

Presentation at the University of Sydney

NorNet at the University of Sydney:
From Simulations to
Real-World Internet Measurements
for Multi-Path Transport Research

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Centre for Digital Engineering

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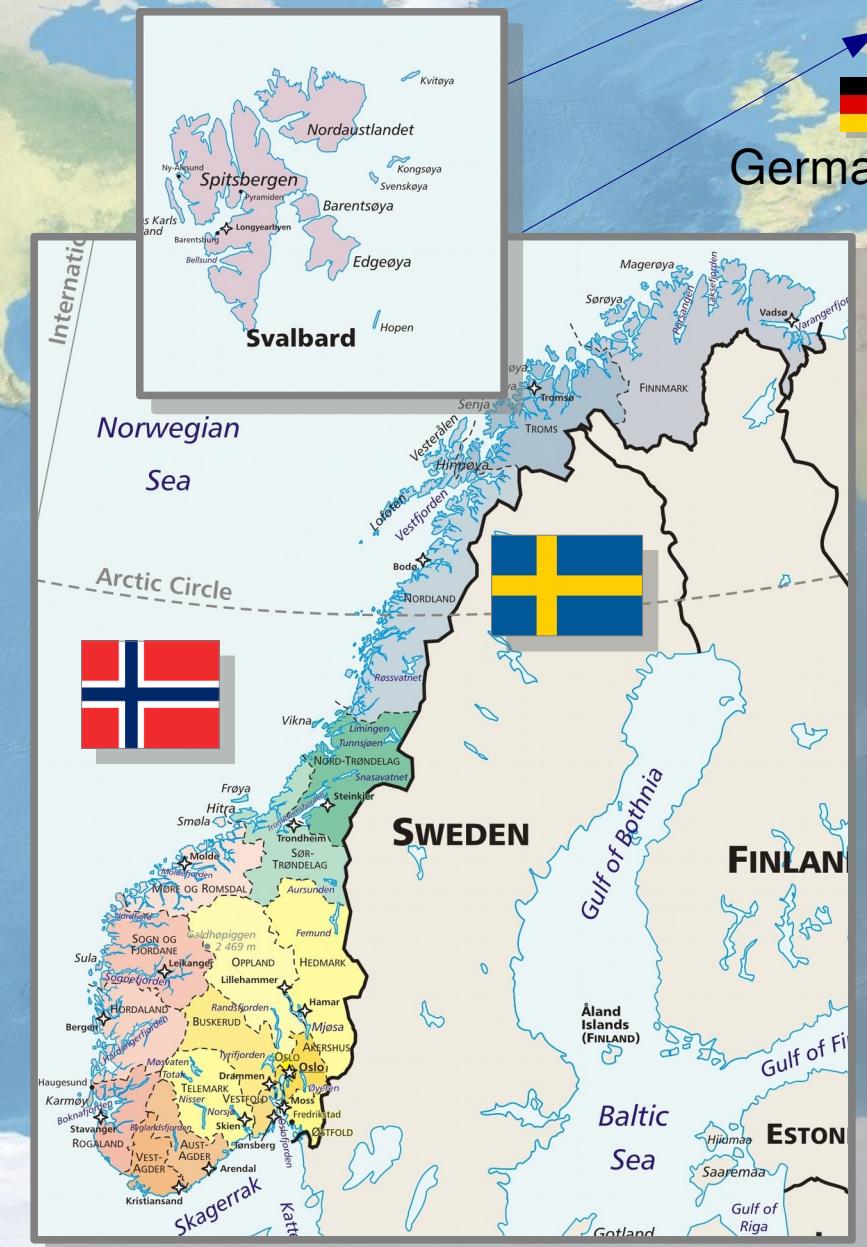
Contents

- About Norway and the Simula Research Laboratory
- From TCP to Multi-Path Transport
- Simulations
- Lab Setups and Internet Setups
- The NorNet Testbed
- Conclusion
- Literature

Overview: About Norway and the Simula Research Laboratory

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Where is Norway?

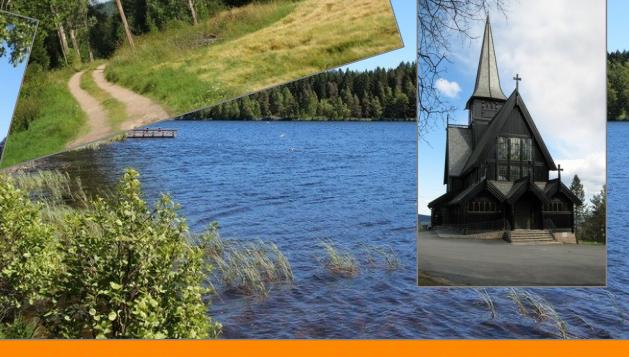


Facts about Norway

Capital:	Oslo
Size:	ca. 385,000 km ²
Population:	ca. 5,214,000
Internet TLD:	.no



The Kingdom of Norway (Kongeriket Norge)



