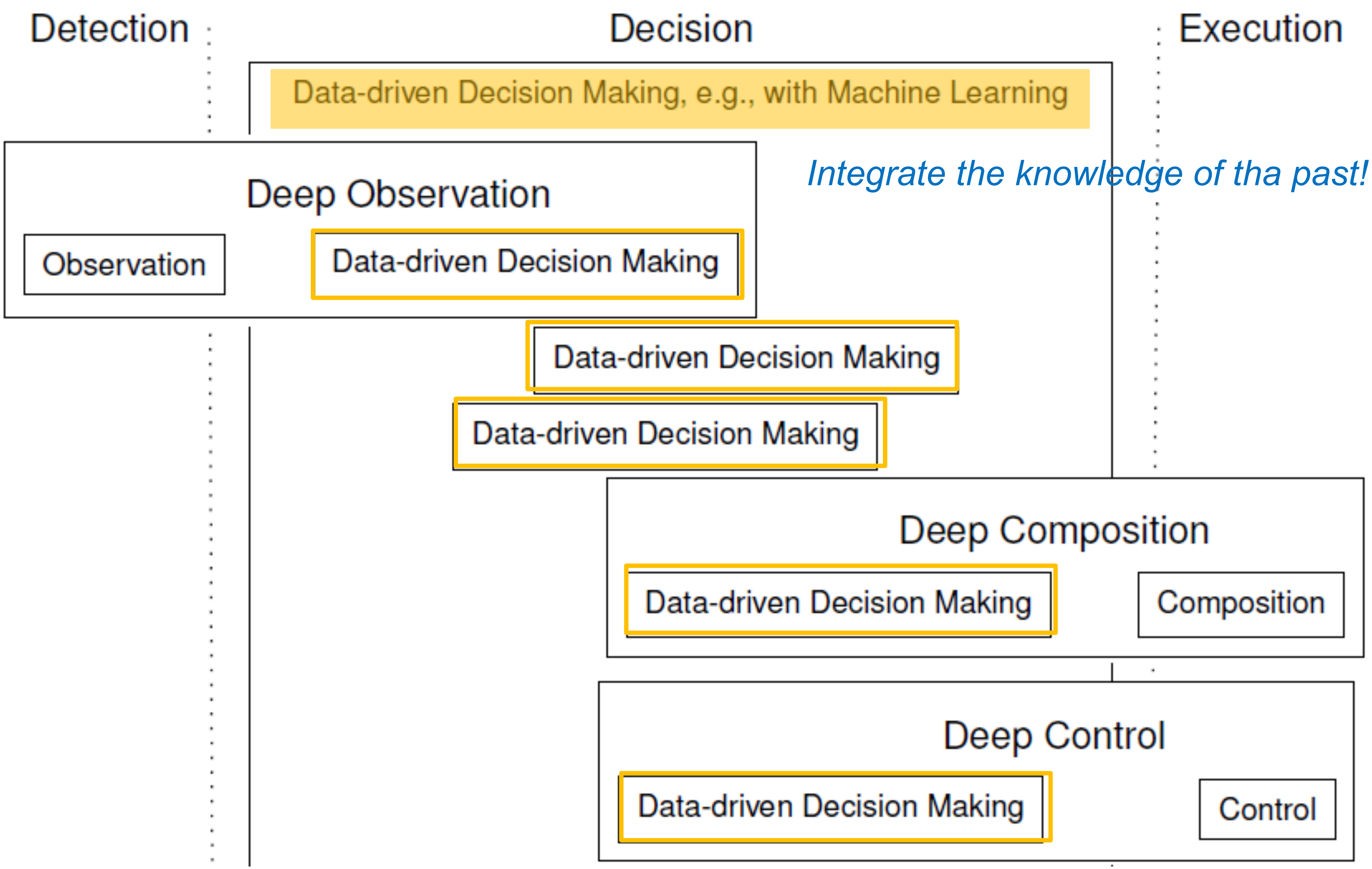
Network Observation (SDN, NFV)

Composition (NFV, NV)

Control (SDN, NV)

challenge: fill the gap!

Our Proposal:
***Deep* Observation, Composition and Control**



W. Kellerer, et al. Adaptable and Data-Driven Softwarized Networks: Review, Opportunities and Challenges. Proc. of the IEEE, 2019.

Algorithmic Decision Making Challenges

Adaptation: (1) Detection – (2) Decision – (3) Execution

Network Observation (SDN, NFV)

Composition (NFV, NV)

Control (SDN, NV)

Increased flexibilities

→ *more options*

→ *optimization potential*

→ *optimization problem*

e.g. constraint-based routing, waypoint routing,...

computational complexity

accuracy of models

We need new ways for improving existing network management algorithms!

