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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Simula Metropolitan Centre for Digital Engineering

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Overview:
About Norway and the Simula Research Laboratory

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

- Capital: Oslo
- Size: ca. 385,000 km²
- 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

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

Redundancy is expensive!

Hot topic in research and standardisation!
Multi-Path Transport with MPTCP and CMT-SCTP

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

Complex system → 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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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

Now really big: NorNet testbed!

Many new ideas!
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)

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

https://www.nntb.no
Overview:
The NorNet Testbed

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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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- The NorNet Testbed
  - NorNet Core
  - NorNet Edge
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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:**
  - IPv6: 2001:700:4100:<PP><SS>::<NN>/64
    (PP=Provider ID; SS=Site ID; NN=Node ID)

- **NorNet-internal DNS setup including reverse lookup**

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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)

<table>
<thead>
<tr>
<th>No.</th>
<th>Site</th>
<th>ISP 1</th>
<th>ISP 2</th>
<th>ISP 3</th>
<th>ISP 4</th>
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<td>Uninett</td>
<td>Kvantel</td>
<td>Telenor</td>
<td>PowerTech</td>
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</tr>
</tbody>
</table>

- IPv4 and IPv6
- IPv4 only (ISP without IPv6 support 😞)
- IPv4 only (site's network without IPv6 support)
- ISP negotiation in progress

[https://www.nntb.no/pub/nornet-configuration/NorNetCore-Sites.html](https://www.nntb.no/pub/nornet-configuration/NorNetCore-Sites.html)
Some Site Statistics (January 2019)

<table>
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<th>Value</th>
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<tr>
<td>Active Sites</td>
<td>19</td>
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<tr>
<td>Distinct ISPs of Active Sites</td>
<td>15</td>
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<tr>
<td>Distinct Countries of Active Sites</td>
<td>7</td>
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<tr>
<td>Total IPv4 Interfaces</td>
<td>36</td>
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<tr>
<td>Total IPv4 Tunnels</td>
<td>630</td>
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<tr>
<td>Total IPv6 Interfaces</td>
<td>22</td>
</tr>
<tr>
<td>Total IPv6 Tunnels</td>
<td>231</td>
</tr>
</tbody>
</table>

https://www.nntb.no/pub/nornet-configuration/NorNetCore-Sites.html
Remote Systems

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
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The NorNet Testbed: NorNet Edge

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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)

See http://robustenett.no/map!
Live Visualisation of NorNet Edge (2):
Real-Time Data and Statistics Database

OSLO, THOMAS’S HOME (NNE497)

LATENCY        PACKET LOSS

This plot shows the round-trip time (rtt) for each connection. One 20 byte UDP packet is sent every second to our server, and we record the time it takes before it returns back to the measurement node.

Note that the rtt depends heavily on the mode of the connection. For example, a 3G connection will generally have lower delays than a 2G connection, and an HSPA+ connection will have lower delay than a WCDMA connection. The mode of a connection again depends on the traffic pattern. Hence, sending more traffic can result in a lower rtt.

See http://robustenett.no/map!
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Conclusion

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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” ... 

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

https://www.nntb.no
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Dreibholz, T.: “Combining NorNet Core with MELODIC” (PDF, 10777 KiB), Invited Talk at Hainan University, College of Information Science and Technology (CIST), Haikou, Hainan/People's Republic of China, December 29, 2017.

Dreibholz, T.: “NorNet Core Beginner Tutorial at Hainan University” (PDF, 6963 KiB), Tutorial at Hainan University, College of Information Science and Technology (CIST), Haikou, Hainan/People's Republic of China, December 15, 2017.


Dreibholz, T.: “NorNet at the University of Sydney – An Introduction to the NorNet Core Testbed” (PDF, 11848 KiB), Invited Talk at University of Sydney, School of Information Technologies, Sydney, New South Wales/Australia, January 24, 2017.
Literature (2)


Any Questions?

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