The Simula Research Laboratory

- Located in Oslo and Fornebu
- Public limited company
 - Non-profit research organisation
 - Ca. 200 people from all over the world
- Research groups
 - Scientific Computing
 - Software Engineering
 - **Resilient Networks and Applications**
(also part of OsloMet, the new Oslo Metropolitan University)
- Norway's leading place for computer science research

[**simula** . research laboratory]



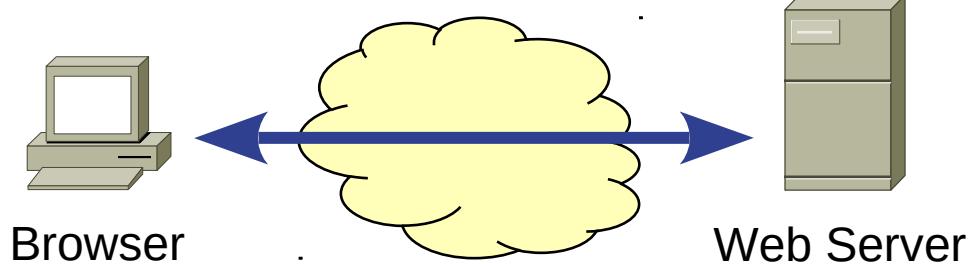
Visit <https://www.simula.no> for further information!

Overview: From TCP to Multi-Path Transport

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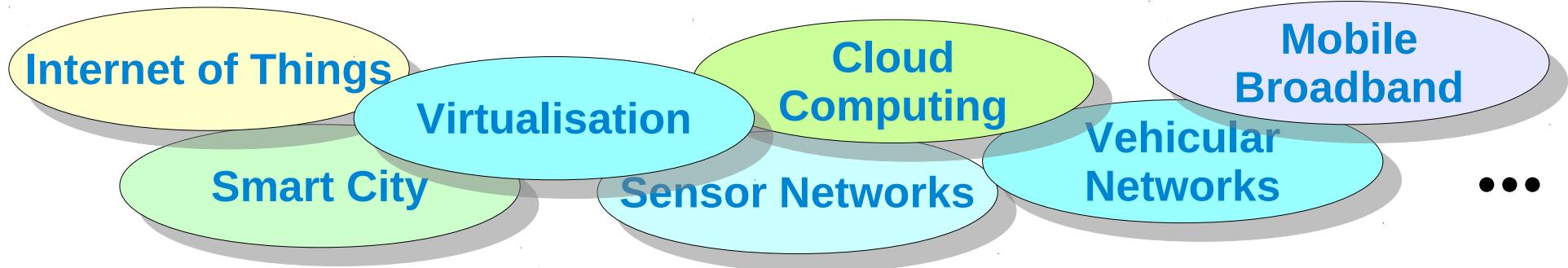
„Classic“ Internet Communication

- Example: World-Wide Web



- Client ↔ Server Communication
 - 1 network interface per device → 1 **IPv4** address
 - Communication with Transmission Control Protocol (**TCP**)

The Current and Future Internet: The Big Picture



- IPv6
 - Devices are frequently IPv4/IPv6 dual stack
 - Usually multiple addresses per interface
- Mobility → address change
- Devices with multiple interfaces
 - Router
 - **Smartphone** (LTE/UMTS, WLAN, Bluetooth?)
 - **Laptop** (Ethernet, WLAN, LTE/UMTS?)



Multi-Homing and Multi-Path Transport

- Multi-Homing
 - Multiple interfaces (addresses)
 - **Redundancy** → Communication even when some paths fail
- Multi-Path Transport
 - Also utilise paths simultaneously → better throughput
 - **MPTCP**: Multi-Path TCP
 - **CMT-SCTP**: Concurrent Multi-Path Transfer for SCTP

