IT:U

interdisciplinary
transformation
university austria

The Internet

A Critical Infrastructure

Prof. Dr. Johanna Ullrich

Johanna Ullrich
whoami

2013	MSc in Automation Engineering
2016	PhD in Computer Science
2017	**Promotio Sub auspiciis praesidentis** by Austrian president Dr. van der Bellen
Since 2019	**Head of Research Group**, SBA Research
2025 - 2026	**Full Professor**, Universität Wien
Since 2026	**Founding Professor**, IT:U Austria

IT:U
Interdisciplinary Transformation University

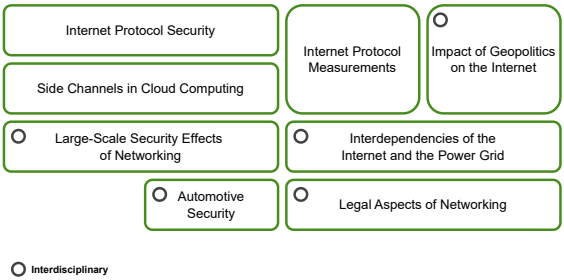
- Newly established public university in Linz, Austria
- Focus on interdisciplinarity
- Research groups around Computer Science and X
- Project-based learning for students
- Currently Master and PHD studies

Vienna
Tourism Director

Zentralfriedhof (Central cementary)

Ludwig Boltzmann

Research Foci



My Topics:

Internet - Security - Measurements - Power Grid

The Internet

or

An Experiment that Escaped the Lab

Transition 1

Commercialization mandates Security.

Security Testing

Security Standards

Security Considerations.

Transition 2

Digital Convergence causes Criticality.

Early Days.

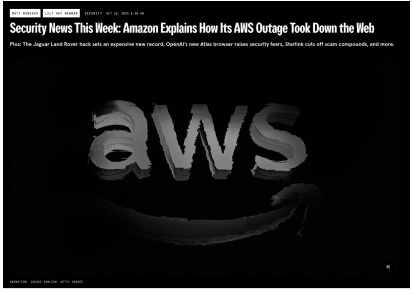
- Internet as an add-on
- Alternative infrastructures such as TV, radio, POTS

Nowadays.

- Living without Internet?
- Phase-out of alternative systems

Transitiation 2

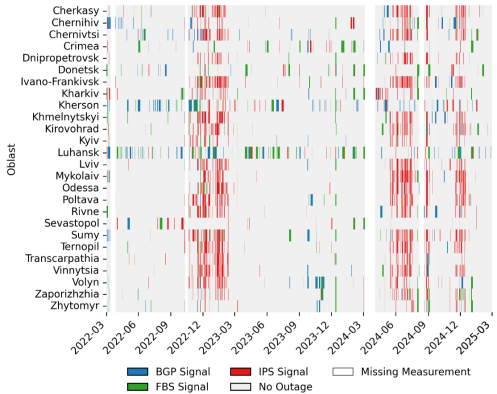
Digital Convergence causes Criticality.



Source: wired.com

Transitiation 2

Digital Convergence causes Criticality.



Source: Holzbauer, F., Strobl, S., Ullrich, J. Tracking Internet Disruptions in Ukraine, IMC, 2025.

Transitiation 2

Digital Convergence causes Criticality.

Source: fm4.ort.at

Transitiation 2

Digital Convergence causes Criticality.

Source: ukrposhta.ua

Transition 3

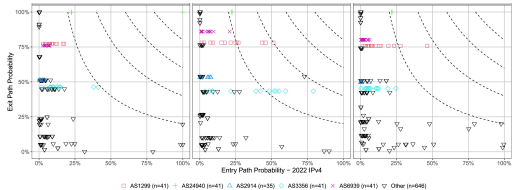
Geopolitical Tension stresses Location.

The Internet no longer borderless :-(

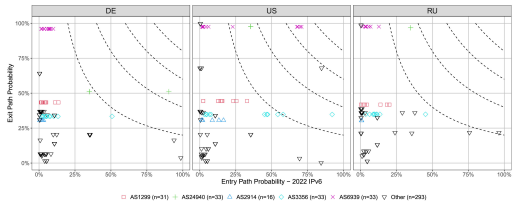
- Firewalls and censorship
- Power of hyperscaler
- Digital sovereignty
- Geopolitical threats
- Internet disconnections

Transition 3

Geopolitical Tension stresses Location.