Data-Driven Decision Making Approaches

Data-driven approaches

- *facilitate fast heuristics*
- *adapt and optimize for the actual state of the network* (rather than for worst case network state …)
- *can consider knowledge of the past*

→ **Machine Learning in softwarized networks**

Machine Learning for Improving SDN/NFV-Related Network Optimization

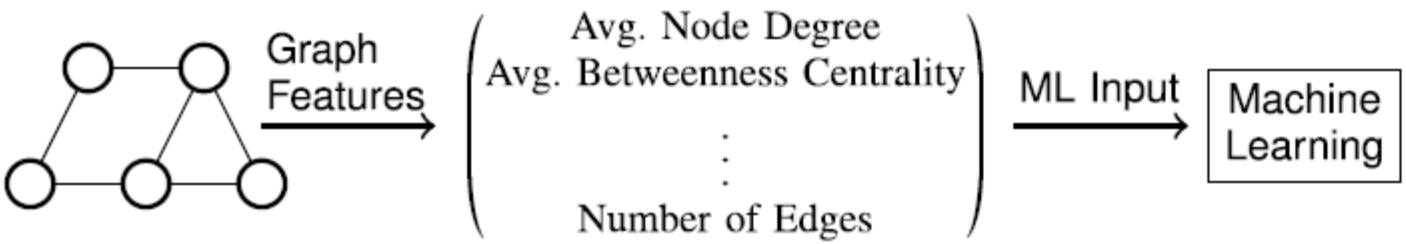
Deep Observation

- Data Acquisition
- Data Representation
  - Dimensionality reduction
  - Representing relational network data
  - Network graph and node transformation

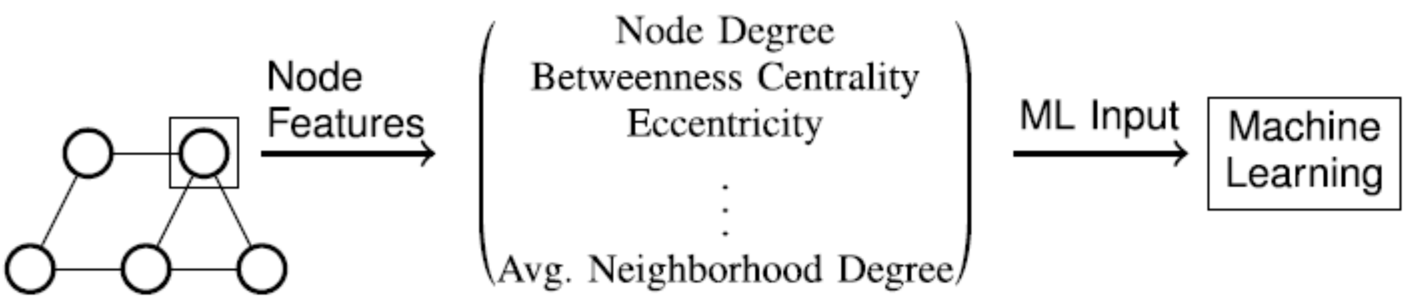
Deep Composition and Deep Control

Network Graph and Node Transformations

From graph to feature vector (topological attributes)



Node feature vector



Machine Learning for Improving SDN/NFV-Related Network Optimization

Deep Observation

- Data Acquisition
- Data Representation
  - Dimensionality reduction
  - Representing relational network data
  - Network graph and node transformation

