Keynote Talk at Hainan University (海南大学)

Multi-Path Transport at Hainan University – From Simulations to Real-World Internet Measurements in the NorNet Testbed

Thomas Dreibholz (托马斯博士)
Simula Research Laboratory

April 18, 2017
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

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

Facts about Norway
- Capital: Oslo
- Size: ca. 385,000 km²
- Population: ca. 5,214,000
- Internet TLD: .no

Sydney, Germany, Beijing, Haikou
The Kingdom of Norway (Kongeriket Norge)

King Harald V
The Simula Research Laboratory

- Located in Fornebu
  - Just outside of Oslo
  - In the IT Fornebu complex
- Public limited company
  - Non-profit research organisation
  - Ca. 160 people from all over the world
- Research groups
  - Scientific Computing
  - Software Engineering
  - Resilient Networks and Applications
- Norway’s leading place for computer science research

Visit https://www.simula.no for further information!
Overview:
From TCP to Multi-Path Transport

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

Redundancy is expensive!
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

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

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

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
  - 23 locations (11 in Norway, 12 abroad)

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

[ simula.research.laboratory ]

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

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

- About Norway and the Simula Research Laboratory
- From TCP to Multi-Path Transport
- Simulations
- Lab Setups and Internet Setups
- The NorNet Testbed
  - NorNet Core
  - NorNet Edge
- Conclusion
- Literature
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:
    (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 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 (April 2017)

<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>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Simula Research Laboratory</td>
<td>Uninett</td>
<td>Kvantel</td>
<td>Telenor</td>
<td>PowerTech</td>
</tr>
<tr>
<td>2</td>
<td>Universitetet i Oslo</td>
<td>Uninett</td>
<td>Broadnet</td>
<td>PowerTech</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Høgskolen i Gjøvik</td>
<td>Uninett</td>
<td>PowerTech</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Universitetet i Tromsø</td>
<td>Uninett</td>
<td>Telenor</td>
<td>PowerTech</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Universitetet i Stavanger</td>
<td>Uninett</td>
<td>Altibox</td>
<td>PowerTech</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Universitetet i Bergen</td>
<td>Uninett</td>
<td>BKK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Universitetet i Agder</td>
<td>Uninett</td>
<td>PowerTech</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Universitetet på Svalbard</td>
<td>Uninett</td>
<td>Telenor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Universitetet i Trondheim</td>
<td>Uninett</td>
<td>PowerTech</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Høgskolen i Narvik</td>
<td>Uninett</td>
<td>Broadnet</td>
<td>PowerTech</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Høgskolen i Oslo og Akershus</td>
<td>Uninett</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Karlstads Universitet</td>
<td>SUNET</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Universität Kaiserslautern</td>
<td>DFN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Universität Duisburg-Essen</td>
<td>DFN</td>
<td></td>
<td>(Versatel)</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Hainan University 海南大学</td>
<td>CERNET</td>
<td>China Unicom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>The University of Kansas</td>
<td>KanREN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Korea University 고려대학교</td>
<td>KREONET</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>HAW Hamburg</td>
<td>DFN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Technische Universität Darmstadt</td>
<td>DFN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Lab. Informatique Grenoble</td>
<td>RENATER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>New York University</td>
<td>Lightower</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Haikou Cg. of Econ. 海口经济学院</td>
<td>China Telecom</td>
<td>CERNET</td>
<td></td>
<td></td>
</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
Some Site Statistics
(April 2017)

Active Sites 22
Distinct ISPs of Active Sites 16
Distinct Countries of Active Sites 7
Total IPv4 Interfaces 40
Total IPv4 Tunnels 780
Total IPv6 Interfaces 24
Total IPv6 Tunnels 276

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

-30°C

Longyearbyen
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 14.04 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
You may use NorNet Core, too!

Join the tutorial session!
Here, at Hainan University!

- Contents:
  - Get access to NorNet Core
  - User and slice management
  - Access to slices
  - Using and configuring slivers with own software
  - How to make use of multi-homing?
Overview:
The NorNet Testbed: NorNet Edge

- About Norway and the Simula Research Laboratory
- From TCP to Multi-Path Transport
- Simulations
- Lab Setups and Internet Setups
- The NorNet Testbed
  - NorNet Core
  - NorNet Edge
- Conclusion
- Literature
NorNet Edge needs to cover many locations!
NorNet Edge Nodes

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”)

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

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

Conclusion

- About Norway and the Simula Research Laboratory
- From TCP to Multi-Path Transport
- Simulations
- Lab Setups and Internet Setups
- The NorNet Testbed
- Conclusion
- Literature
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
  - Improve and refine management software
  - Get more users, may be you?

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!
Overview:

Literature

- About Norway and the Simula Research Laboratory
- From TCP to Multi-Path Transport
- Simulations
- Lab Setups and Internet Setups
- The NorNet Testbed
- Conclusion
- Literature
Literature (1)


- Dreibholz, T.: “An Experiment Tutorial for the NorNet Core Testbed at the the Universidad de Castilla-La Mancha” (PDF, 5244 KiB), Tutorial at the Universidad de Castilla-La Mancha, Instituto de Investigación Informática de Albacete, Albacete, Castilla-La Mancha/Spain, February 16, 2017.


Literature (2)


- **Becke, M.; Adhari, H.; Rathgeb, E. P.; Fu, F.; Yang, X.; Zhou, X.**: “Comparison of Multipath TCP and CMT-SCTP based on Intercontinental Measurements” (PDF, 924 KiB), Proceedings of the IEEE Global Communications Conference (GLOBECOM), Atlanta, Georgia/U.S.A., December 10, 2013.


Any Questions?

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