(b) 2022 IPv4

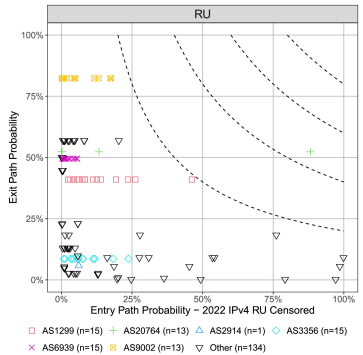


(c) 2022 IPv6

Source: Gegenhuber G., Maier, M., Holzbauer, F., Mayer, W., Merzdovnik, G., Weippl, E., Ullrich, J, An Extended View on Measuring Tor AS-level adversaries, COSE, 2023.

Transition 3

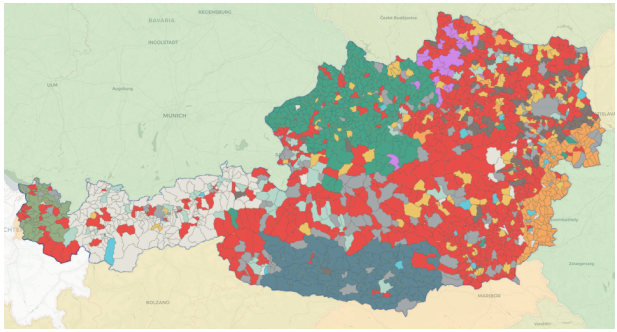
Geopolitical Tension stresses Location.



Source: Gegenhuber G., Maier, M., Holzbauer, F., Mayer, W., Merzdovnik, G., Weippl, E., Ullrich, J, An Extended View on Measuring Tor AS-level adversaries, COSE, 2023.

Transition 3

Geopolitical Tension stresses Location.



Source: Holzbauer, F., Gegenhuber, G., Ullrich, J. Municipalytics: Mapping the Digital Infrastructure of Municipalities Across GDPR Countries, TMA, 2026 https://municipalytics.internetwarte.eu/

Transition in Critical Infrastructures

Not only the Internet

Power Grid

- Geopolictical tensions ...
- Electrification ...
- Digitalization ...

... apart from decentralized operation, large sizes, and ossification ...

Take Away

Transtions need to be monitored and guided.

Insight into the status quo as a basis for

- Standardization like at the IETF
- Policies and Laws
- Security testing and security solutions
- Internet as a Sensor

Internet Measurements

or

The Art of Self-Criticism

Internet Measurements
Hypothesis

To move Internet measurements forward, it is necessary to take a step back and *establish solid foundations first*.

3. Accurate Results

2. Measurement Methods

1. Rigorous Foundations

Induction vs. Deduction

A Pragmatic Definition

Induction. Inferring general rules from observations.

Deduction. Drawing guaranteed conclusions from general rules.

Induction vs. Deduction

A Pragmatic Definition

Induction. Inferring general rules from observations.

Swan 1, swan 2, and swan 3 are white.
Consequently, all swans are white.

Deduction. Drawing guaranteed conclusions from general rules.

Induction vs. Deduction

A Pragmatic Definition

Induction. Inferring general rules from observations.

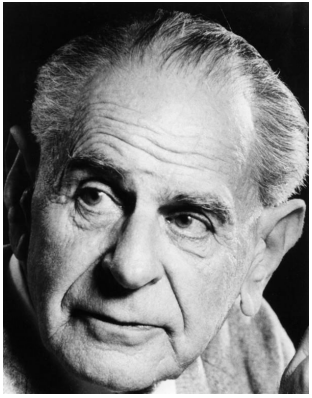
Swan 1, swan 2, and swan 3 are white.
Consequently, all swans are white.

Deduction. Drawing guaranteed conclusions from general rules.

All swans are white.
Consequently, the swan in front of me is white.

Induction vs. Deduction

Karl Raimund Popper



Rejection of induction as a scientific method

Science advances through deduction

Actual science vs. pseudo-science

Induction vs. Deduction

Karl Raimund Popper

Rejection of induction as a scientific method

Science advances through deduction

Actual science vs. pseudo-science

Methodology

Bold Hypotheses and Rigorous Experiments

Natural Sciences

(1) Hypothesis - (2) Experiment - (3) Revise Theory

– repeat, redo –

Induction vs. Deduction
A Black Swan

Hypothesis. All swans are white.

Induction vs. Deduction
A Black Swan

Hypothesis. All swans are white.

Induction vs. Deduction
A Black Swan

Hypothesis. All swans are white.

Refutation.

Methodology

Bold Hypotheses and Rigorous Experiments

Natural Sciences

(1) Hypothesis - (2) Experiment - (3) Revise Theory

– repeat, redo –

Methodology

Bold Hypotheses and Rigorous Experiments

Natural Sciences

(1) Hypothesis - (2) Experiment - (3) Revise Theory

– repeat, redo –

Internet Measurement

(1) Tooling - (2) Experiment - (3) Data Analysis

– stop –

Internet Measurements
Critics

- Measuring of *what we can* vs *what we want*
- *Rule-of-thumb* or *Pareto-principle* outcomes
  Examples (own research): (1) We discovered 23,208 persistent routing loops in IPv4 and 30,090 in IPv6, rendering 0.91% (IPv4) resp. 2.20% (IPv6) of the address space [...] unreachable. (2) A small portion of operators provide email services to the majority of users and domains on the Internet (37%).
- *Repeatability* (ACM: same team, same experiment) is hard, *reproduction* is harder (ACM: different team, same experiment), *replication* (ACM: different team, different experiment) is barely available

Internet Measurements

From Engineering to Natural Sciences

The Internet is an engineered product, and the methods in Internet measurements are *engineering style*. Discovering and explaining Internet phenomena,however, experiments appear more similar to those in natural sciences.

What is true vs. *What works best*

- Discover fundamental phenomena vs. create, optimize, validate solutions
- Explanatory power vs. meet specifications
- Universality vs. fit-for-purpose
- Reproducability (generality) vs. Repeatability (under certain conditions)
- Example: Quantum Theory vs. Digital Twin

Internet Measurements
Consequences

Notable negative example:

- Accuracy of *Geolocation* – it was obvious, however ...
- The fairy tale of the *scale-free* Internet

Despite these outcomes are of interest, it is infeasible to reliably act upon them.

- Standardization of the *Internet Engineering Task Force*
- Policies (e.g., as a consequence of the Internet's defragmentation)
- Security testing (e.g., as mandated by NIS2)
- Internet as a Sensor

Internet Measurements
Hypothesis

To move Internet measurements forward, it is necessary to take a step back and *establish solid foundations first*.

3. Accurate Results

2. Measurement Methods

1. Rigorous Foundations

Internet Measurements
Differences

- Internet is considered to change constantly.
- Internet experiments are cheaper (potentially also the reason for the messiness).

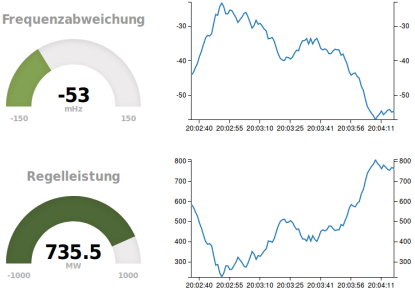
Power Grid

or

The Internet as a Threat

Balancing of Demand and Supply

Grid Frequency as a Stability Indicator



Source: `netzsin.us`

Emergency Routines (ENTSO-E)

49.8 Hz: Alerting, activation of plants, pump shedding

49.0 Hz: Load-shedding of 10-15% of total load

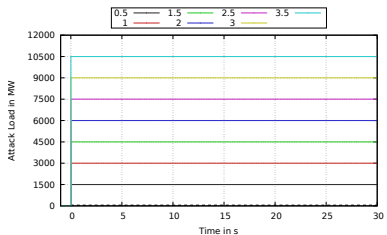
48.7 Hz: Load-shedding of 10-15% of total load

48.4 Hz: Load-shedding of 10-25% of total load

47.5 Hz: Disconnection of all power plants

Manipulation-of-Demand Attacks

Destabilization with Sudden Load Changes



Research Question 1:

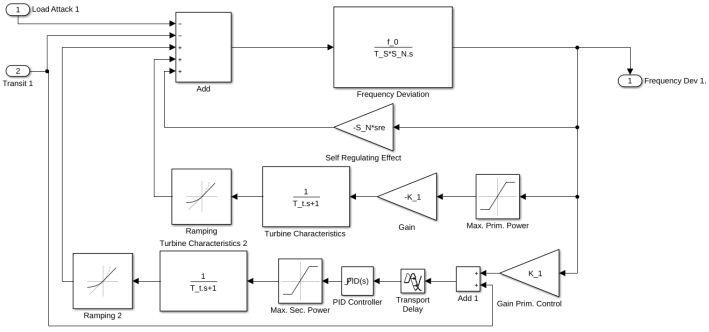
How much electric load is needed?

Research Question 2:

How many bots are needed?

Manipulation-of-Demand Attacks

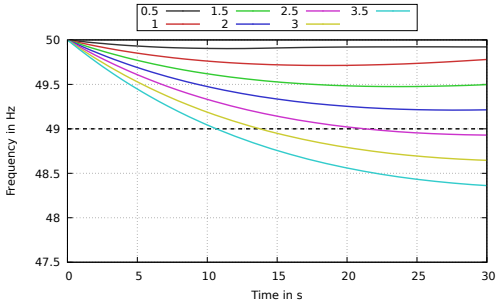
A Model of the European Power Grid



Source: Dabrowski, A., Ullrich, J., Weippl, E. Grid Shock: Coordinated Load-Change Attacks on Power Grids, ACSAC, 2017.

Manipulation-of-Demand Attacks

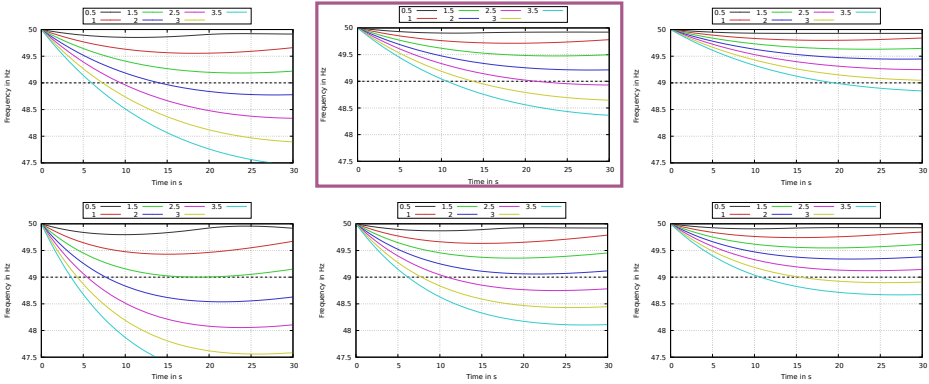
Impact on Power Grid Frequency



Source: Dabrowski, A., Ullrich, J., Weippl, E. Grid Shock: Coordinated Load-Change Attacks on Power Grids, ACSAC, 2017.

Manipulation-of-Demand Attacks

Impact on Frequency in Dependence of Power Grid State



Source: Dabrowski, A., Ullrich, J., Weippl, E. Grid Shock: Coordinated Load-Change Attacks on Power Grids, ACSAC, 2017.

Manipulation-of-Demand Attacks

Number of Necessary Infections

	Scenario 1	*Scenario 2*	*Scenario 3*
Office PC	40%	40%	30%
Home PC	30%	30%	40%
Gaming PC	15%	15%	20%
Server	15%	15%	10%
+ IoT-Mix	-	Mix 1	Mix 2
Avg. Δ Load p. Infection	458.045 W	778.045 W	1 201.125 W
Infections 3000 MW (1 RI)	6 549 575	3 855 819	2 497 659
Infections 4500 MW (1.5 RI)	9 824 363	5 783 728	3 746 488

Source: Dabrowski, A., Ullrich, J., Weippl, E. Grid Shock: Coordinated Load-Change Attacks on Power Grids, ACSAC, 2017.

Manipulation-of-Demand Attacks

Number of Necessary Infections

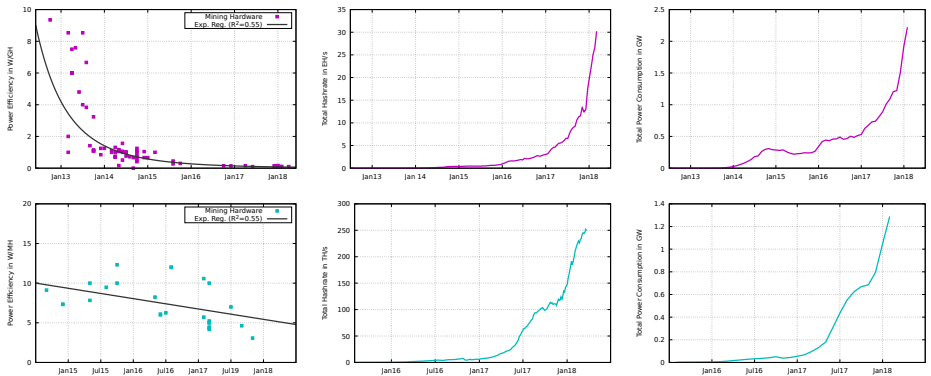
	Scenario 1	*Scenario 2*	*Scenario 3*
Office PC	40%	40%	30%
Home PC	30%	30%	40%
Gaming PC	15%	15%	20%
Server	15%	15%	10%
+ IoT-Mix	-	Mix 1	Mix 2
Avg. Δ Load p. Infection	458.045 W	778.045 W	1 201.125 W
Infections 3000 MW (1 RI)	6 549 575	3 855 819	2 497 659
Infections 4500 MW (1.5 RI)	9 824 363	5 783 728	3 746 488

Nowadays:
only 1.5 Million

Source: Dabrowski, A., Ullrich, J., Weippl, E. Grid Shock: Coordinated Load-Change Attacks on Power Grids, ACSAC, 2017.

Manipulation-of-Demand Attacks

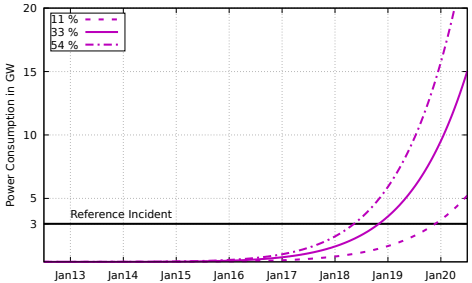
Bitcoin and Ethereum - Technological Monocultures



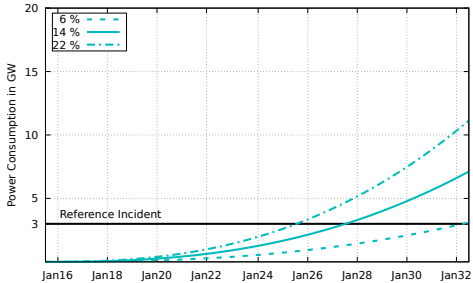
Source: Ullrich, J., Stifter, N., Judmayer, A., Dabrowski, A., Weippl, E. Proof-of-Blackouts? How Proof-of-Work Cryptocurrencies Could Affect Power Grids, RAID, 2018.

Manipulation-of-Demand Attacks

Bitcoin and Ethereum - Technological Monocultures



Bitcoin



Ethereum

Source: Ullrich, J., Stifter, N., Judmayer, A., Dabrowski, A., Weippl, E. Proof-of-Blackouts? How Proof-of-Work Cryptocurrencies Could Affect Power Grids, RAID, 2018.

Manipulation-of-Demand Attacks

Consequences

- Blackout in one or more regions (or even Europe as a whole!)
- Immediate impact on elderly care, public transport, and farming
- Destabilization takes 30 seconds, but restart days!

Take Aways

- The Internet is a threat to the power grid.
- It does not need an adversarial actor ...
- Internet measurements could again help to assess the threat surface ...

Conclusion

Take Aways

The Internet is a critical infrastructure.

The Internet also threatens other infrastructures.

More insight into the status quo is needed.

More rigorous methodology is needed for measurements.

The Internet

A Critical Infrastructure

Prof. Dr. Johanna Ullrich

IT:U

interdisciplinary
transformation
university austria