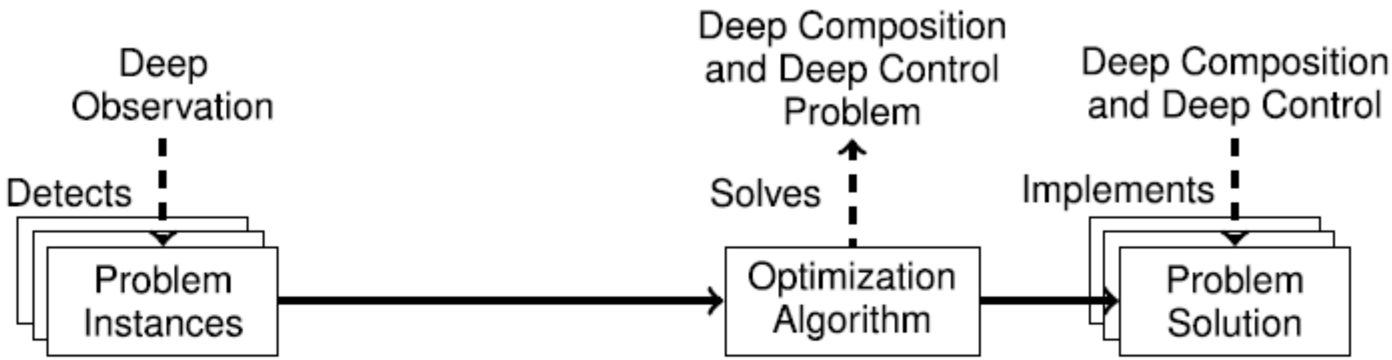
Deep Composition and Deep Control

The boosting approach: find better solutions faster

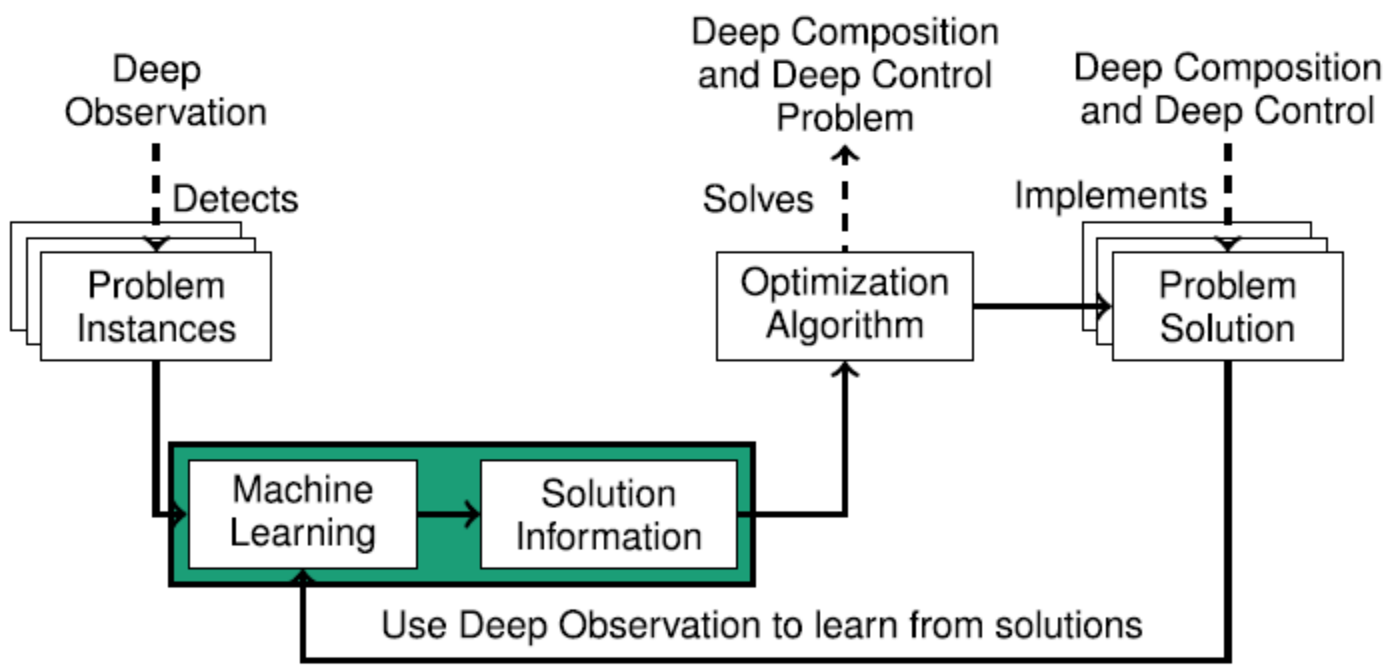
(keep your original optimization algorithm)

