NorNet

Building an Inter-Continental Internet Testbed based on Open Source Software

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• Multi-Homing and Multi-Path Transport
• The NorNet Testbed Setup
• The Software: VMs, Containers and Multi-Homed Networking
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Overview:
Motivation

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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!**
- **Redundancy is expensive!**
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Multi-Homing and Multi-Path Transport

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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

How can I use multi-path transport?
Stream Control Transmission Protocol (SCTP)

- RFC 4960
- Main features:
  - Multi-homing
  - Multi-streaming (independent streams over one connection)
  - Many extensions, e.g. partial reliability, address reconfiguration ...
- Linux: in mainline kernel → works out of the box!
  - Lacks of many features, unfortunately – like CMT-SCTP 😞
  - Interested in helping → master student projects possible!
- FreeBSD: SCTP reference implementation → included in kernel already!
  - All the nice features
  - May be somebody could port it to Linux?
Multi-Path TCP (MPTCP)

- RFC 6824
- Features: multi-homing + multi-path transport
- Backwards-compatible to TCP
  - Communicate with old TCP implementations
  - Works (mostly) even over non-MPTCP middleboxes (e.g. NAT/PAT)
- Linux:
  - UC Louvain → http://www.multipath-tcp.org
- FreeBSD:
  - Swinburne → http://caia.swin.edu.au/newtcp/mptcp/

How can I use MPTCP under Linux?
Routing Tables and Routing Rules for Multi-Path Transport

• Example:
  - Device eth0 → ISP 1
  - Device eth1 → ISP 2

• Problem:
  - First default route (with lowest metric) via ISP 1
  - All traffic uses ISP 1 😞

• Solution:
  - Routing rules
  - Separate routing tables for each ISP
  - “Selector” for actually used table, per source address
A Linux Routing Rule Example

- **Configure eth0:**
  - `ip addr add 10.1.1.42/24 dev eth0`
  - `ip route add default via 10.1.1.1 dev eth0`
  - `ip route add 10.1.1.0/24 scope link dev eth0 table 1`
  - `ip route add default via 10.1.1.1 dev eth0 table 1`

- **Configure eth1:**
  - `ip addr add 172.16.1.42/24 dev eth1`
  - `ip route add 172.16.1.0/24 scope link dev eth1 table 2`
  - `ip route add default via 172.16.1.1 dev eth1 table 2`

- **We have 2 new routing tables now!** Set up routing rules based on source address:
  - `ip rule add from 10.1.1.42 table 1`
  - `ip rule add from 172.16.1.42 table 2`

- **Table numbers difficult to remember?** Set name mapping in `/etc/iproute2/rt_tables`!
The Resulting Configuration

- The routing rules: `ip rule show`
  
  0: from all lookup local
  32764: from 172.16.1.42 lookup 2
  32765: from 10.1.1.42 lookup 1
  32766: from all lookup main
  32767: from all lookup default

- The name mappings: `cat /etc/iproute2/rt_tables`
  
  255 local
  254 main
  253 default
  0 unspec

- Table #1: `ip route show table 1`
  
  default via 10.1.1.1 dev eth0
  10.1.1.0/24 dev eth0 scope link

- Table #2: `ip route show table 2`
  
  default via 172.16.1.1 dev eth0
  172.16.1.0/24 dev eth0 scope link
What about Routing Rules with IPv6?

