

slices DE

A Digital Research Infrastructure for Computing and Communication in Germany and Europe

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Communication and Computation Experimental Research

Current situation

- Shared research interests and goals
- Heterogeneous testbeds – **incoherent and not connected**

Challenges

- **Duplication of effort** across different research groups
- **Fragmentation of research** across Germany and Europe
- Research **limited by scale** of local testbeds
- **Limited comparability and interoperability** of scientific artifacts



Berlin 6G Conference

Goals and Ambition

Problems with reproducibility

- Workshops at ACM SIGCOMM on reproducibility:
  - SIGCOMM'03: MoMeTools workshop: Models, Methods and Tools for Reproducible Network Research (Co-Chairs: Carle, Ritter, Wehrle)
  - SIGCOMM'17: Reproducibility workshop
  - Problems remaining unsolved over many years

Best solution so far . . .

- Artifact Evaluation Committees & Reproducibility Badges
- Problems:
  - High effort for researchers
  - Limited robustness and reuse



ACM badges awarded by Artifact Evaluation Committees

Research directions addressed by SLICES-DE

- How to **understand** the evolving **Internet**?
- What are the right **architectures** for future networked systems?
- How to **integrate AI** with networking and edge/cloud infrastructure?
- How to make these systems **secure and resilient**?
- How to **improve the research** – better *reproducibility* and *reuse*, better *cooperation*, **together** with the **domains affected by the Internet**?

Central research question:

How to evolve the Internet as a critical infrastructure that is intelligent, scalable, reliable, secure and open, to support all aspects of our modern society?

Benefits of SLICES-DE – Researcher Perspective

Shifting Focus to Research

- SLICES-DE is **professionally managed**
- Users can focus on **their research**, no need to set up and maintain own infrastructure

Reuse

- **Long-term availability** of SLICES-DE ($\geq$12 years)
- Research output can be easily **reused**

Data Creation

- SLICES-DE **generates, processes, stores and archives data**
- Researchers are empowered to create **data through sophisticated experiments**

Reproducibility

- Researchers **reproduce results** of others using the **same platform**

Benefits of SLICES-DE – Scientific Community Perspective

Testbed for Research

- SLICES-DE offers **well-structured, automated experiments**
- Structured experiments **simplify reuse**
- **Better utilization** by shared hardware usage

Reuse

- SLICES-DE **avoids inefficient, redundant development and maintenance** of testbeds
- Reuse the **same code** across different research groups, extend and combine

Data Creation

- **Data** is the **"new gold"** in the age of AI
- SLICES-DE allows **large-scale creation of research data**

Reproducibility

- SLICES-DE as a platform for **artifact evaluation**
- More **collaboration and reproducible research** through joint testbed access and usage

SLICES-RI (Research Infrastructure)

SLICES-RI

- Scientific Large Scale Infrastructure for Computing/Communication Experimental Studies (SLICES)
- Goal: Create a European research infrastructure for computing and communication by the community for the community
- Support from 17 European countries:



- Funding framework: European Strategy Forum on Research Infrastructures (ESFRI)
  - Long-term funding framework (**>10 years**) for large-scale infrastructures (e.g., telescopes or particle accelerators)
  - SLICES became part of the European ESFRI roadmap in **2021**
  - SLICES is the first **digital** RI not as a provider for others but for the digital community itself
  - Shared funding between EU (focus on coordination projects) and national funding agencies (focus on infrastructure resources)



Partner countries of SLICES-RI

SLICES-RI (Research Infrastructure)

SLICES-RI milestones

- 2020–2022 SLICES-DS (design study) H2020 project
- 2021–2024 SLICES-SC (starting communities) H2020 project
- 2024 Start of the pre-operation of SLICES-RI
- 2023–2025 SLICES-PP (preparatory phase) Horizon Europe project

Planned steps

- Starting in 2026: SLICES-IP (implementation phase) Horizon Europe project
- Founding of the SLICES-ERIC (European Research Infrastructure Consortium), the legal entity for SLICES-RI
  - Only countries can become member of ERICs
  - National nodes organize the national activities



Partner countries of SLICES-RI

German Roadmap Process

Priorization process for large-scale research infrastuctures

- Goal: Identify important research infrastructure to shape the German research landscape for the next decades
- Application submission in October 2024
- Evaluation lead by the German Science and Humanities Council (Wissenschaftsrat) with three evaluation strands:
  - Science-led assessment
  - Assessment of innovation and transfer potential
  - Assessment of costs and risks
- Results announced on **July 8, 2025** by the Federal Minister of Research Dorothee Bär:
  - *"With bold investments in research infrastructure, we are laying the foundation for remaining internationally competitive in the future."*
- On-site evaluation in **September 2026** by a committee of international reviewers. We are currenlty awaiting the final report.