Machine Learning-enhanced optimization

Traditional problem optimization

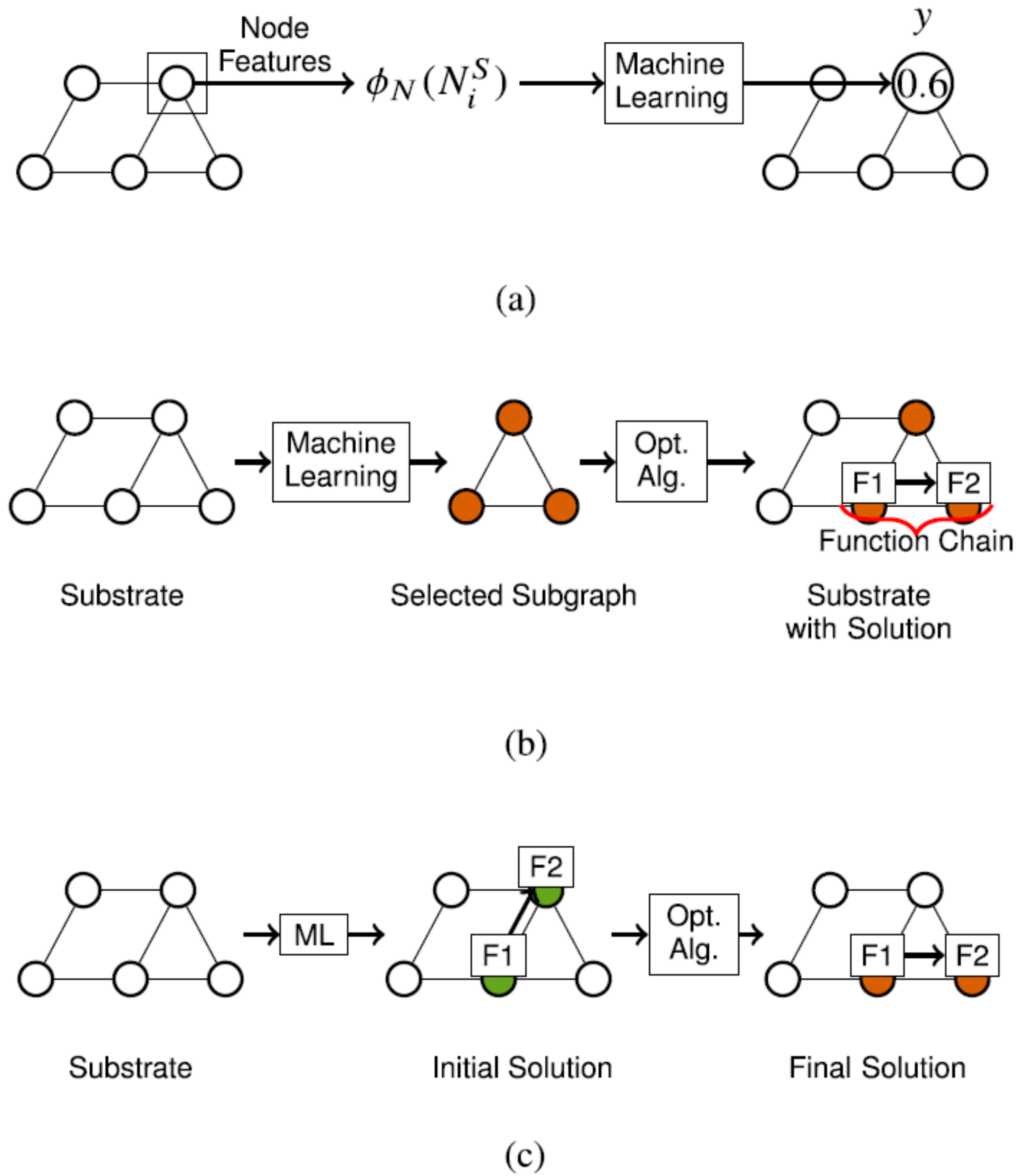


ML-enhanced problem optimization

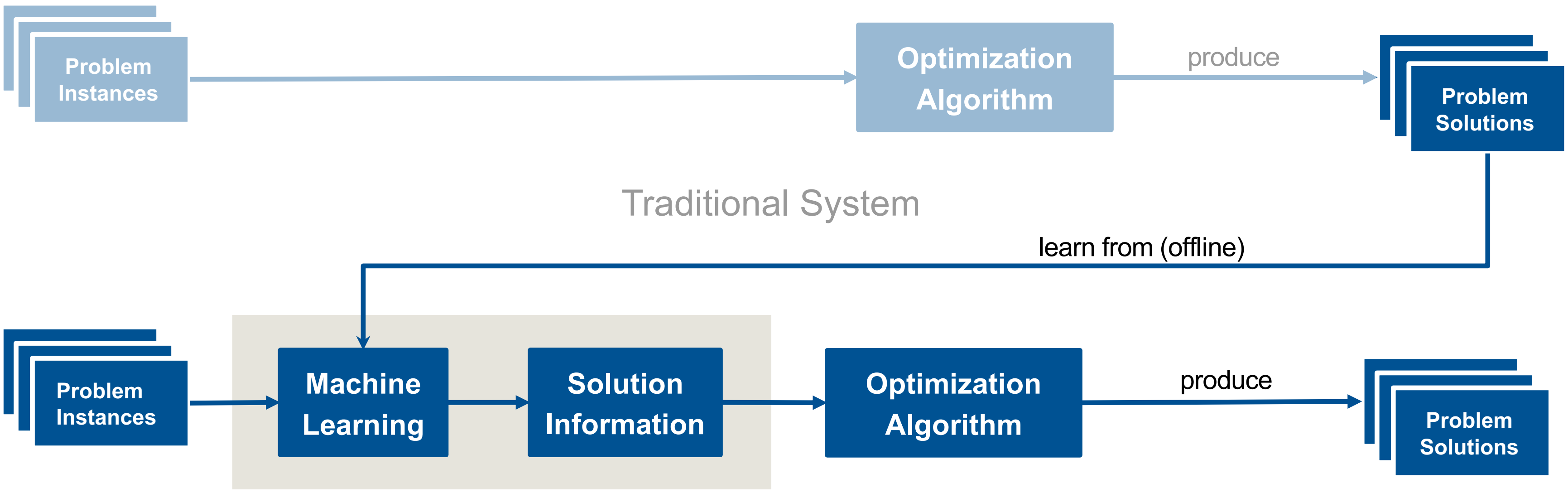


(Problem) Search Space Reduction

Basis for the *boosting approach*



How can we boost the solving of the related optimization problems (leaving you algs. untouched)?



o'zapft is framework [5]

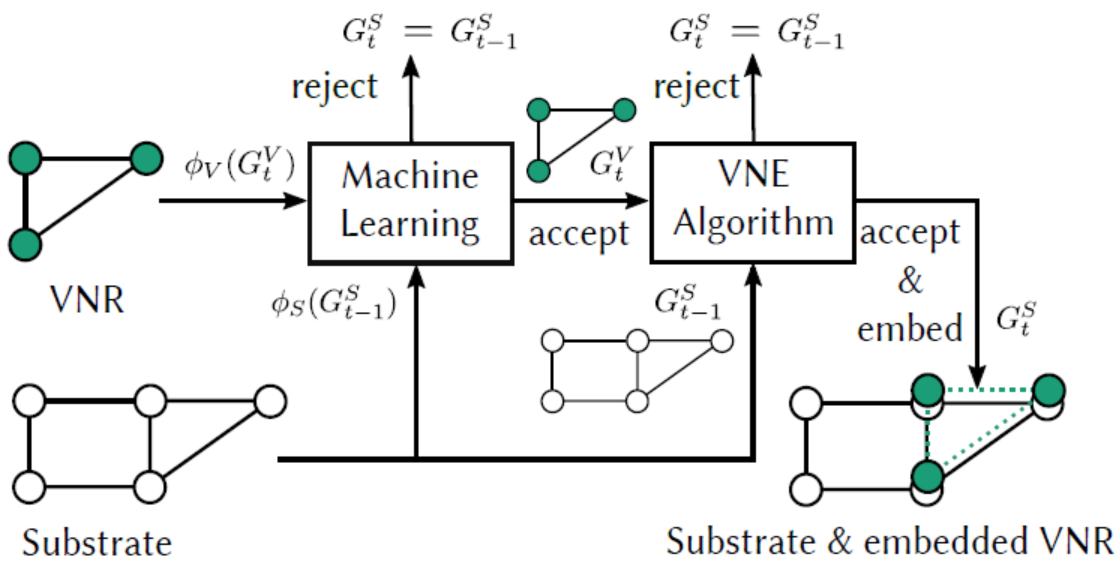
State-of-the-art: Neglects produced data!