- It works with IPv6 as well, of course!
  - `ip -6 addr add 3ffe:cafe:affe:1234::2a/64 dev eth0`
  - `ip -6 route add default via 3ffe:cafe:affe:1234::1 dev eth0`
  - `ip -6 route add 3ffe:cafe:affe:1234::/64 scope link dev eth0 table 1`
  - `ip -6 route add default via 3ffe:cafe:affe:1234::1 dev eth0 table 1`
  - `ip -6 addr add 3ffe:dead:beef:ffff::2a/64 dev eth1`
  - `ip -6 route add 3ffe:dead:beef:ffff::/64 scope link dev eth1 table 2`
  - `ip -6 route add default via 3ffe:dead:beef:ffff::1 dev eth1 table 2`
  - `ip -6 rule add from 3ffe:cafe:affe:1234::2a table 1`
  - `ip -6 rule add from 3ffe:dead:beef:ffff::2a table 2`

- Depending on source address, a packet leaves via network 1 or network 2
  - MPTCP (and CMT-SCTP) will make this choice, depending on subflow
- Connections can even have IPv4- and IPv6 subflows simultaneously!
Finally: Testing MPTCP

- First, boot a MPTCP-enabled kernel
  - See https://multipath-tcp.org for sources
  - MPTCP enabled by default → all TCP connections are MPTCP-capable!

- Configure (and check) the routing
  - Connect to two (or more) ISPs, if possible
  - IPv4 + IPv6 may also give you partially independent paths
  - Just 1 IP address? → multiple paths to a multi-homed remote side!

- Test:
  - Wireshark/T-Shark → https://www.wireshark.org
  - NetPerfMeter → https://www.uni-due.de/~be0001/netperfmeter/
  - ...
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The NorNet Testbed Setup

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Testing Multi-Path Transport (1)
The First Step – A 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:
  - Prior simulations were useful! 😊
  - Bugfixes for the FreeBSD community
  - Open Source software „NetPerfMeter“
  - Learning effects and new ideas!

Internet protocols → testbed in the Internet!
Testing Multi-Path Transport (2)
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!
Testing Multi-Path Transport (3)
The NorNet Testbed

- NorNet Core
  - Cable, up to 4 providers, IPv4+IPv6 (fibre, „consumer-grade” DSL, etc.)
  - Hosts for virtual machines
  - 21 locations (11 in Norway, 10 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
## NorNet Core Site Deployment Status (October 2016)

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<th>ISP 3</th>
<th>ISP 4</th>
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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
HiPerConTracer Observed Routes and Autonomous Systems, from July 1 to July 31, 2016

Work in Progress!
Our servers may be really remote!

The “road” to Longyearbyen på Svalbard, 78.2°N
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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 → 16.04 LTS
  - KVM (Kernel-based Virtual Machine)
  - Other software runs in VMs:
    - Tunnelbox (router) VM
    - Research Node VMs
  - In case of problem: manual/automatic restart or reinstall of VM
Physical Machine Setup

- Ubuntu Server LTS – due to long-term support
- Customisation:
  - File system: ReiserFS 3
    - Ext4 resilience is really awful – manual fsck at remote machines 😞
    - BTRFS has nice features, but awful performance for hosting VMs
    - => ReiserFS!
      - very reliable (it never killed the data of a machine)
      - good performance, also for hosting VMs
    - Not tried ReiserFS 4 (unfortunately not in mainline kernel) or ZFS, yet
  - Virtualisation: now KVM
    - Formerly: VirtualBox (custom package with Open Source VNC, instead of Oracle’s closed source blob)
Tunnelbox – The Router (1)

- Tunnelbox
  - Router at each site
  - Handles all network communication, over multiple ISPs
    - 1 public IPv4 address (+ 1 public IPv6 address) per site and ISP
    - Tunnels among the sites (GRE-over-IPv4, IPv6-over-IPv6)
    - Own systematic addressing scheme
      - IPv6: 2001:700:4100:<Provider><Site>::<Node>/64
  - Direct communication between sites over tunnels
  - Communication between sites and Internet over Simula’s site
    - Security + avoiding legal issues (DE: “Mitstörerhaftung” ...)
IP addresses are difficult to remember

