ns-3 Training

A tutorial on the implementation of TCP in ns-3

June 2017

Objectives of this tutorial

- To provide an overview of TCP implementation in ns-3
  - Learn about the different implementations of TCP in ns-3
  - Understand the architecture of natively implemented TCP in ns-3
  - Walk through a simple TCP example
  - Introduce how to write new TCP extensions
  - Learn about writing test cases for new extensions
  - Learn about the ongoing work related to TCP in ns-3

Outline of the presentation

- TCP implementations in ns-3
- History of ns-3 TCP
- Algorithms for congestion control and loss recovery
- Implementation of ns-3 TCP
- Demonstration of example programs
- How to add a new TCP extension in ns-3?
- Sample test cases for new TCP extension
- Overview of the ongoing work
- Review

TCP implementations in ns-3

TCP implementations in ns-3

- Presently there are following implementations of TCP available for ns-3:
  - a native implementation of TCP in ns-3 (ns-3 TCP)
  - support for Network Simulation Cradle (NSC)
  - support for Direct Code Execution (DCE)
  - others (e.g., combining virtual machines with ns-3)

- ns-3 TCP model supports:
  - a full bidirectional TCP
  - connection setup
  - connection teardown

History of ns-3 TCP

History of ns-3 TCP

- Until ns-3.10
  - it was a port of TCP model from GTNetS (Georgia Tech Network Simulator)
- For ns-3.10
  - it was substantially rewritten by Adriam Tam in 2011
- For ns-3.25
  - the module was refactored as a part of GSoC 2015 project by Natale Patriciello
  - one of the major changes involved how congestion control algorithms are implemented (more details to follow)
  - other notable change was about automating the tests
  - Target is to align the implementation with that of Linux

Algorithms for congestion control and loss recovery

Congestion control algorithms

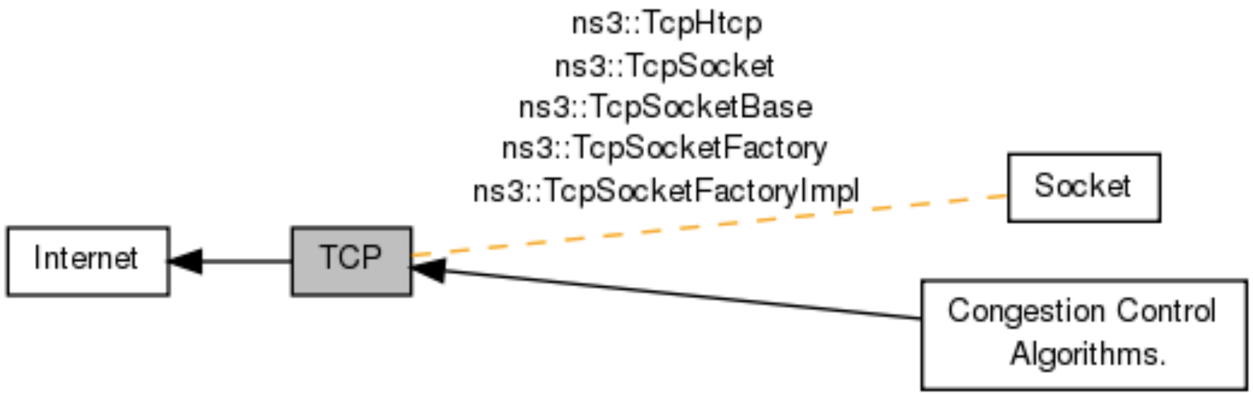
- NewReno (*default*)
- Westwood, Westwood+
- Hybla
- HighSpeed
- Vegas
- Scalable
- Veno
- Binary Increase Congestion Control (BIC)
- Yet another HighSpeed TCP (YeAH)
- Illinois
- H-TCP
- Low Extra Delay Background Transport (LEDBAT)

Loss detection and recovery algorithms

- Fast retransmit
- Fast recovery
- Selective Acknowledgements (SACK)

