HTBQueue: A Hierarchical Token Bucket Implementation for the OMNeT++/INET Framework

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Funding:

EC H2020 TeraFlow

SWC BigQoE

8th of September 2021

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Rate Conformance Validation

Summary

Motivation

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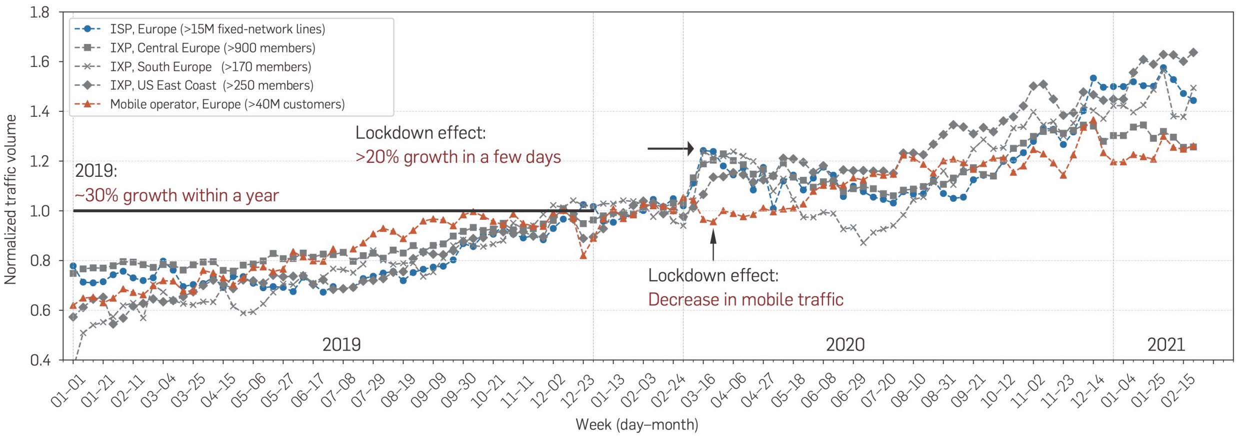

Figure 1: Traffic changes during the COVID-19 pandemic's, taken from [1]

Nowadays Internet: heterogeneous services + increased number of customers + pandemic effects

A key role for network providers – advanced, efficient and scalable traffic shaping, and resource allocation

OMNeT++/INET framework – one of the most prominent discrete simulation frameworks for gaining new knowledge and insights.

Motivation

Desired properties of an advanced traffic shaper:

- 3GPP standard for 5G and beyond network technologies [2] specifies that flows should have two-level bitrate limits: *Guaranteed Flow Bitrate (GFBR)* and *Maximum Flow Bitrate (MFBR)*
- Scalability
- Prioritization
- Efficient resource allocation and isolation in a slice-like manner
- Feasibility to use in research testbeds and for different QoS policy enforcement
- Good rate conformance

Currently no built-in support in OMNeT++

The **Hierarchical Token Bucket** (HTB) fulfills all described properties.
HTBQueue*:* our implementation of the HTB as compound module in OMNeT++/INET framework.

The Hierarchical Token Bucket

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The Hierarchical Token Bucket

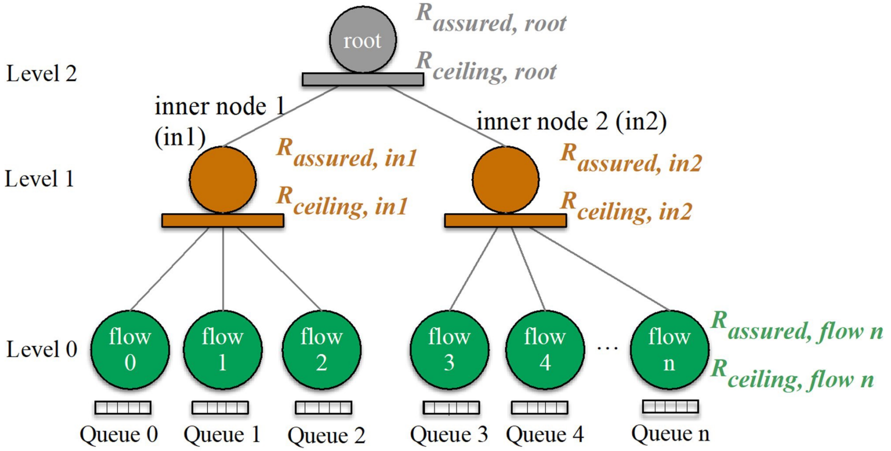
A classful token bucket bucket algorithm