Idea: Use problem/solution data generated by algorithms regularly solving problems

A. Blenk, P. Kalmbach, S. Schmid, W. Kellerer: ***o'zapft is: Tap Your Network Algorithm's Big Data!***
ACM SIGCOMM 2017 Wrksp. on Big Data Analytics and Machine Learning for Data Communication Networks (Big-DAMA), 2017.

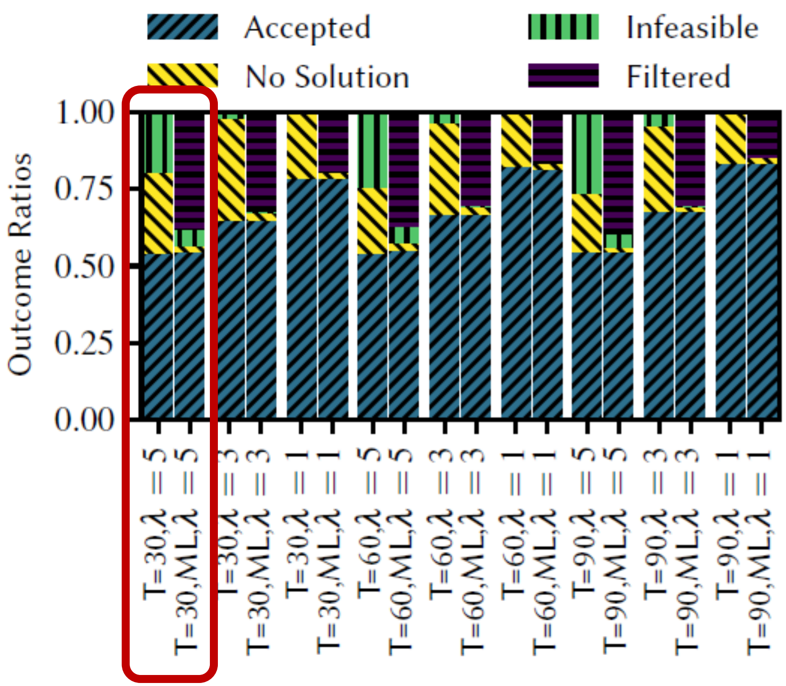
Data Available: P. Kalmbach, J. Zerwas, M. Manhart, A. Blenk, S. Schmid, W. Kellerer. Data on "o'zapft is Tap Your Network Algorithm's Big Data!",2017 https://doi.org/10.14459/2017md1361589

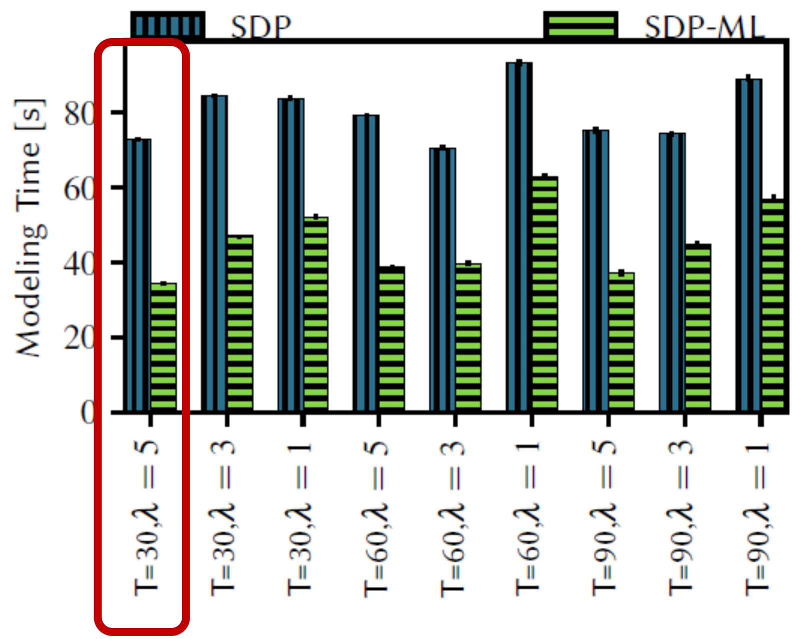
Case Study: Predicting Acceptance Probabilities of VNE Requests



- Supervised learning: use data with accepted and rejected requests! Offline training!
- Recurrent neural network (RNN) for classification
- Filter infeasible and requests with unacceptable algorithm runtime (“no solution“)

Can we speed-up optimal algorithms using admission control?