Implementation of ns-3 TCP

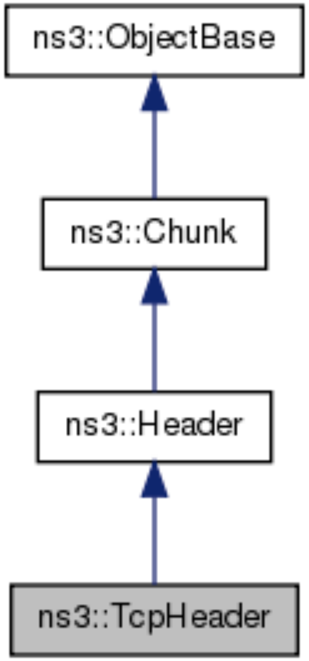
TCP implementation in ns-3



- Source code can be found at: `src/internet/model/`
  - `tcp-header.{h,cc}`
  - `tcp-socket.{h,cc}`
  - `tcp-socket-base.{h,cc}`
  - `tcp-socket-factory-impl.{h,cc}`
  - `tcp-l4-protocol.{h,cc}`
  - `tcp-congestion-ops.{h,cc}`
  - `...`

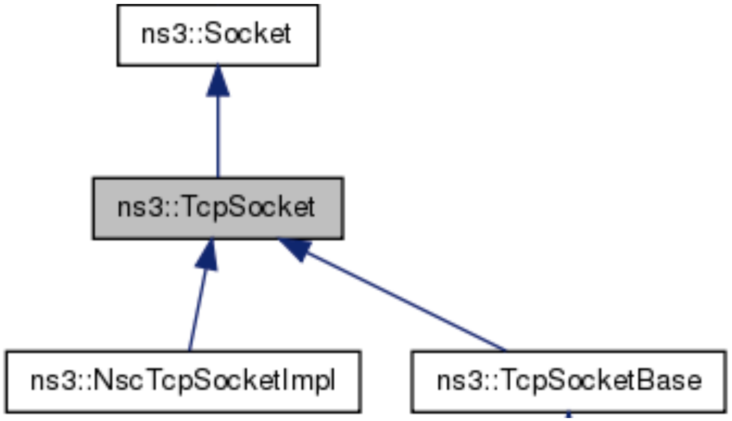
TcpHeader class

- This class implements the TCP header and contains:
  - port numbers
  - sequence numbers
  - acknowledgment numbers
  - flags
  - …
- It also contains:
  - setters and getters
  - methods for serialization
  - and deserialization



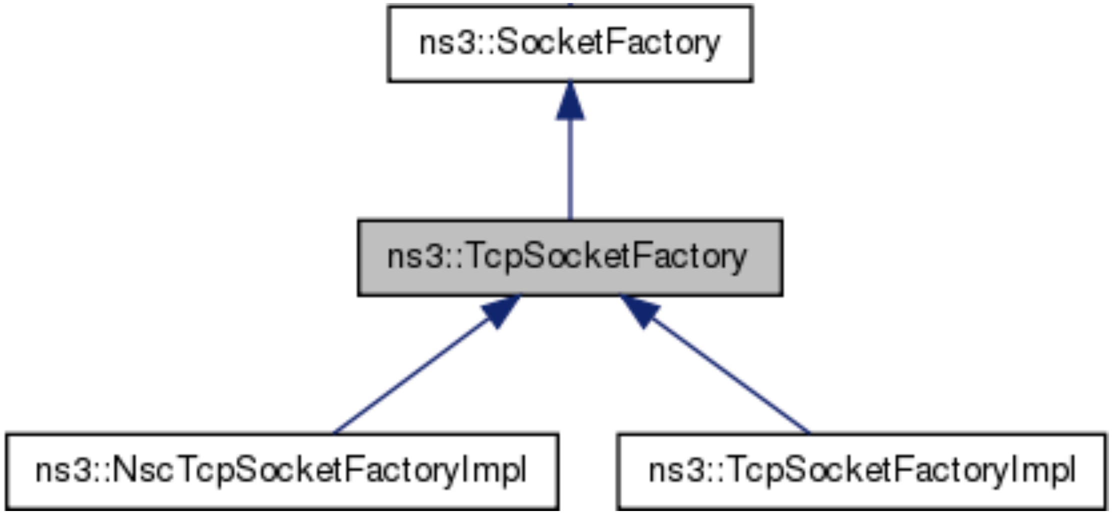
TcpSocket class

- This class:
  - is an abstract base class for all TcpSockets
  - contains TcpSocket attributes that can be reused across different implementations.
- Examples of such attributes include:
  - `SndBufSize`
  - `RcvBufSize`
  - `SegmentSize`
  - `InitialCwnd`
  - `DelAckCount`
  - `DelAckTimeout`
  - …



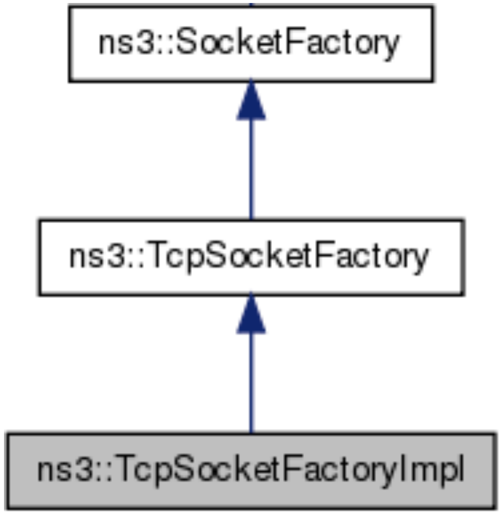
TcpSocketFactory class

- This class:
  - is an abstract base class
  - defines API for TCP sockets
  - contains global default variables to initialize new sockets



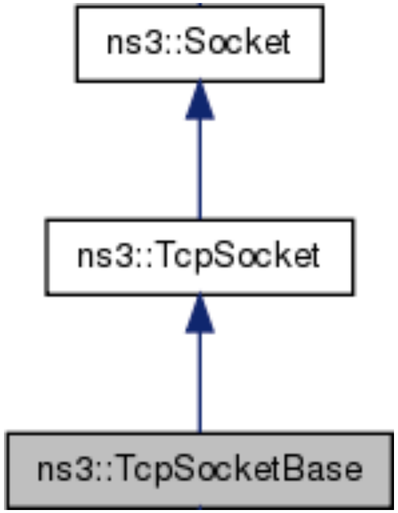
TcpSocketFactoryImpl class

- This class:
  - is an implementation of socket factory for ns-3 TCP
  - creates sockets of type TcpSocketBase



TcpSocketBase class

- This class:
  - is a base class for the implementation of TCP stream socket
  - contains essential components of TCP and provides a socket interface for upper layers to call
- Examples of components include:
  - Connection orientation
  - Sliding window mechanism
  - Fast retransmit
  - Fast recovery
  - Enable/disable window scaling, timestamps
  - Congestion state machine
  - Congestion control interface



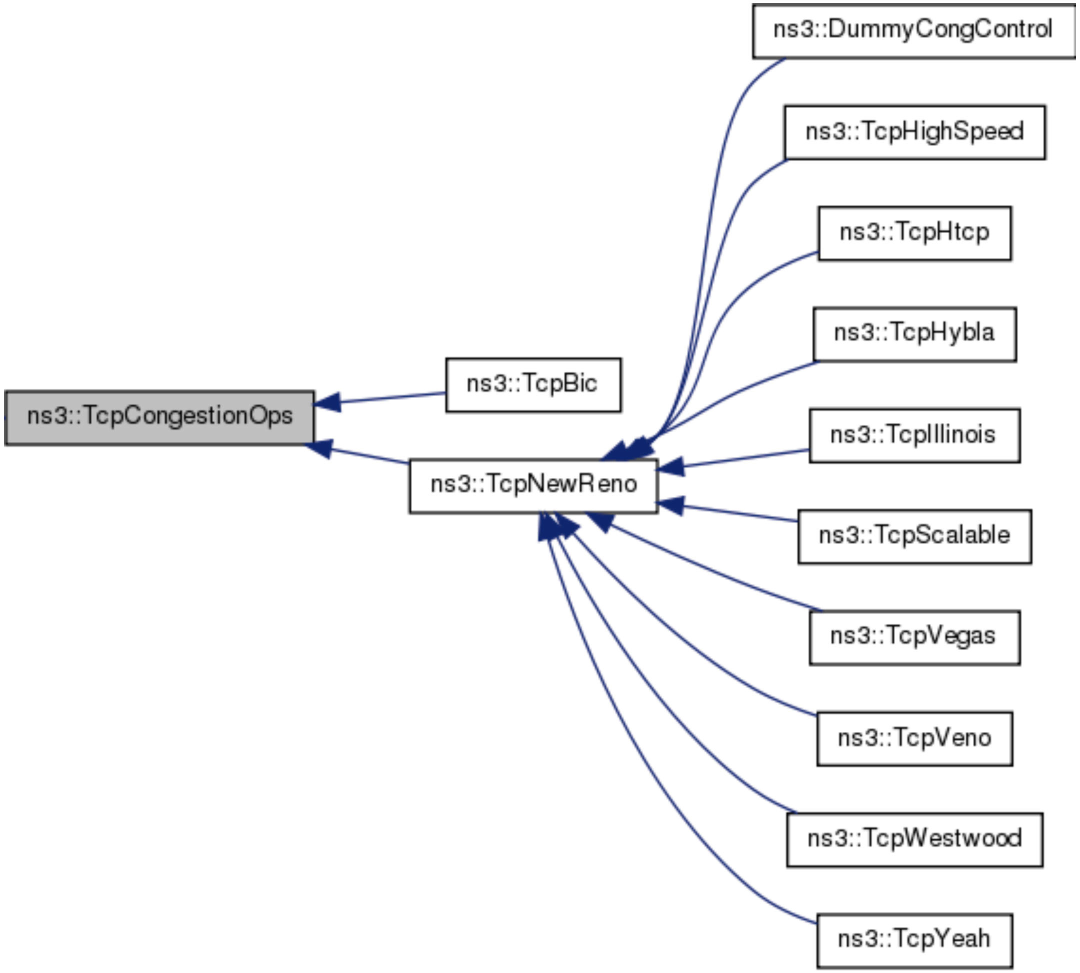
TcpSocketState class

- This class:
  - records the congestion state of a connection
  - saves the information that is passed between the socket and the congestion control algorithms
- Examples of such information include:
  - the current value of congestion window
  - the current congestion state (CA_OPEN, CA_RECOVERY, etc)
  - the current value of slow start threshold
  - Last sequence number acknowledged
  - Next sequence number to be transmitted
  - …

TcpCongestionOps class

- This class:
  - is an abstract class for congestion control
  - provides an interface between the main socket code and congestion control; variables are stored in TcpSocketState
  - inspired by the design in Linux
- Some methods implemented in this class include:
  - `GetSsThresh (Ptr<TcpSocketState>, uint32_t)`
  - `IncreaseWindow (Ptr<TcpSocketState>, uint32_t)`
  - `CongestionStateSet (Ptr<TcpSocketState>, TcpSocketState::TcpCongState_t)`
  - `PktsAcked (Ptr<TcpSocketState>, uint32_t, Time)`

TcpCongestionOps class



Demonstration of example programs:

`examples/tcp/`

How to add a new TCP extension in ns-3?

Steps to add a new TCP extension in ns-3

1. Create tcp-new.{h,cc} files for the new TCP extension in src/internet/model/
2. Create a class for new TCP extension, which can be inherited from TcpCongestionOps (or TcpNewReno as shown before)
3. Some of the following methods may require a specific implementation for the new TCP extension:
   - GetSsThresh
   - IncreaseWindow
   - PktsAcked
4. Make necessary modifications in src/internet/wscript
5. Configure and build ns-3 (resolve errors, if any)
6. Setup an example program for this extension (or use an existing one).
7. Write tests and update the documentation in src/internet/doc/tcp.rst

Sample test cases for new TCP extension

Sample test cases for new TCP extension

1. Some of the following test cases are very commonly used across different TCP extensions
   - CwndIncrementTest
   - CwndDecrementTest
2. Some TCP extensions need exclusive test cases, such as in the case of LEDBAT
   - LEDBAT should be same as NewReno during Slow Start
   - LEDBAT should be same as NewReno when timestamps are disabled
3. Individual algorithms can be tested too
   - test the working of slow start algorithm
   - test the working of window scaling algorithm

Overview of the ongoing work

Ongoing work

MPTCP model
in
ns-3

DCTCP, TCP Prague
models in
ns-3

TCP BBR model
in
ns-3

TCP Evaluation
Suite for
ns-3

Review

Review

- Different TCP implementations can be used with ns-3
- ns-3 TCP has been recently refactored
- The new architecture is simple and user friendly for
  - adding new congestion control algorithms
  - testing them
- Scope to develop more extensions
  - e.g., TCP extensions for Data Center Networks

Thank you!