

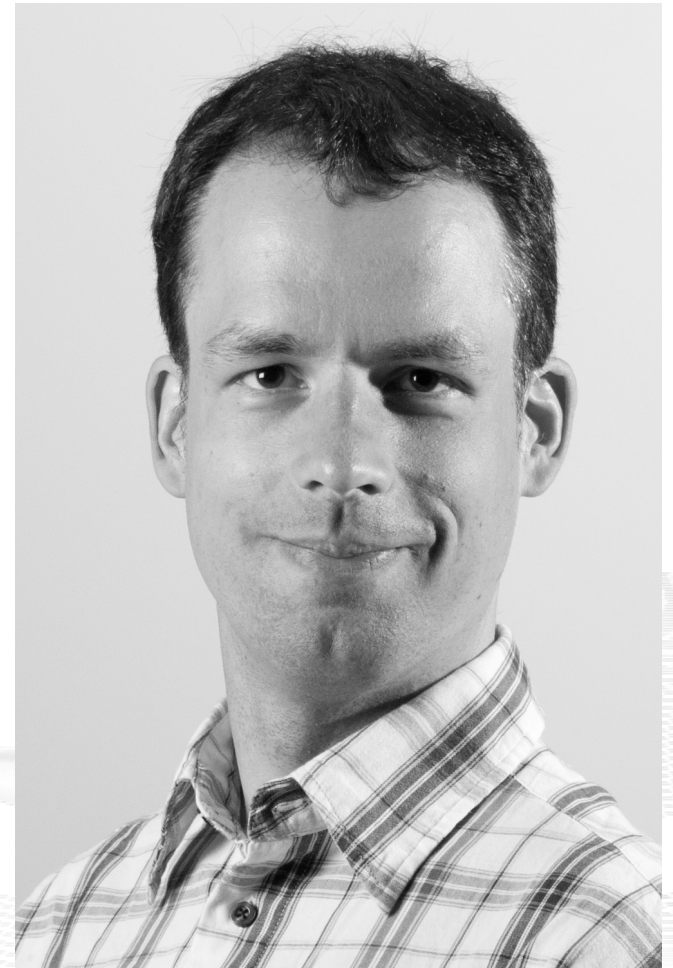
Invited Talk at the Universidad de Castilla-La Mancha

# Multi-Path Transport with OMNeT++ and the INET Framework

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- Motivation
- The CMT-SCTP Model
- The Modified IPv4NetworkConfigurator
- The NetPerfMeter Application Model
- SimProcTC – The Simulation Processing Tool-Chain
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# Overview: Motivation

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# 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