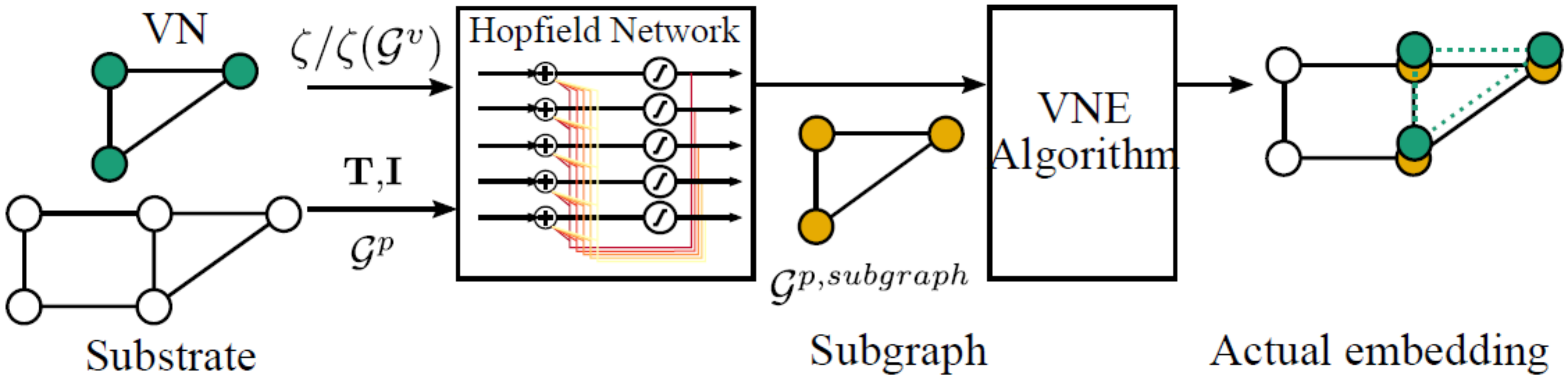




Efficient Filtering of infeasible and unacceptable requests
Efficient saving of model creation time

More results: Neurovine

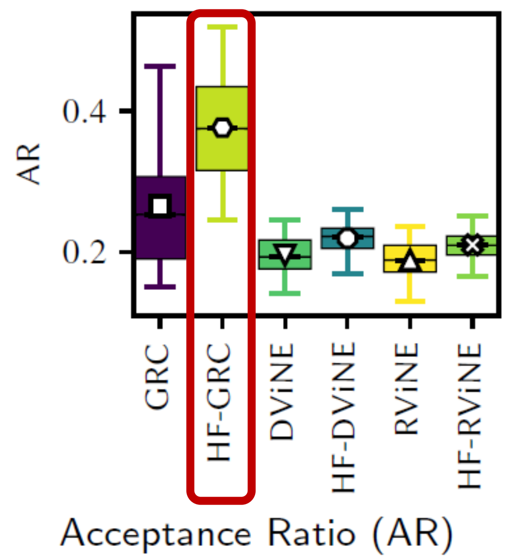
Hopfield neural network to preprocess (subgraph extraction) VNE algorithms – tailored filtering

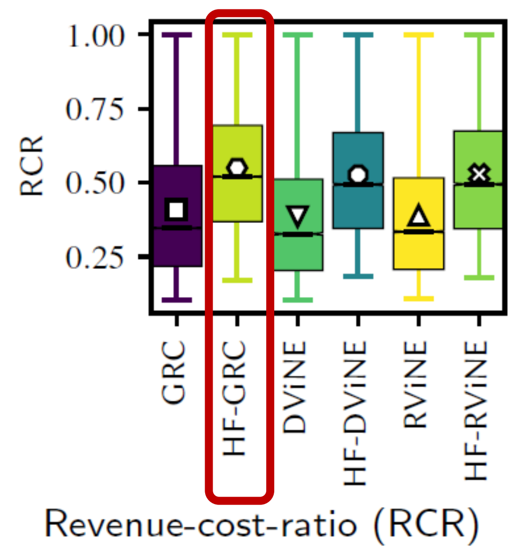


- Idea: Extract subgraph with physical nodes close to each other and high available capacities

A. Blenk, P. Kalmbach, J. Zerwas, M. Jarschel, S. Schmid, W. Kellerer: ***NeuroViNE: A Neural Preprocessor for Your Virtual Network Embedding Algorithm*** IEEE INFOCOM 2018 (main conference), Honolulu, HI, USA, April 15-19, 2018.

Neurovine:
Efficiency on Real Network Topologies



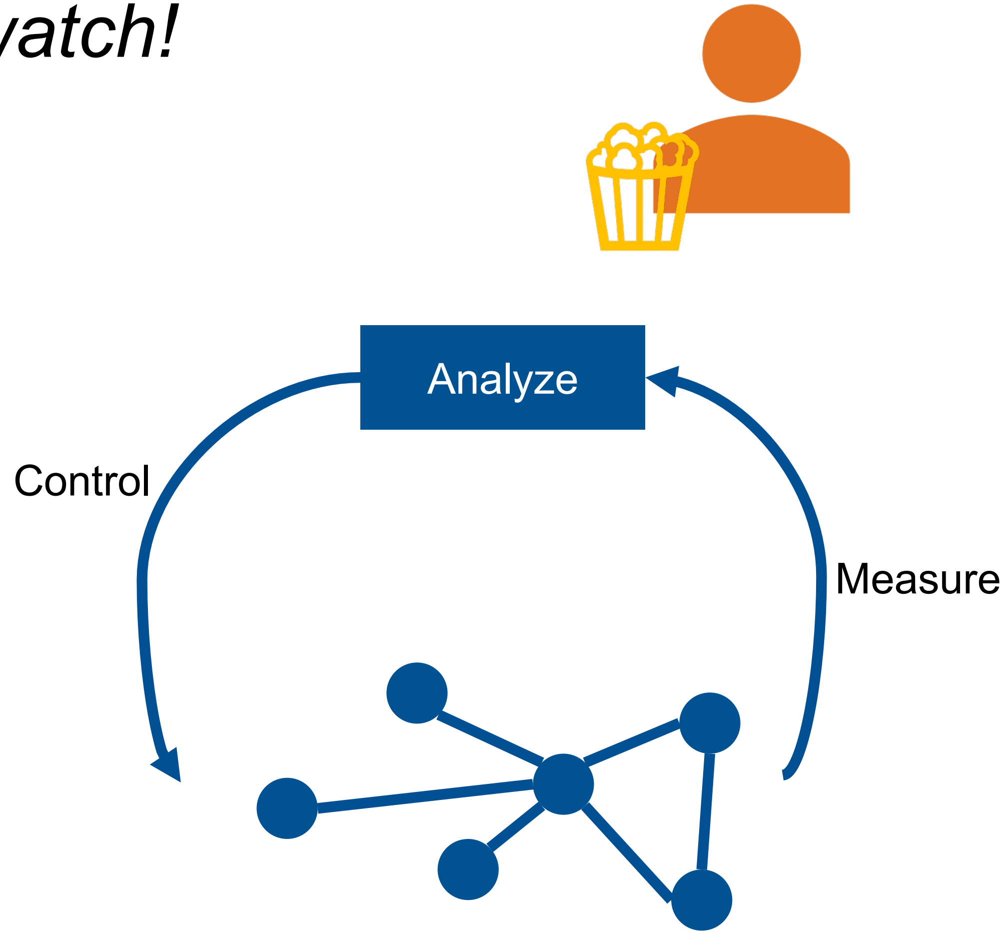


- VNE algorithms (GRC, DViNE, RViNE) vs. Hopfield variants (HF-GRC, HF-DViNE, HF-RViNE)
- NeuroViNE accepts more networks with less costs

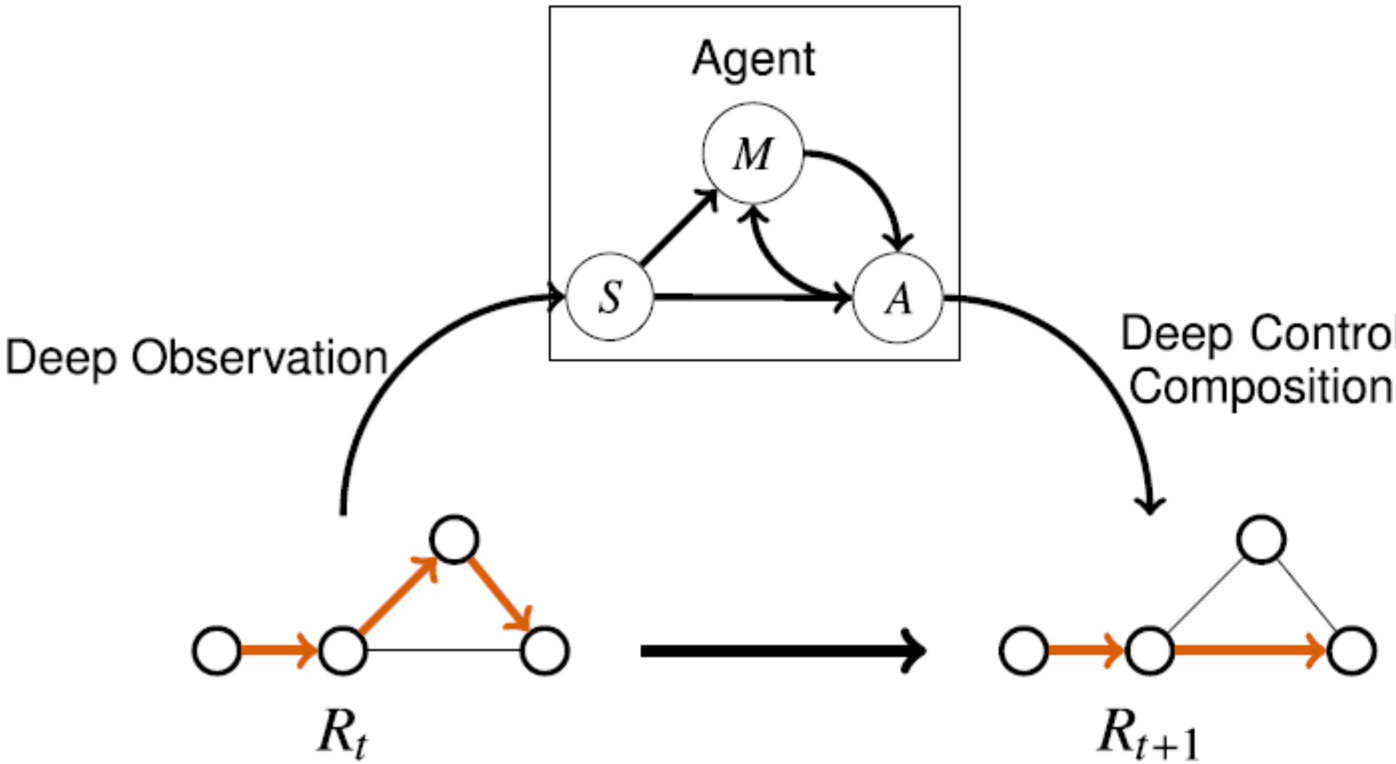
Towards Autonomous Networks

Network Managers' all-time Dream:

lean back and watch!

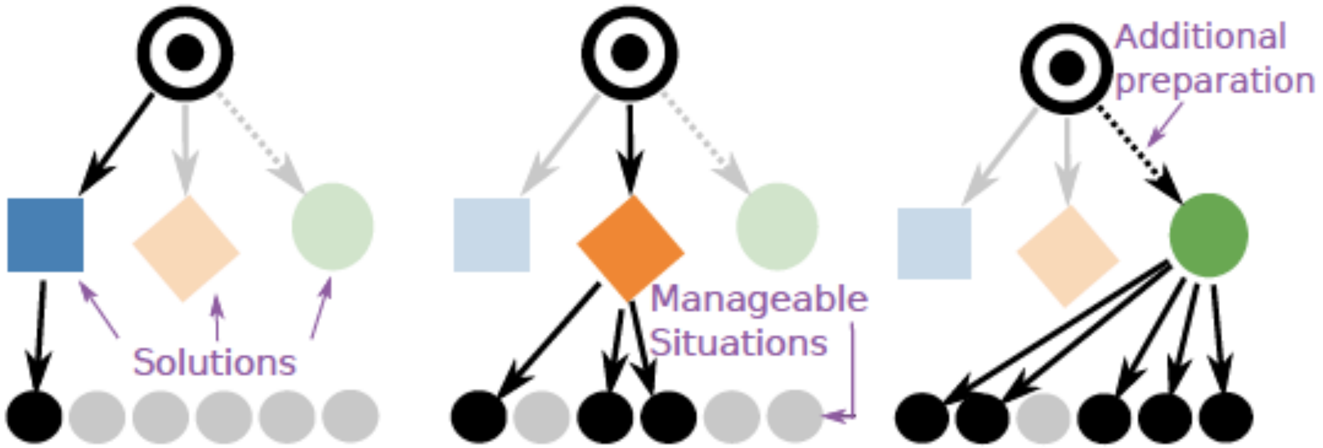


Proposed concept: Empowerment



Empowering Networks

empowerment: quantify the influence of an agent on its environment: agent (several actuators, 1 sensor) restructures networks to maximize options (c) - <u>not</u> an objective as in optimization (a) and (b)



(a) Simple. (b) Robust. (c) Empowerment.

P. Kalmbach, J. Zerwas, P. Babarczi, A. Blenk, W. Kellerer, S. Schmid: ***Empowering Self Driving Networks***, ACM SIGCOMM 2018 workshop on self-driving networks August 2018.

Lessons Learned

- Softwarized Networks provide the adaptability required for future dependable and flexible communication networks
- *Adaptation(netsoft) = observation, composition and control*
- Challenges: more data and more options → algorithmic nature
- Benefits from data-driven decision making based on ML
- First step towards self-driving networks

8 Research Challenges to take home

1) Adaptation is a process over time. How to consider time constraints?

2) At which scale of network sizes do the new concepts provide improvements for adaptation?

3) Adaptation functionalities provided by the control plane or by the data plane?

4) Can adaptation be supported by hardware (P4?) or purely by software?

5) How can system performance be guaranteed based on adaptation?

6) How to measure the adaptation potential in relation to the provided flexibility?

7) How can Machine Learning be supported by hardware?

8) How far can we go with empowerment?

FlexNets

join us on networkflexibility.org

find our research videos on YouTube Channel “LKN TUM“

wolfgang.kellerer@tum.de

Some References

W. Kellerer, P. Kalmbach, A. Blank, A. Basta, S. Schmid, M. Reisslein: *Adaptable and Data-Driven Softwarized Networks: Review, Opportunities and Challenges*. **Proc. of the IEEE**, 2019 (open access).

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

M. He, A. Martinez Alba, A. Basta, A. Blenk, W. Kellerer. *Flexibility in Softwarized Networks: Classifications and Research Challenges*. **IEEE Communication Surveys & Tutorials**, 2019.

P. Kalmbach, J. Zerwas, P. Babarczi, A. Blenk, W. Kellerer, S. Schmid, *Empowering Self-Driving Networks.* **ACM SIGCOMM 2018 Workshop** on Self-Driving Networks - SelfDN 2018

A. Blenk, P. Kalmbach, J. Zerwas, M. Jarschel, S. Schmid, W. Kellerer: *NeuroViNE: A Neural Preprocessor for Your Virtual Network Embedding Algorithm.* **IEEE INFOCOM** 2018 (main conference), Honolulu, HI, USA, April 15-19, 2018.

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

A. Blenk, P. Kalmbach, S. Schmid, W. Kellerer: *o'zapft is: Tap Your Network Algorithm's Big Data!* **ACM SIGCOMM 2017 Wrks**. on Big Data Analytics and Machine Learning for Data Communication Networks (Big-DAMA), 2017.

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

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.