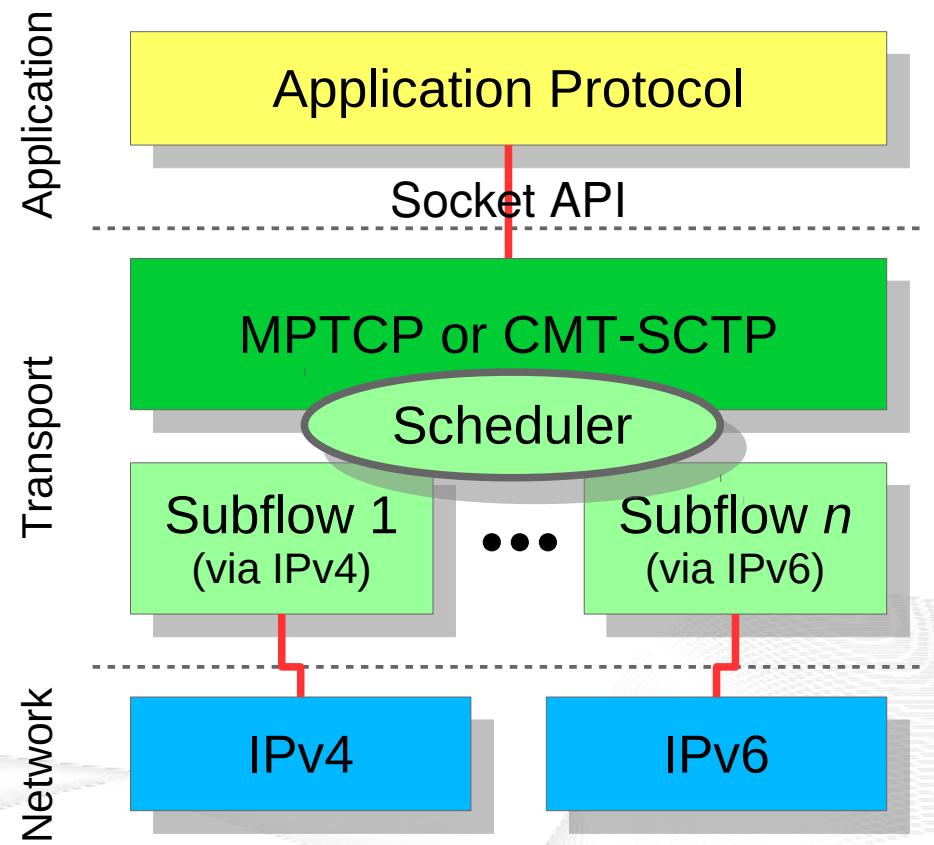


SCTP: Stream Control Transmission Protocol
TCP: Transmission Control Protocol

Hot topic in research and standardisation!

Multi-Path Transport with MPTCP and CMT-SCTP

- Subflow \leftrightarrow path
- Fairness
 - Paths may overlap (fully or partially)
- Scheduling
 - Different path characteristics
 - Bandwidth
 - Latency and jitter
 - Packet loss



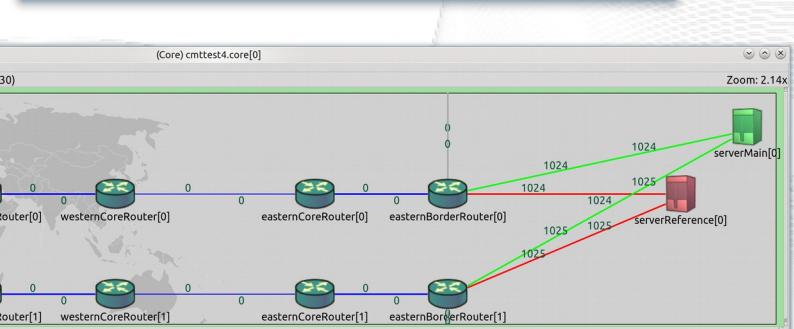
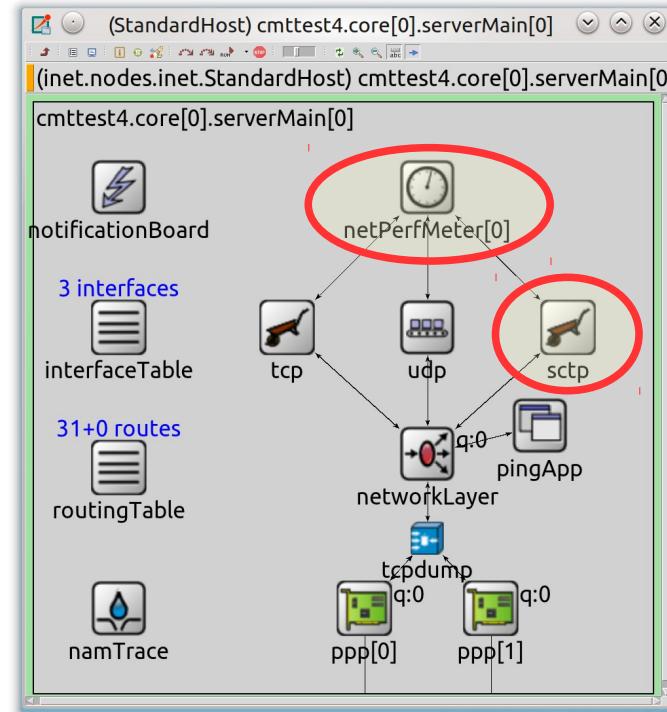
Complex system \rightarrow analyses are necessary!