- DNS setup (bind9) with private TLD “.nornet”
- Convenience 1: easy naming scheme:
  - fjellrev.telenor.unis.nornet: node “fjellrev” with ISP “Telenor” at “UNIS”
  - borbeck.ude.nornet: node “borbeck” with primary ISP at “UDE”
  - østhorn.kvantel.simula.nornet → xn--sthorn-9xa.kvantel.simula.nornet
  - 三亚 .cnunicom.hu.nornet → xn--ehqrn.cnunicom.hu.nornet
- Convenience 2: SSHFP (SSH key fingerprints) and LOC (geolocation) RRs
- Squid HTTP proxy
  - Caching HTTP accesses (mainly: package updates)
  - If necessary: forward every request to Simula (to avoid legal issues)
Research Node

- “Usual” research node:
  - A VM (usually KVM), managed by PlanetLab Central (PLC)-based software
    - 2.5 GiB RAM, 1-2 cores
    - Fedora Core 23, Linux kernel v4.1.32 with MPTCP v0.91 + API patch
  - User gets a “sliver” of the research node → LXC container
    - “Own” Fedora installation, with development tools, T-Shark, ...
    - “Own” IP addresses (IPv4 + IPv6, for each ISP of the site)
    - Root permission (only within the LXC container, with limitations)
    - But: A slice is basically a BTRFS clone of a template
      - File duplicates only necessary upon changes
      - Very lightweight setup per user
  - Custom VMs as research nodes are also possible (currently requires manual setup)
The Different Entities: Server, Node, Slice and Sliver

Server (physical)
Node (virtual)
- Sliver hu_multipath
- Sliver srl_tutorial
- Sliver ntnu_test
- Sliver due_rserpool
- ...

Node (virtual)
KVM VM
LXC containers

Slice:
- User list
- Node list

Sliver = an instance of a slice on a node

ssh <Slice>@<Node>

Forwarding to sliver!
A Look into a Sliver

- SSH login to the sliver
- Here: 2 ISPs
  - 2x IPv4
  - 2x IPv6
- Kernel with MPTCP
- For security:
  - SSH key fingerprints
  - Superuser (“su” or “sudo”)
    - dnf install ...
    - tcpdump -i eth0 ...
    - tshark -i eth0 ...
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Conclusion and Future Work

- Multi-homed devices increasingly widespread → multi-path transfer
- Realistic, large-scale Internet testbed infrastructure is available: NorNet
- NorNet Core is an open testbed!
  - Interested in using NorNet? Just ask!

Future work: extend NorNet Core's scope beyond multi-path transport topic:
- Network Function Virtualisation (NFV) and Software-Defined Networking (SDN)
- Cloud Computing and applications

See https://www.nntb.no for more information!
Any Questions?

https://www.nntb.no

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Links

- HiPerConTracer: https://github.com/dreibh/hipercontracer
- Linux Multi-Path TCP: http://multipath-tcp.org
- Multi-Path TCP Page: http://www.iem.uni-due.de/~dreibh/mptcp/
- NetPerfMeter: https://www.uni-due.de/~be0001/netperfmeter/
- NorNet Project: https://www.nntb.no
- NorNet Core Sites: https://www.nntb.no/pub/nornet-configuration/NorNetCore-Sites.html
- NorNet Software: https://www.nntb.no/software/
  - Management: https://github.com/simula/nornet-control
  - Research Node: https://benlomond.nntb.no/releases/
- SCTP Project Page: http://www.iem.uni-due.de/~dreibh/sctp/
- Simula Research Laboratory: https://www.simula.no
- Wireshark/T-Shark: https://www.wireshark.org


Dreibholz, T.: "An Experiment Tutorial for the NorNet Core Testbed at Hainan University", Tutorial at Hainan University, College of Information Science and Technology (CIST), Haikou, Hainan/People's Republic of China, May 2016.


Dreibholz, T.: "An Experiment Tutorial for the NorNet Core Testbed at NICTA", Tutorial at National Information Communications Technology Australia (NICTA), Sydney, New South Wales/Australia, January 2016.


Also see https://www.nntb.no/publications/!