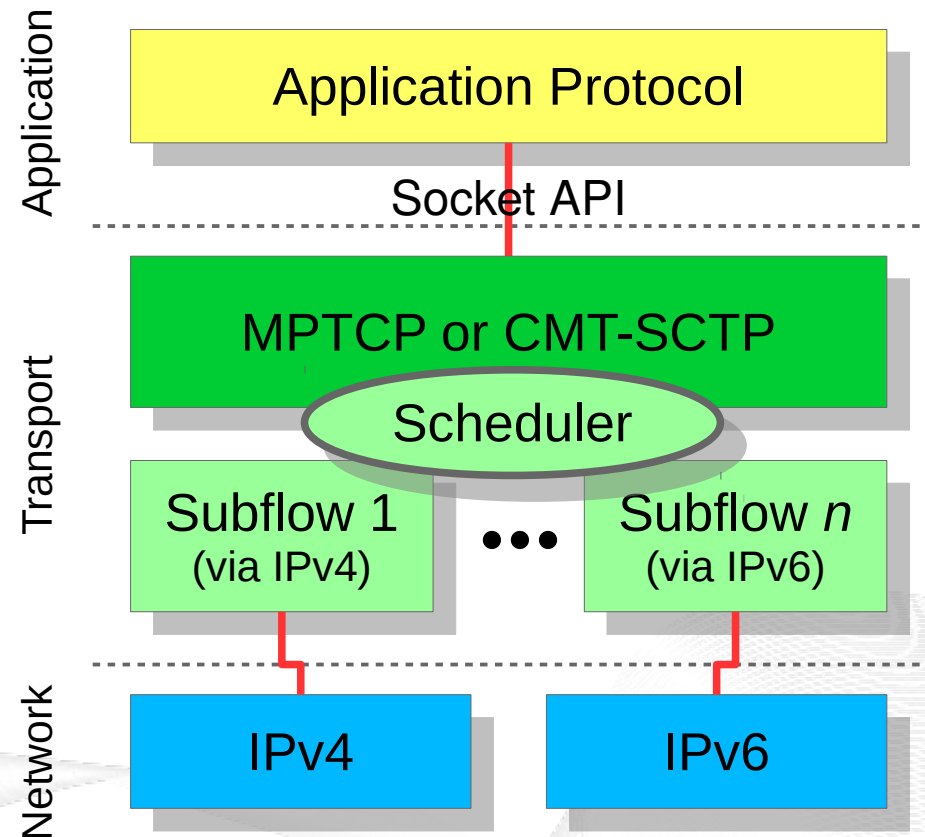


SCTP: Stream Control Transmission Protocol  
TCP: Transmission Control Protocol

Hot topic in research and standardisation!

# Multi-Path Transport with MPTCP and CMT-SCTP

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



Complex system → analyses are necessary!

# OMNeT++ and the INET Framework

- Simulations? → OMNeT++ and INET Framework!
  - Well-known Open Source network simulation framework
  - Initial SCTP model (without CMT-SCTP) already available
- Goal: state-of-the-art SCTP model
  - Particularly: with CMT-SCTP, of course!



SCTP Project at Universität Duisburg-Essen

<https://www.uni-due.de/~be0001/sctp/>

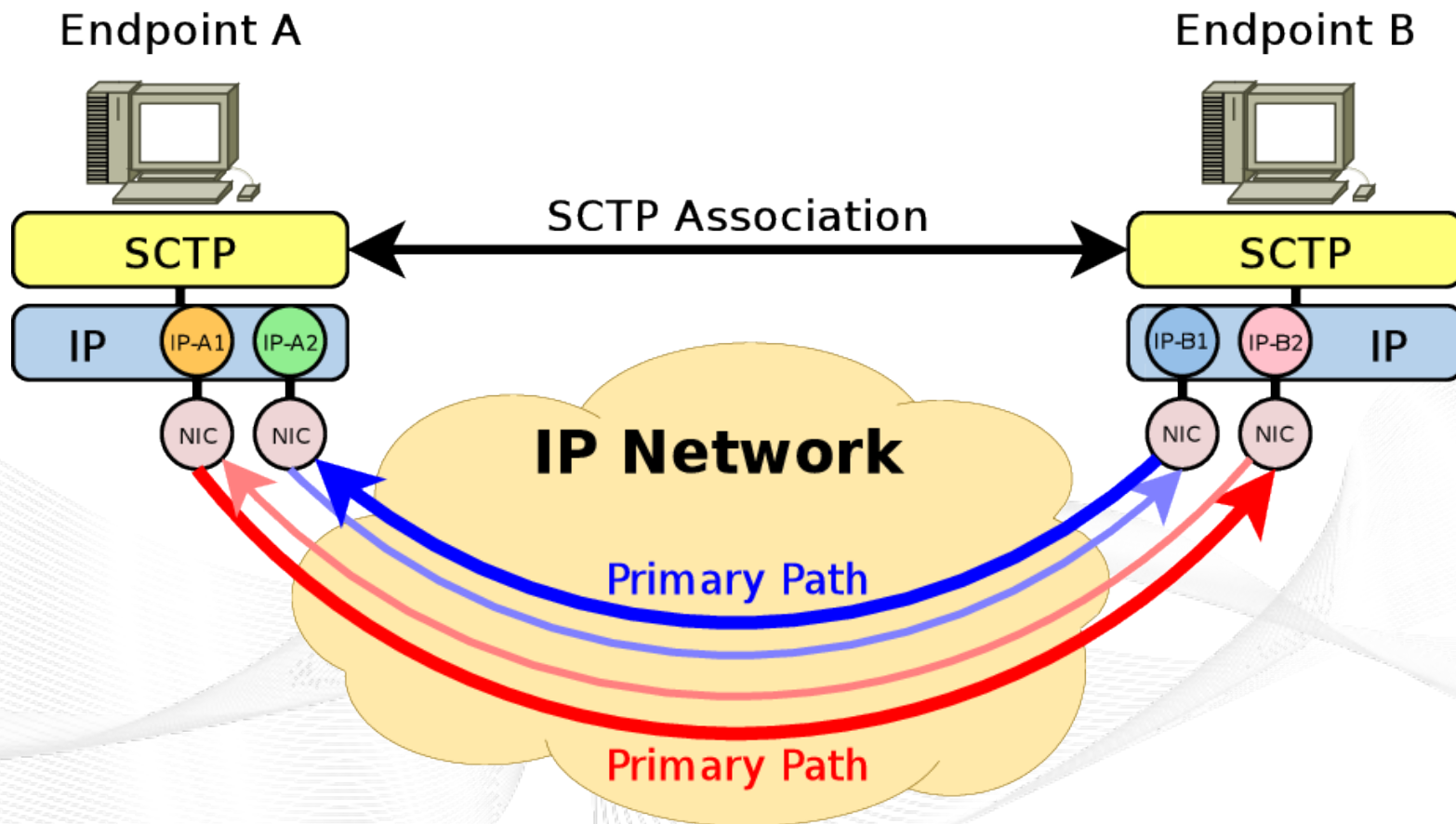
# Overview:

## The CMT-SCTP Model

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# Stream Control Transmission Protocol (SCTP)

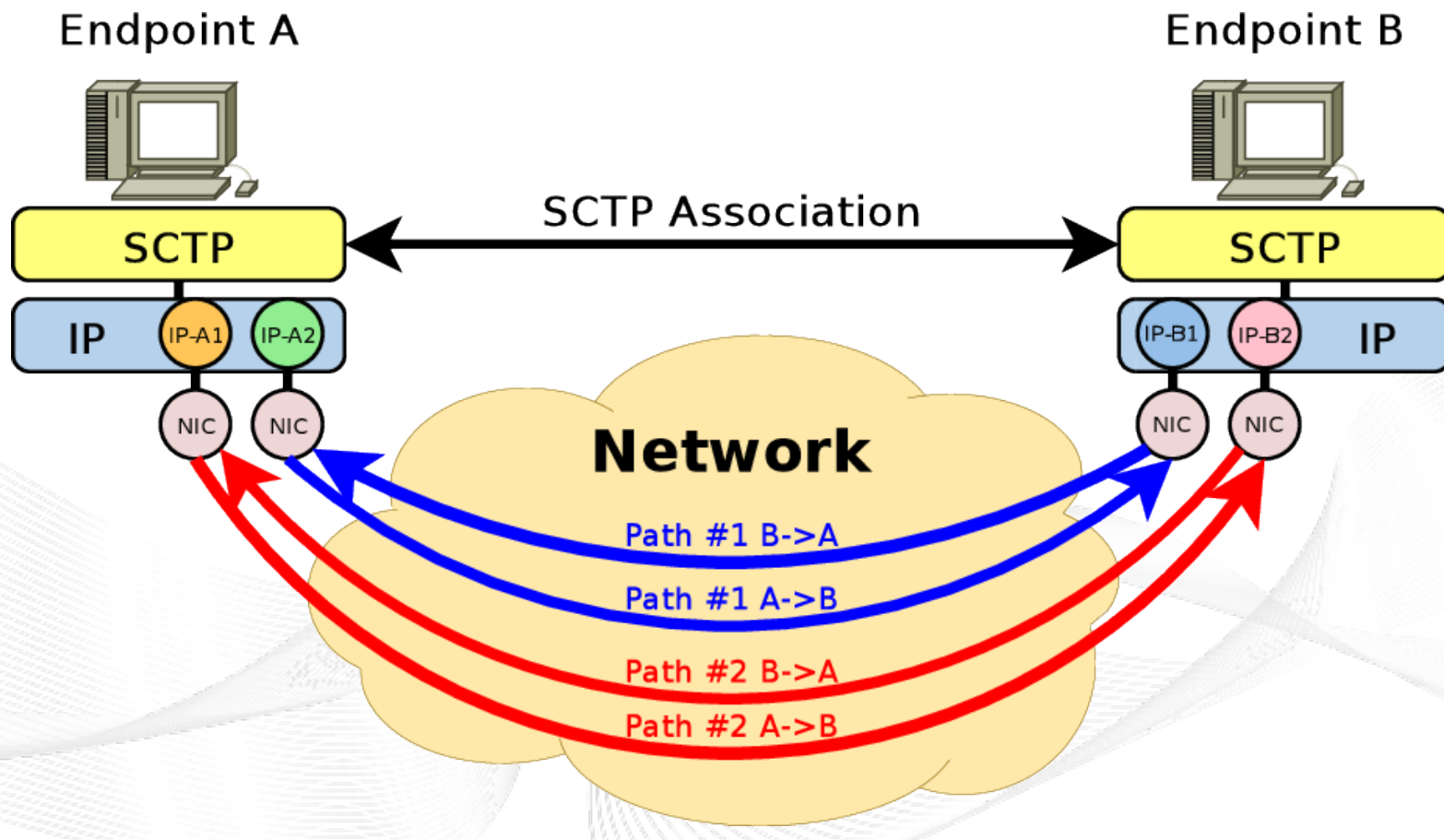
- Defined in RFC 4960
- Choose one “primary path” per direction for payload transport
- Other paths are just backups → redundancy only





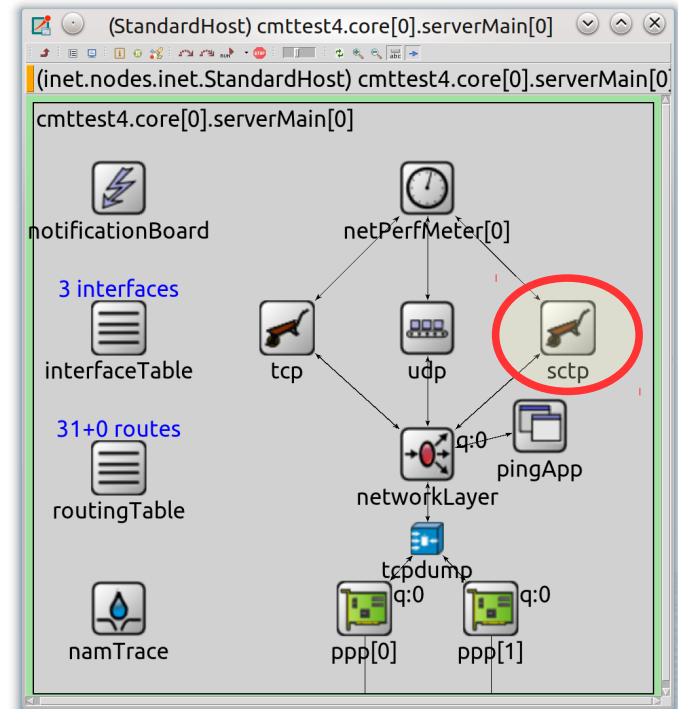
# Concurrent Multipath Transfer for SCTP (CMT-SCTP)

- Defined in draft-tuexen-tsvwg-sctp-multipath
- All paths can be used for payload transport
- Scheduler makes choices (not defined how to do this → implementer!)

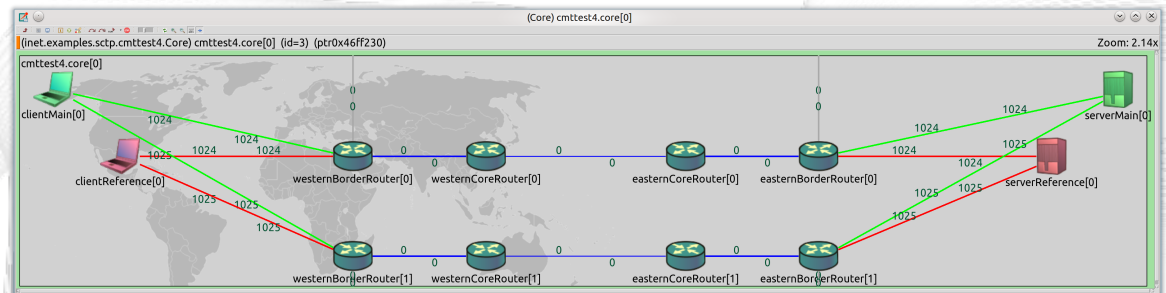


# The SCTP Model in OMNeT++ (1)

- SCTP in OMNeT++
  - State-of-the-art SCTP model
  - SCTP protocol extensions
- Open Source
  - SCTP model is included in the INET framework!



<https://inet.omnetpp.org>



# The SCTP Model in OMNeT++ (2)

- SCTP, according to RFC 4960
- All relevant protocol extensions (RFCs + Internet Drafts):
  - Partial Reliability (PR-SCTP)
  - Dynamic Address Reconfiguration (“Add-IP”)
  - Chunk Authentication
  - Stream Reset
  - Packet Drop Reporting
  - Selective Acknowledgement (SACK) Immediately
  - ...
- Added for CMT-SCTP:
  - CMT-SCTP, of course
  - Non-Renegable Selective Acks (NR-SACK)
  - + **lots of bug fixes**



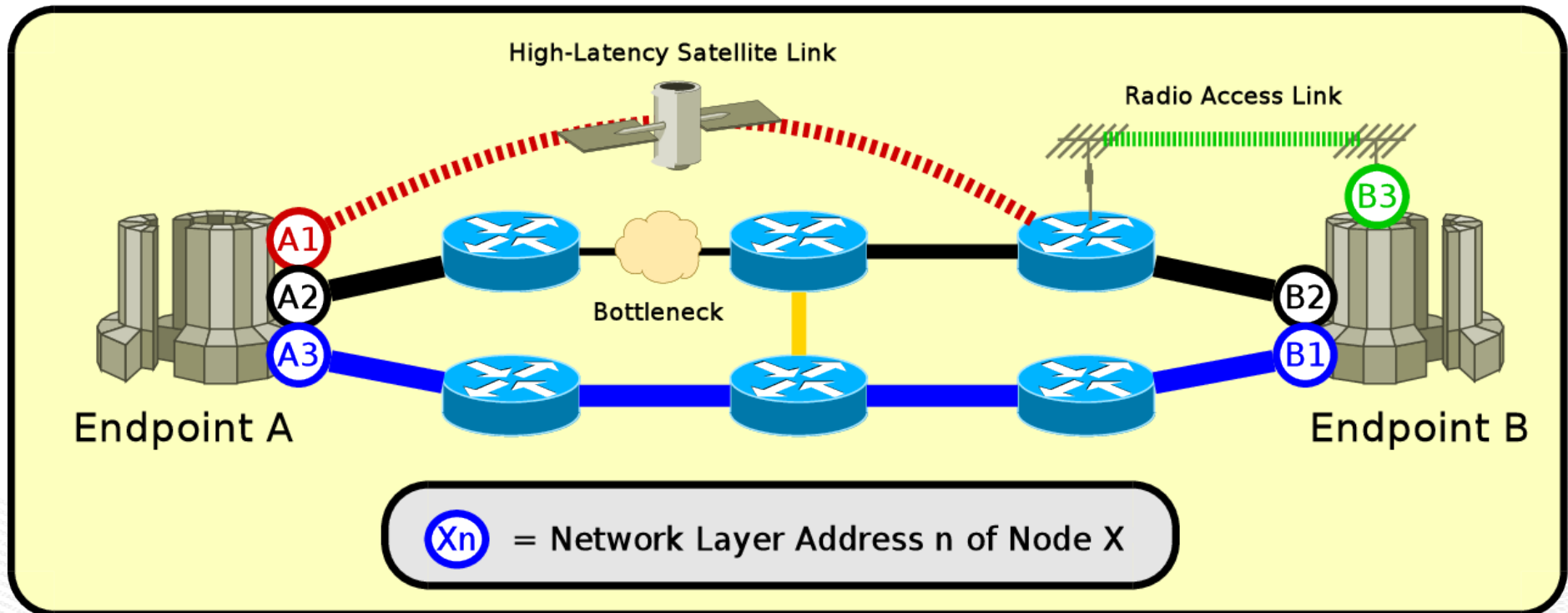
# Overview:

## The Modified IPv4NetworkConfigurator

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# A Multi-Homed Network: How to make use of the redundancy?

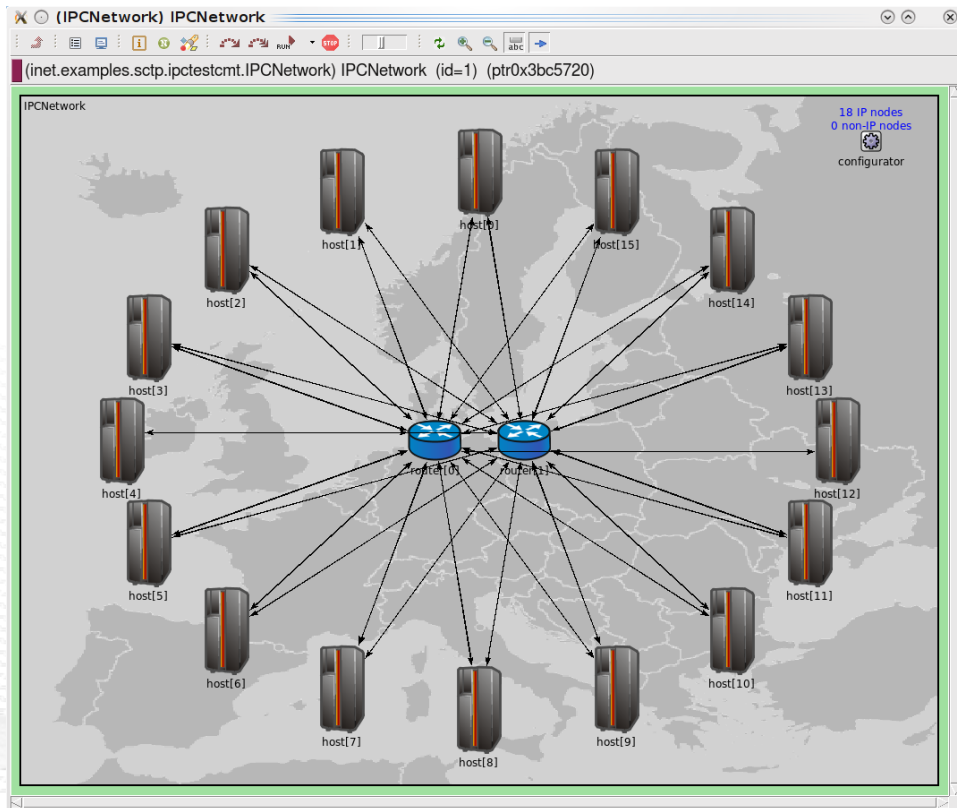
- Example: how to route from A to B?



- “Classic” routing: just one route (the cheapest) from A to B
- Routing requirement: create separate networks with own routes
  - E.g.  $A1 \rightarrow B3$ ,  $A2 \rightarrow B2$ ,  $A3 \rightarrow B1$

# The Modified IPv4NetworkConfigurator - An Auto-Configurator for Multi-Homed Networks

How to set up multi-homed networks easily?



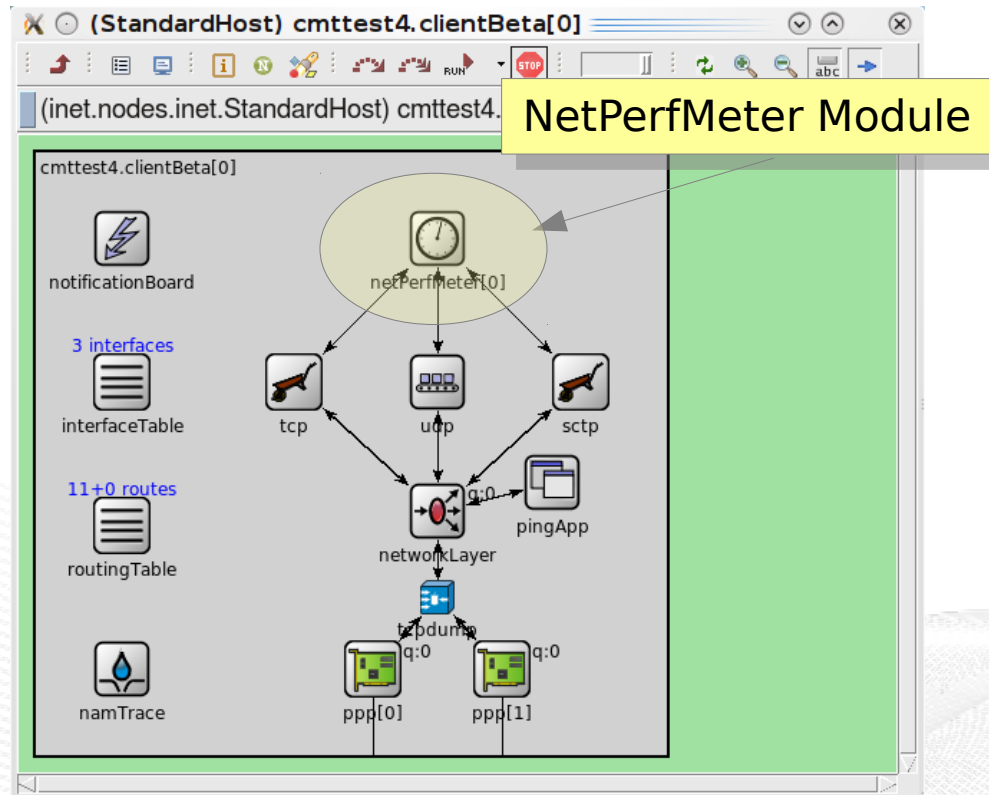
- IPv4NetworkConfigurator
  - Automatic configuration of IP addresses and routing tables
  - Links belong to a network
    - NetID: the network identifier
    - Special NetID "0": all networks
  - Dijkstra algorithm is separately applied on each network
- Not yet adapted to IPv6 → to do

# Overview:

## The NetPerfMeter Application Model

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# NetPerfMeter – The Multi-Protocol Network Test Application Model



- NetPerfMeter model
  - Throughput measurements
  - Application delay measurements
  - Multi-protocol support
    - SCTP (of course)
    - TCP
    - UDP
  - Sender options
    - Saturated (“as much as possible”)
    - Non-saturated (“frame rate / frame size”)



# Putting Everything Together: A Running Example!

Note: This is not the upstream INET repository!

- Get the sources (for current version):
  - `git clone https://github.com/dreibh/inet.git td-inet`
  - `cd td-inet`
  - `git checkout td-netperf-meter-for-integration`
- Build:
  - Currently with OMNeT++ 5.1pre3
  - `make makefiles && make`
- Run the example
  - `cd examples/sctp/advancedmultipath/`
  - `./run`
- See `advancedmultipath.ned` and `omnetpp.ini` for configuration and parameters!

# NetPerfMeter – The Real Multi-Protocol Network Test Application

- NetPerfMeter Model ↔ NetPerfMeter Application
  - Real application for Linux, FreeBSD, etc.
  - Supports transport protocols of underlying operating system:
    - Linux → Linux MPTCP, SCTP (without CMT, yet), DCCP, TCP, UDP
    - FreeBSD → SCTP (inclusive CMT), TCP, UDP
  - Allows for comparison of real-world measurements and simulations
    - Same parameters and application behaviour!
- NorNet Core slivers have NetPerfMeter already pre-installed!

See <https://www.uni-due.de/~be0001/netperfmeter/> for details!

# Overview:

## SimProcTC – The Simulation Processing Tool-Chain

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# Requirement for Parameter Studies

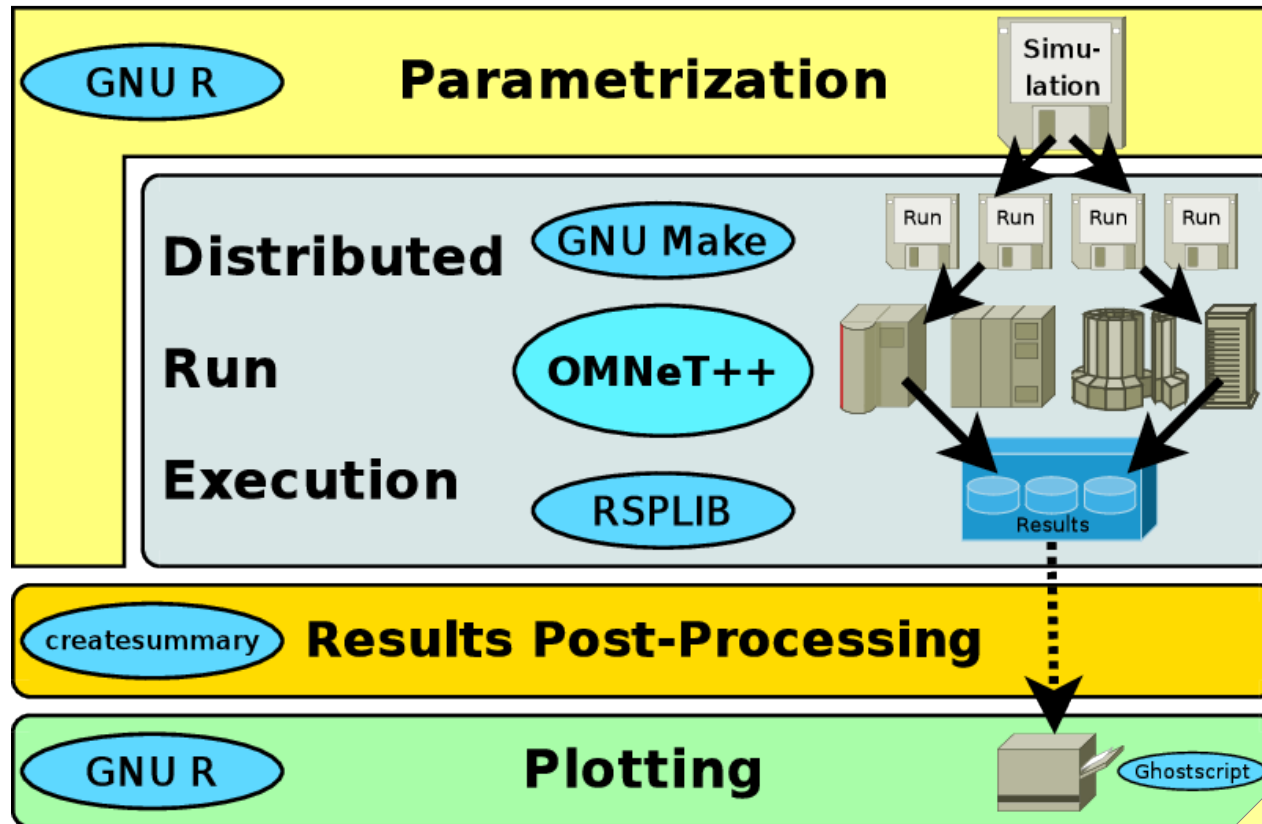
Parameter studies need a lot of runs ...

- We have a pool of PCs for student exercises
  - Can we make use of these resources when not otherwise used?
- Reliable Server Pooling (RSerPool!)
  - Reference implementation RSPLIB
  - + A simple distribution application
  - + A collection of scripts
- Interesting fact:
  - RSerPool (RFC 5351-5356) uses SCTP
  - A good stress test for RSerPool + SCTP implementations!



<https://www.uni-due.de/~be0001/rserpool/>

# Simulation Processing Tool-Chain (SimProcTC)



Note: website needs update!

See <https://www.uni-due.de/~be0001/omnetpp/> for details!

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# Conclusions

- OMNeT++ and INET Framework
  - Powerful and easy to use network simulation framework
  - Open Source
- Multi-path transport
  - CMT-SCTP
  - NetPerfMeter application model
  - Allows for comparison to real network measurements → **NorNet testbed!**
- Future work
  - Contribution of missing parts into upstream INET framework project
  - (most improvements are already there!)
  - MPTCP model? → work at University of Duisburg-Essen/HAW Hamburg!

Thank you for your attention!  
Any questions?

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