Overview: Simulations

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Research (1) – The Beginning: Simulations

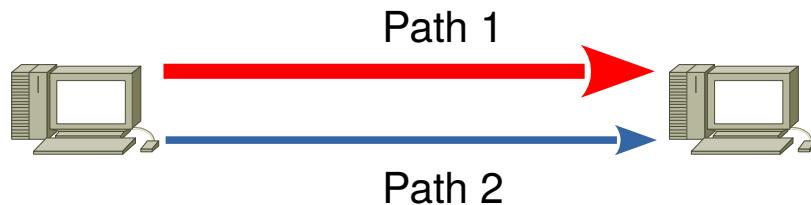
- SCTP in OMNeT++
 - SCTP extensions
 - Application model “NetPerfMeter”
- Open Source
 - Mostly part of the OMNeT++ INET Framework
 - Some parts still need merging



<https://inet.omnetpp.org>

Challenge: CMT-SCTP over Dissimilar Paths

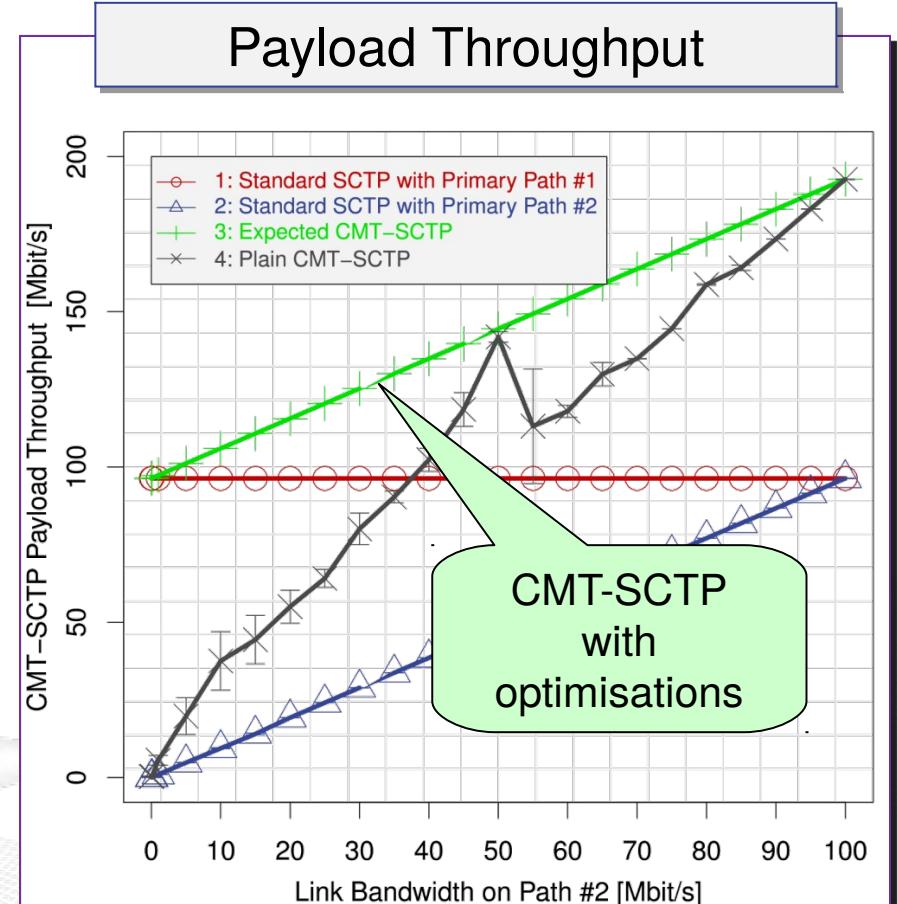
Setup



- 2 paths;
100 Mbit/s, 1 ms, 0% packet loss
- Saturated sender
- Bandwidth variation on path 2

Simulation results

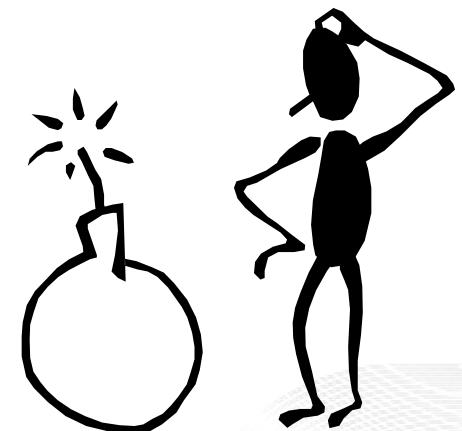
- SCTP, primary path via Path 1
- SCTP, primary path via Path 2
- Expected for CMT-SCTP
- Original CMT-SCTP



Lesson learned: interaction among mechanisms

Efficient CMT-SCTP over Dissimilar Paths

- **Complexity** due to **interaction** of different mechanisms
 - Congestion control
 - Management of send and receive buffers
 - Handling of retransmissions
 - Acknowledgement mechanism
 - Options for message delivery (in-sequence? lossless?)
- Need for a lot of research



How „good“ are the simulations? Comparison to real system!

Overview: Lab Setups and Internet Setups

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Research (2) – The Next Step: Lab Setup

- Surprisingly big effort:
 - Strange effects of cheap network components:
„It's only cheap on the paper!“
 - Debugging of SCTP in FreeBSD
- But valuable:
 - **The simulations were useful!** 😊
 - Bugfixes for the FreeBSD community
 - Open Source software „**NetPerfMeter**“
 - **Learning effects** and **new ideas!**



Internet protocols → testbed in the Internet!