German Roadmap Process

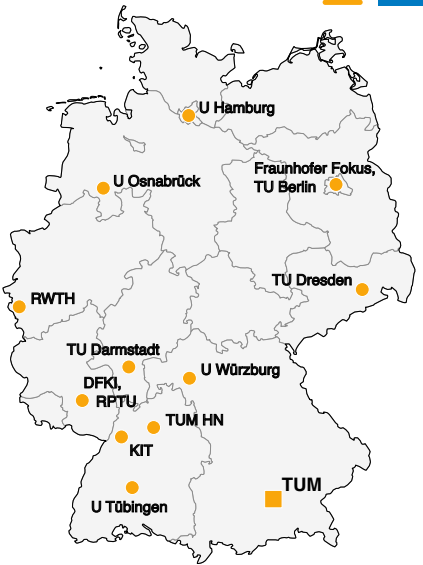
Result: Shortlist of reserach infrastructures

	Infrastructure	Research Field	Installation	Operation
C	CREATION	Cell therapy	84 M	100 M
D	DALI	Matter research	292 M	355 M
E	Einstein Telescope	Gravitational waves	200 M	–
H	HBS-I	Neutron research	118 M	125 M
I	IceCube-Gen2	Neutrino research	71 M	46 M
L	LEGEND-1000	Neutrino research	66 M	29 M
P	PETRA IV	X-ray microscope	1740 M	3150 M
R	RIDLOP	Social science	50 M	122 M
S	**SLICES-DE**	**ICT research**	**60 M**	**37 M**



SLICES-DE

- TUM is the designated national node for Germany
- Goal: Create the German national research infrastructure aligned with the other infrastructures in SLICES-RI
- Coordination of activities in Germany with SLICES-RI
- Technically: Connecting German testbeds to SLICES services, with authentication (OpenID) and reproducibility (with pos)



SLICES-DE: Technical Background

Infrastructure

- Shared testbed resources (Europe & Germany)
- Basic services for access and reservation
- Connectivity between different testbeds

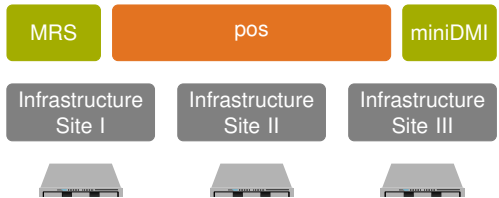


[0] [1] S. Gallenmüller*, D. Scholz*, H. Stubbe, and G. Carle, „The pos Framework: A Methodology and Toolchain for Reproducible Network Experiments“, in CoNEXT '21: The 17th International Conference on emerging Networking EXperiments and Technologies, Virtual Event, Munich, Germany, December 7 - 10, ACM, 2021. DOI: 10.1145/3485983.3494841

SLICES-DE: Technical Background

Reproducibility and Data Management

- Reproducibility and data management are an integral part of SLICES-RI
- Data management
  - Automated collection of data and metadata for experiments
  - Compliance with FAIR principles:
    Findable, **A**ccessible, **I**nteroperable, **R**eusable
  - Alignment with European and German initiatives:
    - European Open Science Cloud (EOSC)
    - Nationale Forschungsdateninfrastruktur (NFDIxCS)
  - SLICES services for data management
    - MRS (metadata registry service)
    - miniDMI (mini data management infrastructure)
- Plain orchestrating service (pos)[1]
  - Framework to ensure reproducible experiments through a well-structured experiment workflow
  - Developed at our research group at TUM
  - Already part of SLICES-RI pre-operation (Nov. 2024)



[1] S. Gallenmüller*, D. Scholz*, H. Stubbe, and G. Carle, „The pos Framework: A Methodology and Toolchain for Reproducible Network Experiments“, in CoNEXT '21: The 17th International Conference on emerging Networking EXperiments and Technologies, Virtual Event, Munich, Germany, December 7 - 10, ACM, 2021. DOI: 10.1145/3485983.3494841

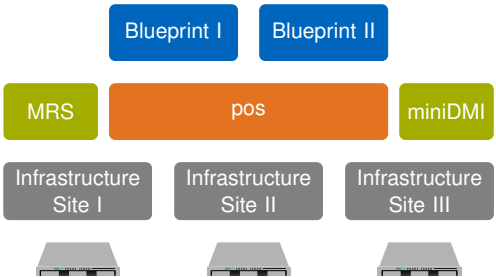
SLICES-DE: Technical Background

Blueprints

- Fundamental building principle of SLICES
- Blueprints represent a reference experiment for a specific community (e .g., 6G, Cloud-edge continuum)
- Scientific communities create and extend blueprints
- Blueprints allow to focus on the actual experiment rather than infrastructure maintenance