Rate control using two nested token buckets, controlling the assured and ceiling rate

Utilizes a tree hierarchy to control multiple traffic classes.
Three class types exist: root, inner and leaf

Inner classes allow grouping of leaf classes
Possible use-case: 5G network slicing

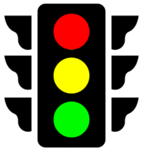
Sum of children's assured rates cannot exceed assured rate of the parent



The Hierarchical Token Bucket – Rate Borrowing Principle

Mode of class determined by three different states:

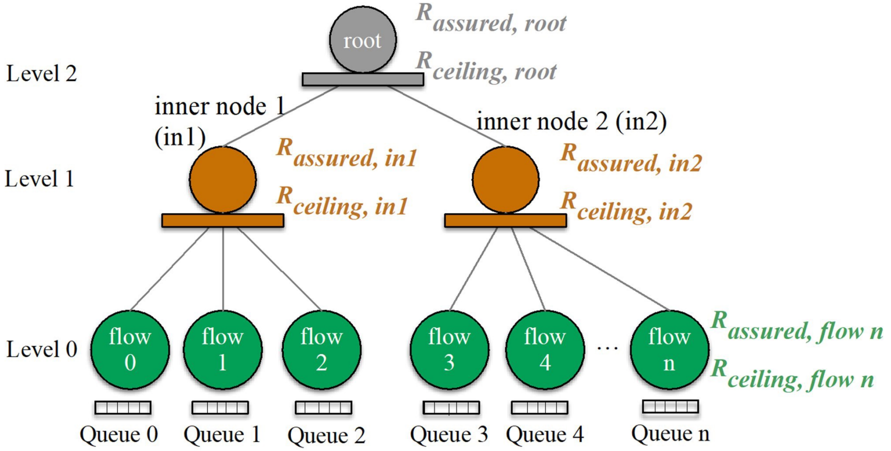
- ***can send***
- ***may borrow***
- ***can´t send***



Each class on Level *L > 0* keeps a list of its descendant nodes that would like to borrow D_{class} .

Key parameters per class:

- *Ceiling rate* - $R_{ceiling}$
- *Assured rate* - $R_{assured}$
- *Current rate utilized by the parent* - R_{parent}
- *Quantum of the class* - Q_{class}
- *Borrowed bandwidth* - B_{class}



HTB Implementation for OMNeT++/INET

HTB Implementation for OMNeT++/INET

HTBQueue

- Implemented as an OMNeT++ compound module
- Extension of the INET Framework

Packet queue module, similarly to e.g. *PriorityQueue*

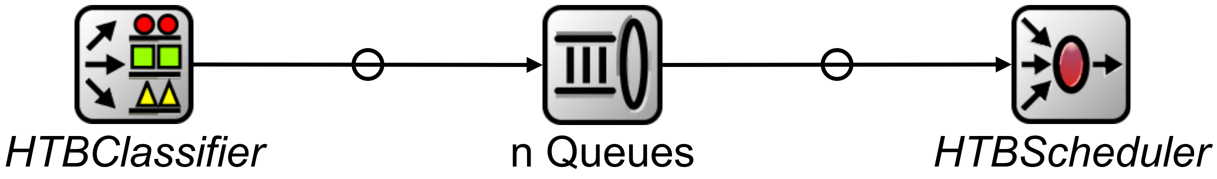
- Used as a replacement for any packet queue on an interface
- Applicability limited to the PPP interface

Implementation based on Linux HTB by Martin Devera [3]

- Linux HTB source code [4] port to C++
- OMNeT++ specific adjustments

Implementation available on Github: https://github.com/fg-inet/omnet_htb

The HTBQueue Compound Module



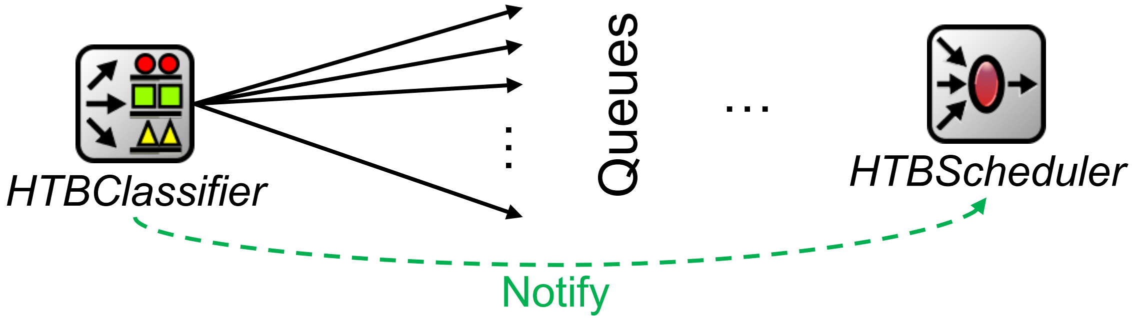
Compound queue implementing the Hierarchical Token Bucket algorithm

- Queuing module for PPP interface
- Utilization of already existing queues for leaf queues

Consists of three modules

- *HTBClassifier* – Classifies packets into correct leaf classes
- Queues – Generic queues, number of which corresponds to number of leaf classes
- *HTBScheduler* - Schedules packets and implements the actual functionality of HTB

The HTBClassifier Module



HTBClassifier

- Extension and adaptation of the *ContentBasedClassifier* [5]
- Functionality for filtering and forwarding packets analogous to *ContentBasedClassifier*
- Support for signalling to the *HTBScheduler* module

Packet filtering based on

- Packet type (e.g. ping packet)
- Packet information (e.g. packet source IP)

The HTBScheduler Module

HTBScheduler

- Implementation of scheduling functionality of HTB
- Enforcement of classful HTB scheduling hierarchy
- Enforcement of assured and ceiling rates for each class

HTBScheduler

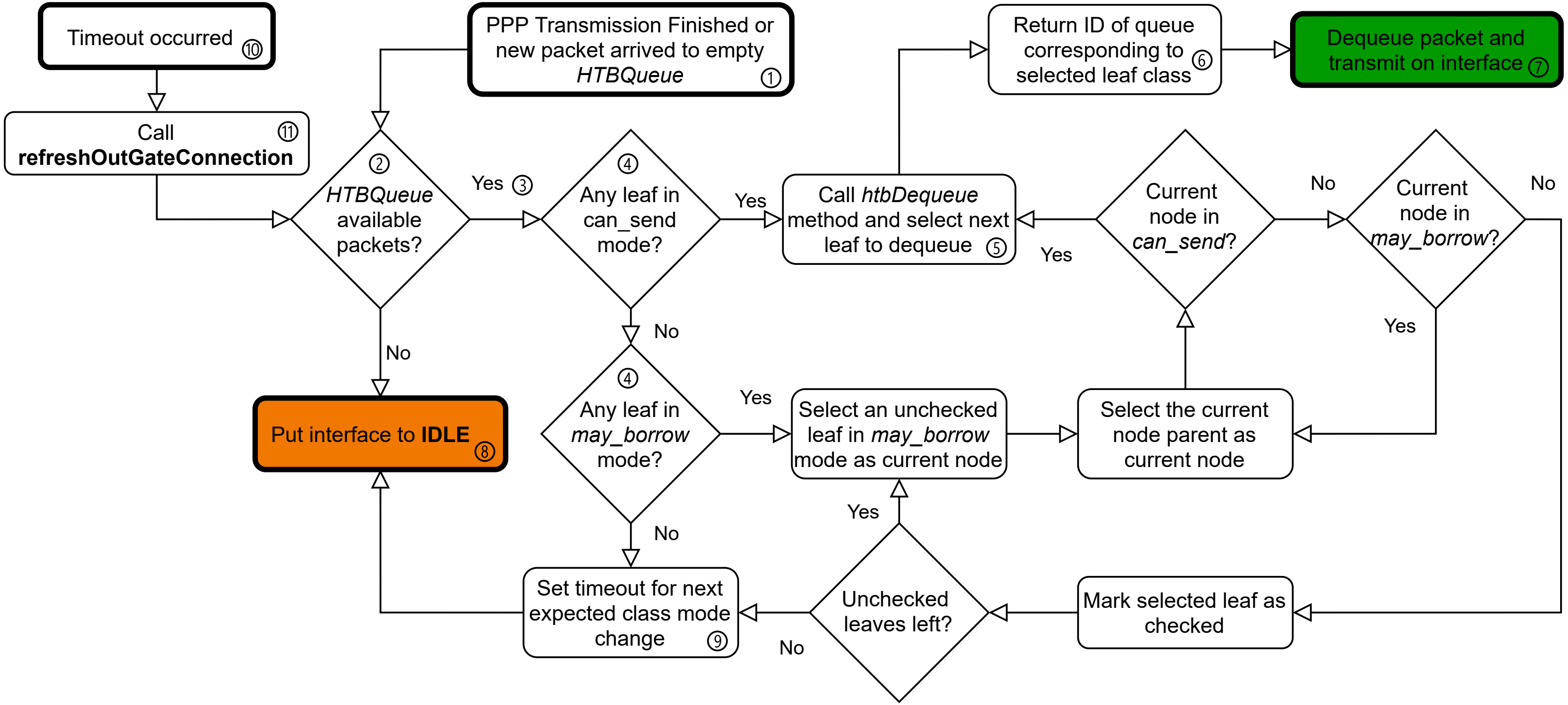
Selection of the next leaf class/queue to dequeue when

- The interface finished transmission event occurs
- An event with a new packet arriving to the queue and interface being idle occurs
- A timeout occurs – i.e. an active leaf class can send again

The timeout

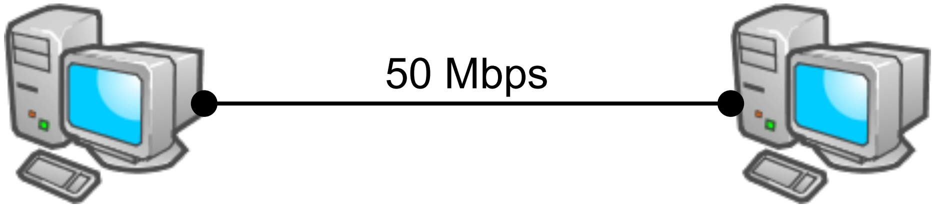
- Set if there are only packets in leaf queues that can't be sent during either of the first two events
- Invokes *refreshOutGateConnection* method of the **PPP module**
- PPP Interface modification → the *refreshOutGateConnection* method has to be public

The HTBScheduler Module – Functional Overview



Rate Conformance Validation

Rate Conformance Validation

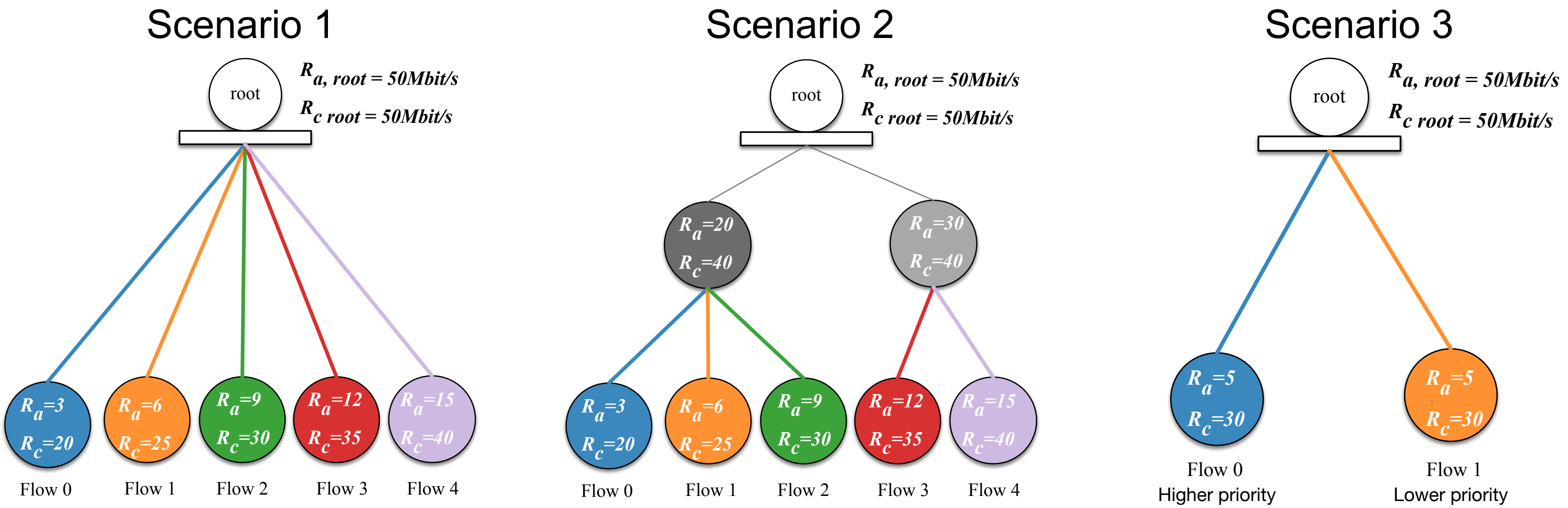


Rate limiting and sharing verified in simple experiments with two directly connected hosts

- Hosts connected via PPP interfaces
- *HTBQueue* configured on each PPP interface
- UDP flows between hosts sending 1500 Byte packets every 100µs in one direction
- Each flow corresponds to one leaf class
- Flows started in 10s intervals and ran for 100s

Three scenarios covering different configurations w.r.t. inner/leaf nodes and priorities

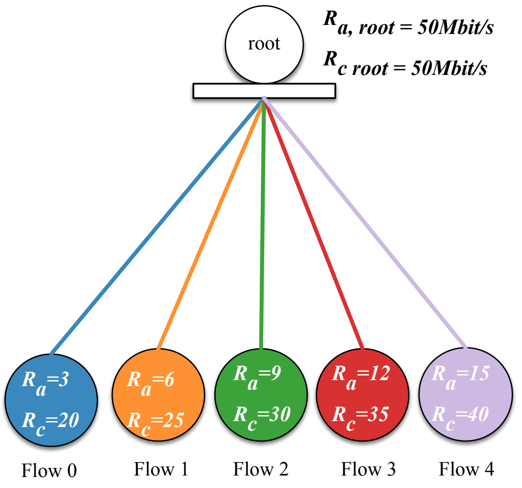
Rate Conformance Validation – HTB Configuration

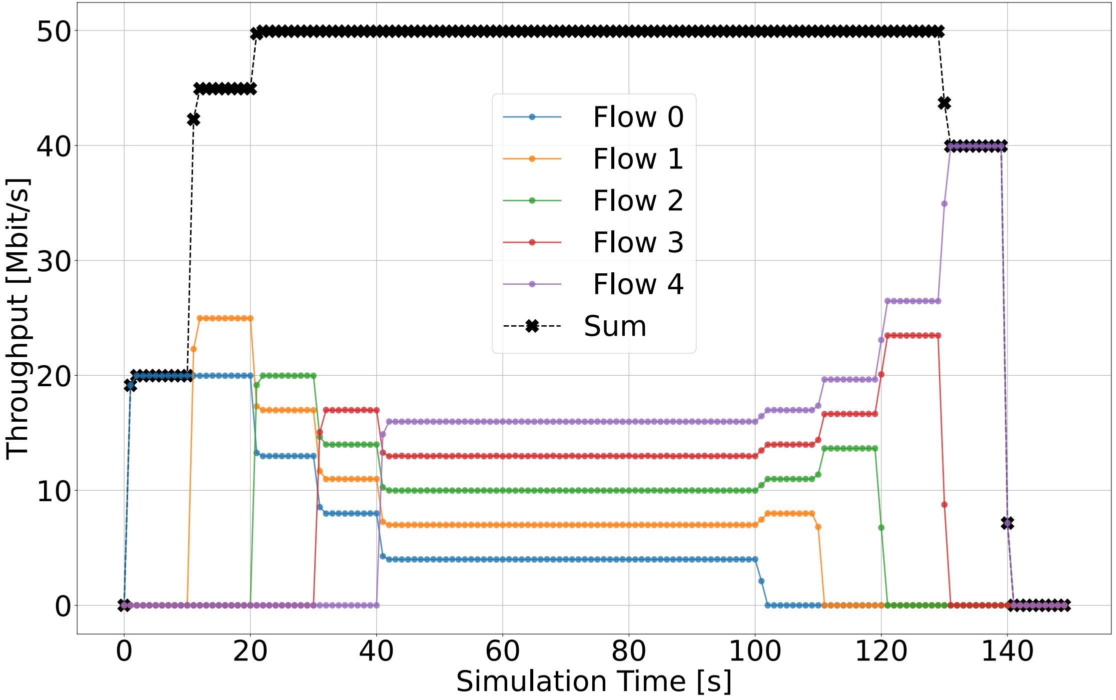


R_a = assured rate (in Mbit/s)

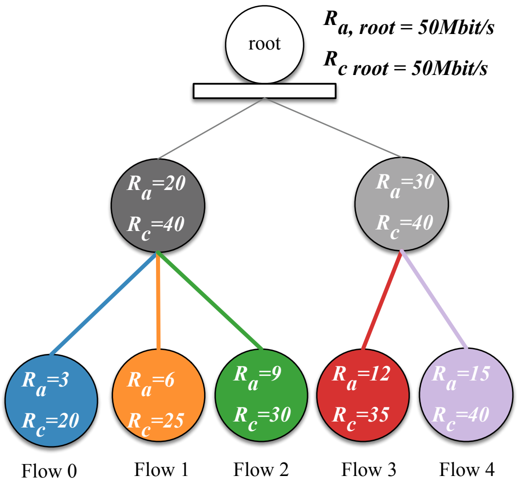
R_c = ceiling rate (in Mbit/s)

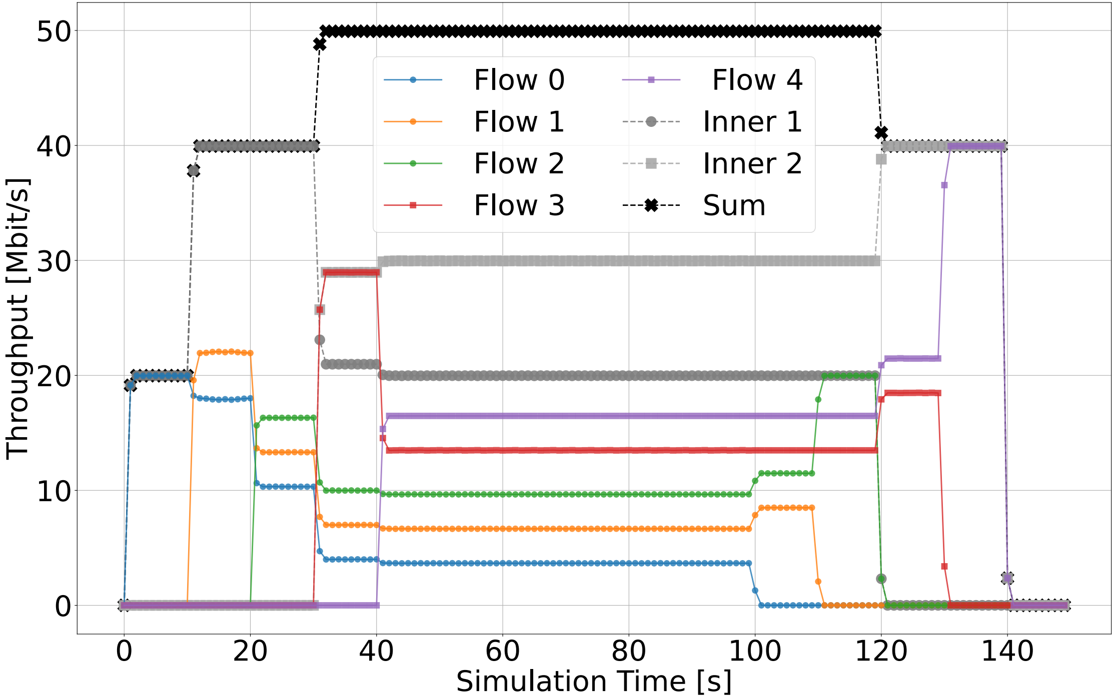
Rate Conformance Validation – Scenario 1



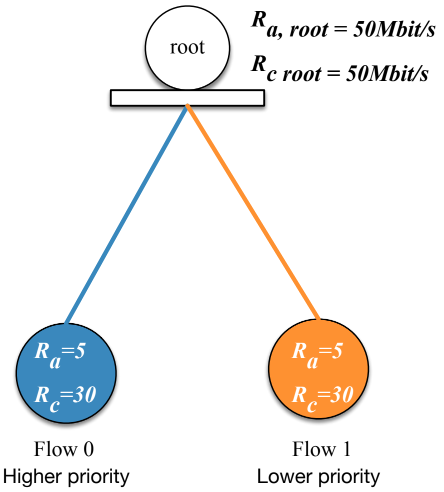


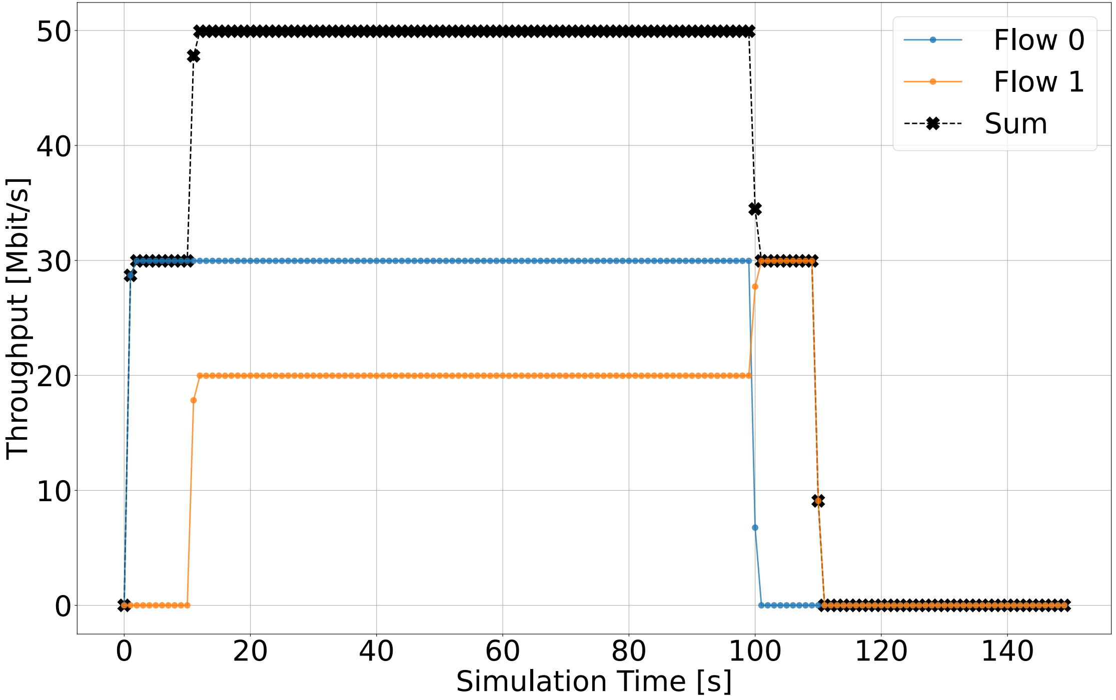
Rate Conformance Validation – Scenario 2





Rate Conformance Validation – Scenario 3





Summary

Summary

Motivation for *HTBQueue* implementation

- Key role for network operators nowadays – traffic shaping and optimal resource allocation
- No built-in advanced traffic shaper allowing for hierarchical two level bitrate guarantees in OMNeT++
- HTB concepts still in use today and applicable to numerous use-cases (5G and beyond)

Design and implementation of a compound module in *INET* framework – *HTBQueue*

- Consists of classifier, generic queues and scheduler
- Code based on the Linux HTB implementation

HTBQueue validation in different scenarios

- Good rate conformance for leaf and inner classes
- Enforces different priority settings

Thank You!

Q&A

Demo


Scenario 2
50 Mb/s
45 Mb/s
40 Mb/s
35 Mb/s
30 Mb/s
25 Mb/s
20 Mb/s
15 Mb/s
10 Mb/s
5 Mb/s
0 Mb/s
15:34:00
15:35:00
15:36:00
15:37:00
15:38:00
Flow0
Flow1
Flow2
Flow3
Flow4

HTBQueue Integration into an Existing Project

Copy the HTB Implementation files over from github

- https://github.com/fg-inet/omnet_htb
- I.e. merge the code/inet4 folder with your inet4 folder

Compile INET

Configure HTBQueue as the packet queue on interfaces in the INI file

```
*.serverFDO*.ppp[0].ppp.queue.typename = "HTBQueue"
*.serverFDO*.ppp[0].ppp.queue.numQueues = 5
*.serverFDO*.ppp[0].ppp.queue.queue[*].typename = "DropTailQueue"
*.serverFDO*.ppp[0].ppp.queue.htbHysterisis = false
*.serverFDO*.ppp[0].ppp.queue.htbTreeConfig = xmldoc("tree_scenario1.xml")
*.serverFDO*.ppp[0].ppp.queue.queue[*].packetCapacity = 500
*.serverFDO*.ppp[0].ppp.queue.classifier.defaultGateIndex = 1
*.serverFDO*.ppp[0].ppp.queue.classifier.packetFilters ="*;*;*;*;*"
*.serverFDO*.ppp[0].ppp.queue.classifier.packetDataFilters ="destinationPort(1042);destinationPort(1043);
destinationPort(1044);destinationPort(1045);destinationPort(1046)"
```

Prepare XML HTB configuration → (example)

```xml
<config>
    <class id="root">
        <parentId>NULL</parentId>
        <rate type="int">50000</rate>
        <ceil type="int">50000</ceil>
        <burst type="int">2000</burst>
        <cburst type="int">2000</cburst>
        <level type="int">2</level>
        <quantum type="int">1500</quantum>
        <mbuffer type="int">60</mbuffer>
    </class>
    <class id="innerC1">
        <parentId>root</parentId>
        <rate type="int">20000</rate>
        <ceil type="int">40000</ceil>
        <burst type="int">2000</burst>
        <cburst type="int">2000</cburst>
        <level type="int">1</level>
        <quantum type="int">1500</quantum>
        <mbuffer type="int">60</mbuffer>
    </class>
    <class id="leafhostFDO0">
        <parentId>innerC1</parentId>
        <rate type="int">3000</rate>
        <ceil type="int">20000</ceil>
        <burst type="int">2000</burst>
        <cburst type="int">2000</cburst>
        <level type="int">0</level>
        <quantum type="int">1500</quantum>
        <mbuffer type="int">60</mbuffer>
        <priority>0</priority>
        <queueNum type="int">0</queueNum>
    </class>
</config>
```

References

References

1. *Anja Feldmann, Oliver Gasser, Franziska Lichtblau, Enric Pujol, Ingmar Poese, Christoph Dietzel, Daniel Wagner, