6G meets Future Networking

Wolfgang Kellerer
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„6G will be human focused“

- 4G: mobile apps and video
- 5G: machine-to-machine communication
- 6G: the human in the center – extension of the human intelligence and the human abilities

- for robots collaborating with humans 1ms RTT and 5 nines availability is no longer enough

What does this mean for 6G?

- Terahertz-frequency spectrum up to LIFI
- Multi-network (network-of networks)
- In-network computing
- Network adaptation (communication + processing + storage)
- Network-as-a-Sensor: joint communication and sensing
- AI/ML-native communication
- Sustainability: end-to-end energy efficiency
- Resilience, security, privacy and trust by design
- Beyond paradigms: post-shannon communication, quantum networks, molecular networks

Processing, storage and energy are included in the 6G system optimization

What is in for networking (and network management)?
6G clearly builds on strong future networking concepts

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6G Experimental Platform

https://www.5g-munich.de/html/demo.html

Foto: TUM/Heddergott
5G / 6G Testbed at the Chair of Communication Networks at TUM

- Programmable core network with latency guarantee
- Sliced, SW-defined radio access network
- AI-enabled edge clouds

Platforms

- Movo Mobile Robot
- Etus USRPs B200/B210/X310
- P4 Tofino
- 5G Core Function(s)
- Digital Twin(s)
- gNB DU
- In-Network Processing
- NB API
- SD-RAN Controllers
- OAI and LTE - UE
- Samsung S20 5G Phone
- LiFi Dongle

Cooperations

- DLR
- TUM-MSRM
- ZITIS
- UniBW CODE
- Gateway

- VPN connections
- Control Plane
- Data Plane + Signaling
- One or multiple links

- Servers
  - SD-RAN Software Defined Radio Access Network
  - DU Distributed Unit
  - CU Centralized Unit
  - GPU Cards

- Goshi, Jarschel, Pries, He, Kellerer: Investigating Inter-NF Dependencies in Cloud-Native 5G Core Networks. 17th International Conference on Network and Service Management (CNSM 2021)
AI-enabled edge clouds
platforms

sliced, SW-defined radio access network

programmable core network with latency guarantee

- Goshi, Jarschel, Pries, He, Kellerer: Investigating Inter-NF Dependencies in Cloud-Native 5G Core Networks. 17th International Conference on Network and Service Management (CNSM 2021)
Chameleon: Guaranteed end-to-end low latency in the network

- Principle:
- Realization in a programmable network with central controller: "Chameleon"

Van Bemten, Amaury; Deric, Nemanja; Varasteh, Amir; Schmid, Stefan; Mas Machuca, Carmen; Blenk, Andreas; Kellerer, Wolfgang: Chameleon: Predictable Latency and High Utilization with Queue-Aware and Adaptive Source Routing. CoNEXT 2020.
Chameleon: Guaranteed end-to-end low latency in the network

- Chameleon successfully provides latency guarantees, reaches higher network utilization than existing approaches, and scales to networks with tens of thousands of servers.
... supported by in-network computing and network programmability

- There is no free lunch
- From our research on "quantifying flexibility in communication networks" (ERC Consolidator Grant FlexNets: 2015 - 2021) \(\rightarrow\) **Consider the Cost of Flexibility!**

- The total operating cost \( Q = K + C^P + C^R \) of a flexible network is the sum of:
  - **Readiness cost** \( K \): cost of operating the network at the current state given an active demand
  - **Proaction cost** \( C^P \): cost of finding a new state during the proaction phase
  - **Reaction cost** \( C^R \): cost of implementing a new state during the reaction phase

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<table>
<thead>
<tr>
<th>Readiness phase</th>
<th>Proaction phase</th>
<th>Reaction phase</th>
<th>Readiness phase</th>
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<tbody>
<tr>
<td>( \langle d_0, s_0 \rangle )</td>
<td>( \langle d_1, s_0 \rangle )</td>
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<td>( s_0 )</td>
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</tbody>
</table>
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![Diagram of network states](image)

- Example of readiness cost: \( K(d_0, s_0) \)
- Example of proaction cost: \( C^P(d_0) \)
- Example of reaction cost: \( C^R(s_0) \)

**Martínez Alba, Alberto; Babarczi, Péter; Blenk, Andreas; He, Mu; Krämer, Patrick; Zerwas, Johannes; Kellerer, Wolfgang:**
Example: dynamic flow allocation in SDN network

- **Service**: provide a connection between two nodes when demanded
- **Objective**: minimize number of used links

\[ \tau = 19 \]
Example: evaluating adaptation algorithms

- Operator uses a **genetic algorithm** to find a near-optimal integer path
- Possible initial populations: $p = \{250, 750, 1250, 1750, 2250, 2750\}$
- Which initial population values lead to **profitable** networks?

![Graph showing the ratio $\hat{R}_\beta / K_\Delta(\delta)$ vs. $\alpha/(\alpha \varphi - 1)\beta$ with different initial population values.](image)

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And what about complexity?

- Softwarization vastly increases the degree of freedom
  → complexity increases, amount of data increases

- **Artificial Intelligence** (AI) in future networks can help to solve optimization problems better

Kellerer, Wolfgang; Kalmbach, Patrick; Blenk, Andreas; Basta, Arsany; Reisslein, Martin; Schmid, Stefan: Adaptable and Data-Driven Softwarized Networks: Review, Opportunities, and Challenges. Proceedings of the IEEE 107 (4), 2019, 711 – 731
How can we boost the solving of the related optimization problems (leaving your algorithms untouched)?

- 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

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!*
Digital Twins

- Network Digital Twin = synchronized copy of a system (component)
- DTs may interact in simulation space
- 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; Kollerer, Wolfgang; Blenk, Andreas; Schmid, Stefan: NetBOA: Self-Driving Network Benchmarking. ACM SIGCOMM 2019 Workshop on Network Meets AI & ML (NetAI ’19), 2019
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NetBOA: Self-Driving Network Benchmarking

- Example

Figure 6: RS vs. BO. Relative deviation of CPU load from the known optimal value after 100 iterations.
Summary

- 6G clearly builds on a strong multi-network paradigm and addresses future networking

- New requirements demand for new networking and network management concepts on top of in-network computing and network programmability
  - Flexibility & adaptation: consider cost
  - AI-driven networking
  - Digital Twins
  - Autonomous benchmarking
  - Autonomous networking

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Thank you

https://6g-life.de
https://www.6g-future-lab.de/
https://www.5g-munich.de

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