Differences to other testbeds

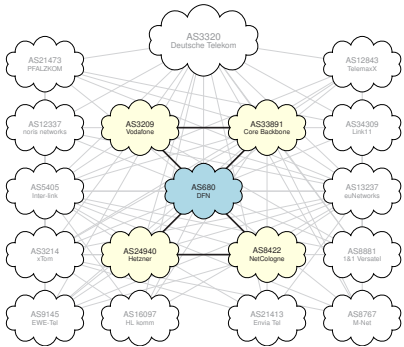
- Testbeds typically focus on providing resources
- SLICES offers a platform for experiments offering additional services
  - Reproducibility through pos
  - Services for data management
  - Reference experiments (blueprints)



Examples of Blueprints

Blueprints (BPs)

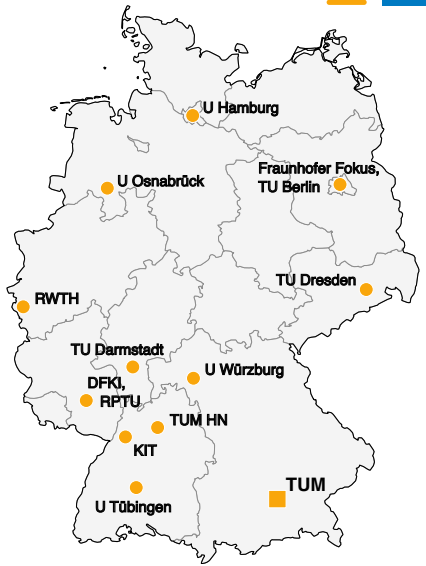
- Post5G BP
  - Provides Hardware resources & software stack to setup a working 5G network (based on Open Air Interface), using pos
  - In pre-operation since Nov ’24
  - Joint effort:
- Internet Digital Twin BP
  - Creating a virtual clone of the entire Internet
  - Based on Internet measurements
  - Allows *what-if* experiments, not possible on the real Internet
- Selected further BPs
  - Security related BPs (Security hardware, post quantum crypto, . . .)
  - Training and Teaching BP



Autonomous Systems that constitute a significant portion of the German Internet

SLICES-DE Partners

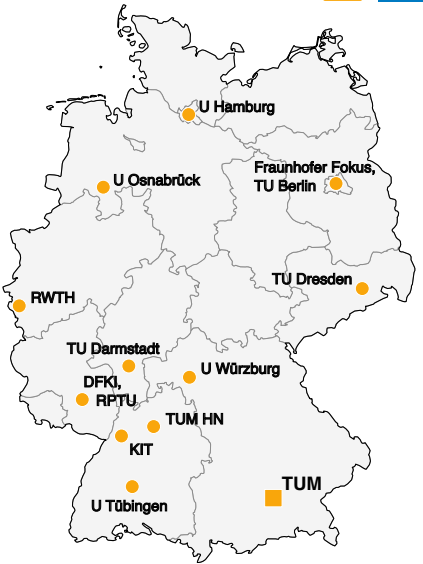
Organization	Participants	Selected Reserach Areas
TUM	G. Carle, S. Gallenmüller, J. Ott, W. Kellerer, I. Weber and others	NFV, Performance-Measurement, 6G, Edge, PQ-Crypto, AI for HPC
Fraunhofer FOKUS	Thomas Magedanz	6G RIC, AI for 6G
TU Berlin	Falko Dressler	Wireless Networks
DFKI RPTU	Hans Schotten	6G RAN, Digital Twinning and AI
Dresden University of Technology	Frank Fitzek, Giang Nguyen, Matthias Wählisch	6G Core and RAN, IoT, Quantum Networks, Resilient Internet
RWTH Aachen University	Klaus Wehrle	Networked Cyber-Physical Systems
TU Darmstadt	Björn Scheuermann, Matthias Hollick	Secure Communication, Mobility
KIT	Thorsten Strufe, Martina Zitterbart	High-Performance Networks, AI for Networks, Security
U Würzburg	Tobias Hossfeld	Network Performance
U Hamburg	Mathias Fischer, Hannes Federrath, Janick Edinger	Secure Networks, Privacy, Edge AI, Security and Privacy for AI
U Osnabrück	Nils Aschenbruck	Hybrid NTNs
U Tübingen	Michael Menth	Network Softwarization



SLICES-DE Community

Benefits of SLICES-DE

- SLICES-DE is planned to be available for the whole community
- . . . for academia:
  - **Research:** Access to state-of-the-art hardware & software for experiments
  - **Teaching & education:** Individual resources for each student
- and industry:
  - **Collaboration Models:** Flexible cooperation opportunities with academia and research institutions.
  - **Reuse of results:** Simplified transfer of results from academia to industry through joint infrastructure.



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Bibliography

[1] S. Gallenmüller*, D. Scholz*, H. Stubbe, and G. Carle, „The pos Framework: A Methodology and Toolchain for Reproducible Network Experiments“, in CoNEXT '21: The 17th International Conference on emerging Networking EXperiments and Technologies, Virtual Event, Munich, Germany, December 7 - 10, ACM, 2021. DOI: 10.1145/3485983.3494841