Research (3) – Real Internet: 3 Cities and 2 Continents



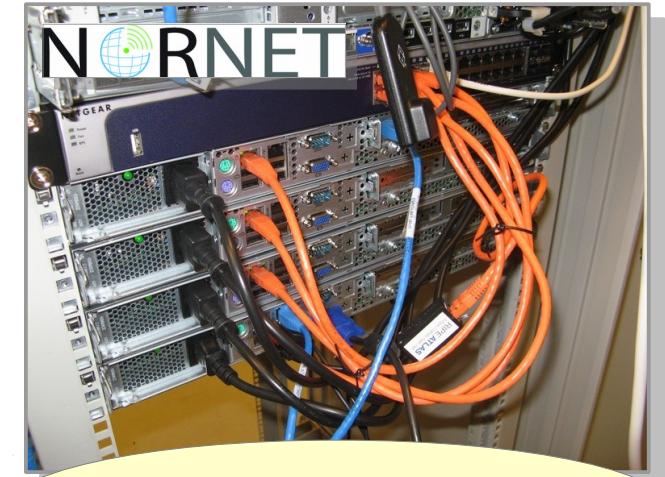
- 3 connected lab setups
 - Establishment of an international cooperation
 - **Essen, Burgsteinfurt** (FH Münster), **Haikou 海口** (Hainan University)
- Very interesting scenario:
 - CMT-SCTP and MPTCP evaluation
 - Very different path characteristics
→ Ideas for further experiments

Many new ideas!

Now really big: NorNet testbed!

The NorNet Testbed

- NorNet Core
 - Cable, up to 4 providers, IPv4+IPv6 (fibre, „consumer-grade” DSL, etc.)
 - Hosts for virtual machines
 - 22 locations (11 in Norway, 11 abroad)



<https://www.nntb.no>

- NorNet Edge
 - Embedded system „Ufoboard“
 - Up to 4x 2G/3G/4G, 1x CDMA, 1x Ethernet
 - Hundreds of locations (in Norway)



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Goals of the NorNet Project

- Building up a **realistic** multi-homing testbed
- Wired and wireless
 - Wired → “NorNet Core”
 - Wireless → “NorNet Edge”
- **Perform research with the testbed!**



How to get a **realistic** testbed?

Idea: Distribution of NorNet over whole Norway

- **Challenging topology:**
 - Large distances
 - A few “big” cities, huge rural areas (outback)
 - Svalbard:
 - Interesting location
 - Many polar research institutions
 - **Deployment:**
 - Core: 11 sites in Norway + CN, DE, SE, US, KR, AU, FR
 - Edge:
hundreds of nodes in Norway



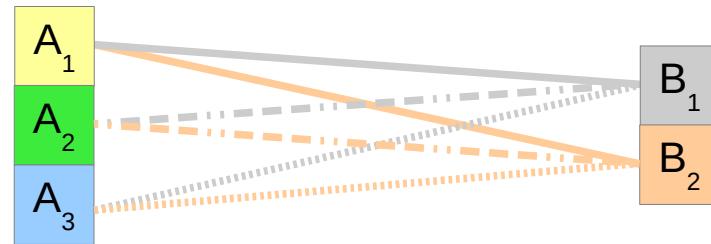
Overview:

The NorNet Testbed: NorNet Core

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Idea for NorNet Core: Tunnelling

- Researchers require control over used ISP interfaces
 - Which outgoing (local site) interface
 - Which incoming (remote site) interface
- Idea: Tunnels among sites
 - Router at site A: IPs A_1, A_2, A_3
 - Router at site B: IPs B_1, B_2
 - IP tunnel for each combination:
 $A_1 \leftrightarrow B_1, A_1 \leftrightarrow B_2, A_2 \leftrightarrow B_1, A_2 \leftrightarrow B_2, A_3 \leftrightarrow B_1, A_3 \leftrightarrow B_2$
 - Fully-connected tunnel mesh among NorNet Core sites
 - Each site's router (called **tunnelbox**) maintains the tunnels
 - Static tunnels
 - NorNet-internal addressing and routing over tunnels



Address Assignment

- NorNet-internal address spaces:
 - Private NorNet-internal IPv4 “/8” address space (NAT to outside)
 - Public NorNet-internal IPv6 “/48” address space
- Systematic address assignment:
 - IPv4: 10.<Provider ID>.<Site ID>.<Node ID>/24 per site
 - IPv6: 2001:700:4100:<PP><SS>>::<NN>/64
(PP=Provider ID; SS=Site ID; NN=Node ID)
- NorNet-internal DNS setup including reverse lookup

Make it as easy as possible to keep the overview!

