Invited Talk at the New York University, Polytechnic School of Engineering

The NorNet Testbed – Overview and Selected Results from Multi-Path Transport Research

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- Motivation
- The NorNet Testbed
  - NorNet Core
  - NorNet Edge
- Selected Research Topics
- Conclusion
Overview:

Motivation

The NorNet Testbed
  - NorNet Core
  - NorNet Edge

Selected Research Topics

Conclusion
Motivation: Robust Networks

- More and more applications rely on ubiquitous Internet access!
- However, our current networks are not as robust as they should be ...

How to make networks more robust?
Resilience by Redundancy

Multi-Homing

- Connections to multiple Internet Service Providers (ISP)
- Idea: if one ISP has problems, another connection still works

Is resilience really improved? What about multi-path transport?
Idea: A Testbed for Multi-Homed Systems

- A multi-homed Internet testbed would be useful
  - Something like PlanetLab?
  - Perhaps with better node availability?
  - Support for mobile access (e.g. 3G) as well as wired?
- **NorNet** – A research testbed for multi-homed systems!
  - Lead by the Simula Research Laboratory in Fornebu, Norway
  - Supported by Forskningsrådet

[Research in realistic setups is necessary!](https://www.nntb.no)
Overview:
The NorNet Project

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  - NorNet Edge
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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, many large rural areas
  - Svalbard:
    - Interesting location
    - Many polar research institutions

- **NorNet Core:**
  - Currently 11+3 sites

- **NorNet Edge:**
  - Currently ca. 400 nodes
Overview:
NorNet Core

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Idea: 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 (< 20)
  - Each site's router (called **tunnelbox**) maintains the tunnels
    - Static tunnels
    - NorNet-internal addressing and routing over tunnels
A usual NorNet Core site:

- 1x switch
- 4x server
  - 1x tunnelbox
  - 3x research systems
- At least two ISP connections
  - Uninett
  - Other providers
- IPv4 and IPv6 (if available)
## Site Deployment Status
(May 2014)

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>ISP 1</th>
<th>ISP 2</th>
<th>ISP 3</th>
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<td>UNINETT</td>
<td>Kvantel</td>
<td>Telenor ²</td>
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<td>Unicom ¹</td>
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<td>Karlstads Universitet</td>
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<td>SUNET</td>
<td>– ⁴</td>
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</table>

1) IPv6 available from ISP, but not deployed to setup
2) IPv6 not available from ISP ☹
3) Consumer-grade ADSL connection
4) Negotiations in progress
Remote Systems

Our servers may be really remote!

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

- Experimentation software is experimental
- How to avoid software issues making a remote machine unusable?
- Idea: virtualisation
  - Lightweight, stable software setup: Ubuntu Server 12.04 LTS
  - VirtualBox 4.3
  - Other software runs in VirtualBox 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

“Anything that can go wrong, will go wrong.”
[Murphy's law]
Idea: *PlanetLab*-based Software for Experiments

- **Key idea:**
  - Researchers should get virtual machines for their experiments
  - Like *PlanetLab* ... 
  - ... but with multi-homing and IPv6, of course

- ***PlanetLab* software:**
  - Different “stable” distributions: *PlanetLab*, *OneLab*, etc.
  - Current implementation: based on *Linux VServers*
    - Not in mainline kernel
    - Patched kernel, makes upgrades difficult
  - The future: **Linux Containers** (LXC)
    - Active development by *PlanetLab/OneLab*
    - We are maintaining a NorNet-specific branch
Overview: NorNet Edge

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The NorNet Edge Box: Ready for Deployment (1)

Box contents:

- Ufoboard or Beagle Bone embedded Linux system
- 4x USB UMTS:
  - Telenor, NetCom,
  - Network Norway, Tele2
- 1x ICE CDMA mobile broadband
- 1x Ethernet
- 1x WLAN (optional)
- Power supplies
- Handbook
Ufoboard:
- Debian Linux
- Kernel 3.11.x
- **MPTCP (0.88)**
NorNet Edge Visualisation

See http://demo.robustenett.no!
Overview:
Selected Research Topics

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Multi-Path TCP

Multi-Path TCP (MPTCP):

- Multi-path extension for TCP (RFC 6182/RFC 6824)
- Combination of sub-flows (like TCP)
- Idea: improve throughput and resilience

How behaves MPTCP in real networks?
Using NorNet Edge nodes (NNE):

- Two 3G ISPs (2G/3G)
- WLAN at the node location: real-world public WLAN hotspot (i.e. many users and interferences)
Standard MPTCP does not work very well …

3G + 3G Paths

Paths are heterogeneous

- Varying overall goodput
- High RTTs → bufferbloat!

Performance issues caused by bufferbloat!
Standard MPTCP does not work very well …  
3G + WLAN Paths

How to avoid the bufferbloat issues?

The same performance issues apply for combining 3G and WLAN
Multi-Path Transport Bufferbloat Mitigation (MPT-BM)

Algorithm 1 Per-Subflow Bufferbloat Mitigation by MPT-BM

Initialization:
\( sRTT \leftarrow \infty \)
\( sRTT_{\text{min}} \leftarrow \infty \)

RTT estimation:
\( sRTT_{\text{min}} \leftarrow \min(sRTT_{\text{min}}, sRTT) \)

How many segments can be sent?
\( cwnd_{\text{limit}} \leftarrow \lambda \times (sRTT_{\text{min}}/sRTT) \times cwnd \)
\( \text{send} \leftarrow \begin{cases} 
max(0, \min(cwnd, cwnd_{\text{limit}}) - \text{inflight}) & (RTT_{\text{min}} \geq \Theta) \\
max(0, cwnd - \text{inflight}) & (RTT_{\text{min}} < \Theta) 
\end{cases} \)

- Idea:
  - Avoid extreme growth of the congestion window (cwnd)
  - Limitation controllable (parameter: \( \lambda \))
  - Only necessary for large RTTs (parameter: \( \Theta \))
Evaluation: Round-Trip Times

- Significant RTT reduction => bufferbloat is avoided

How does it affect the goodput?
Evaluation: Goodput

- No negative impact, sometimes even slightly better
- Variance is reduced
Evaluation:
MPTCP Buffer Delay and Buffer Size

(a) $3G_1 + 3G_2$
(b) $3G_1 + WLAN$
(c) $3G_2 + WLAN$
Further Details


https://www.nntb.no/publications
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Conclusion and Future Work

- The NorNet testbed is progressing!
  - Initial deployment completed
  - Ready for experiments (also for your experiments!)

- Future work:
  - Make more NorNet Core sites multi-homed (additional ISPs, IPv6)
  - Some additional sites
  - Improve and refine management software
  - Get more users (may be you?)

And, of course, do further research!
“NorNet wants to be a building block of the railroad to heaven” ...

... and not be another unused testbed that paves the road to hell!
Coming Soon: The 2nd NorNet Users Workshop (NNUW-2)

See https://www.nntb.no/

Dates will be announced soon! (Probably: End of August 2014)
Any Questions?

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