A NorNet Core Site Deployment

A usual NorNet Core site:

- 1x switch
- 4x server
 - 1x tunnelbox
 - 3x research systems
- At least two ISP connections
 - Research network provider
 - Other providers
- IPv4 and IPv6 (if available)



Additional researcher-provided sites:

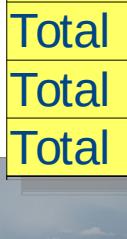
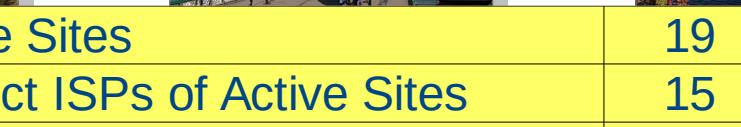
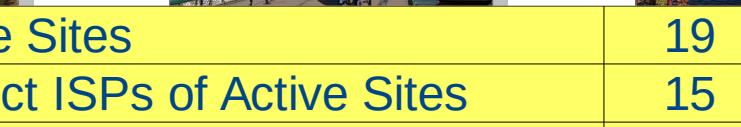
- Varying configurations
- VM setups, powerful servers,
“retro-style” PCs ...

NorNet Core Site Deployment Status (January 2019)

No.	Site	ISP 1	ISP 2	ISP 3	ISP 4
1	Simula Research Laboratory	Uninett	Kvantel	Telenor	PowerTech
2	Universitetet i Oslo	Uninett	Broadnet	PowerTech	
3	Høgskolen i Gjøvik	Uninett	PowerTech		
4	Universitetet i Tromsø	Uninett	Telenor	PowerTech	
5	Universitetet i Stavanger	Uninett	Altibox	PowerTech	
6	Universitetet i Bergen	Uninett	BKK		
7	Universitetet i Agder	Uninett	PowerTech		
8	Universitetet på Svalbard	Uninett	Telenor		
9	NTNU Trondheim	Uninett	PowerTech		
10	Høgskolen i Narvik	Uninett	Broadnet	PowerTech	
11	Oslo Metropolitan University	Uninett			
12	Karlstads Universitet	SUNET			
13	Universität Kaiserslautern	DFN			
14	Universität Duisburg-Essen	DFN			
15	Hainan University 海南大学	CERNET	China Unicom		
16	The University of Kansas	KanREN			
17	Korea University 고려대학교	KREONET	IPv4 and IPv6		
18	HAW Hamburg	DFN	IPv4 only (ISP without IPv6 support ☺)		
19	Technische Universität Darmstadt	DFN	IPv4 only (site's network without IPv6 support)		
20	Lab. Informatique Grenoble	RENATER	ISP negotiation in progress		
21	New York University	Lightower			
22	Haikou Cg. of Econ. 海口经济学院	China Telecom	CERNET		

<https://www.nntb.no/pub/nornet-configuration/NorNetCore-Sites.html>

Some Site Statistics (January 2019)

	  	   
	 	 19
	 	 15
	 	 7
		 36
		 630
		 22
		 231

<https://www.nntb.no/pub/nornet-configuration/NorNetCore-Sites.html>

Remote Systems

❄ -30°C
Longyearbyen

Our servers may be really remote!

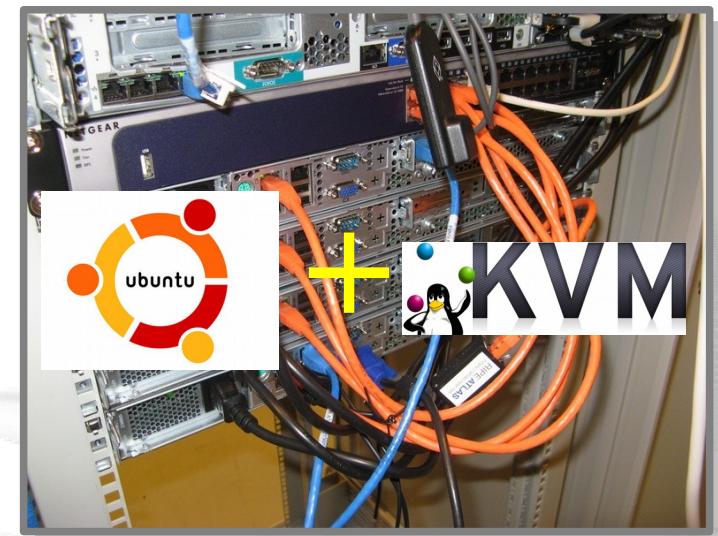


The “road” to Longyearbyen på Svalbard, 78.2°N

Virtualisation

“Anything that can go wrong, will go wrong.”
[Murphy's law]

- Experimentation software is experimental
- How to avoid software issues making a remote machine unusable?
- Idea: virtualisation
 - Lightweight, stable software setup:
Ubuntu Server 16.04 LTS
 - KVM (Kernel-based Virtual Machine)
 - Other software runs in VMs:
 - Tunnelbox VM on physical server #1
 - 2 LXC-based research node VMs
on physical servers #2 to #4
 - In case of problem: manual/automatic restart or reinstall of VM



Overview: The NorNet Testbed: NorNet Edge

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NorNet Edge – Wireless Network Conditions at Heterogeneous Locations



NorNet Edge needs to cover many locations!



NorNet Edge Nodes

Solution: embedded systems instead of servers!

Ufoboard:

- Custom-made for NorNet
- Based on off-the-shelf smartphone board (Samsung Galaxy S)
- 1 GHz ARM Cortex-A8 CPU
- 512 MiB RAM
- 16-32 GB disk (SD card)
- 7 USB ports + Ethernet port
- Debian Linux 7.6 (“Wheezy”)



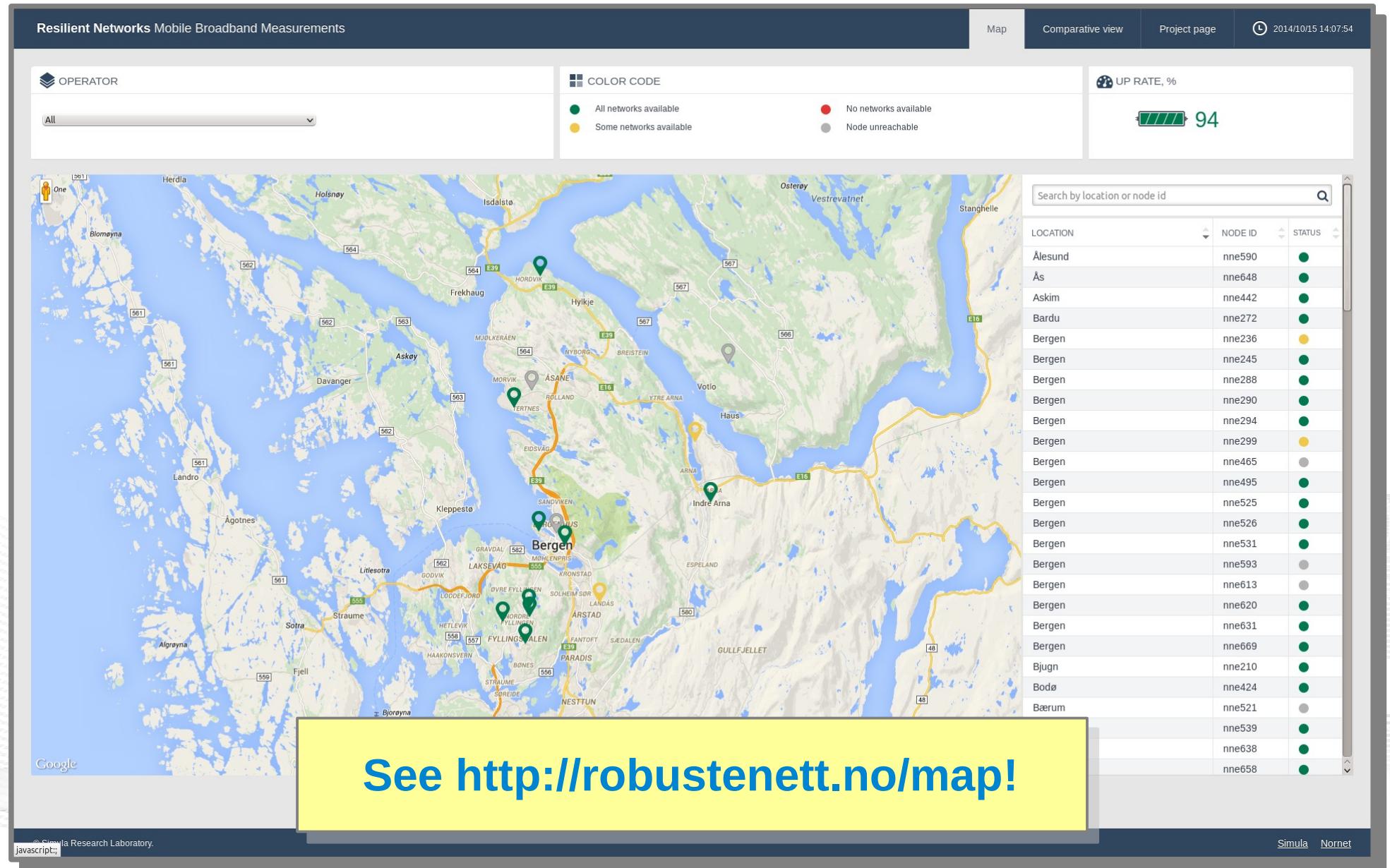
The NorNet Edge Box: Ready for Deployment

Box contents:

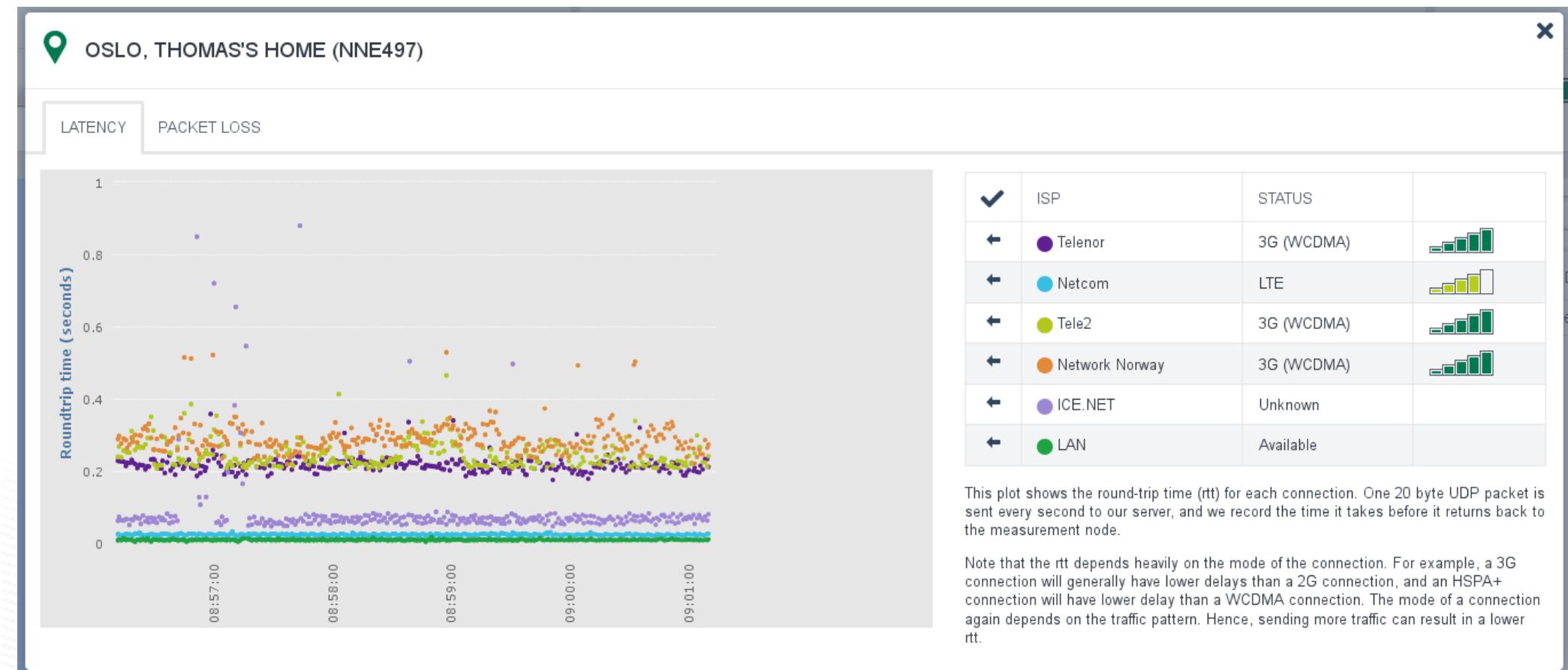
- Ufoboard
- Up to 4x USB UMTS or LTE:
 - Telenor, Telia,
 - Network Norway, Tele2
- 1x ICE CDMA mobile broadband
- 1x Ethernet
- 1x WLAN (optional)
- Power supplies
- Handbook



Live Visualisation of NorNet Edge (1)



Live Visualisation of NorNet Edge (2): Real-Time Data and Statistics Database



See [http://robustenett.no/map!](http://robustenett.no/map)

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Conclusion and Future Work

“The road to hell is paved with unused testbeds.”
[James P. G. Sterbenz]

- The NorNet Core testbed is ready for experiments!
 - Do you have experiment ideas? → Talk to us!
- Future work:
 - NorNet Core
 - Additional sites, more IPv6 endpoints
 - **OpenStack support** → **MELODIC project**
 - NorNet Edge
 - **5G support** → **5G-VINNI project**



Visit <https://www.nntb.no> for further information!

“NorNet wants to be a building block of the railroad to heaven” ...



<https://www.nntb.no>

... and not be another unused testbed that paves the road to hell!

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Literature (1)

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Literature (2)

- **Fu, F.; Zhou, X.; Dreibholz, T.; Wang, K.; Zhou, F.; Gan, Q.:** “Performance Comparison of Congestion Control Strategies for Multi-Path TCP in the NorNet Testbed” (PDF, 172 KiB), Proceedings of the 4th IEEE/CIC International Conference on Communications in China (ICCC), pp. 607–612, DOI 10.1109/ICCCChina.2015.7448667, ISBN 978-1-5090-0243-6, Shenzhen, Guangdong/People's Republic of China, November 3, 2015.
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Any Questions?



Visit <https://www.nntb.no> for further information!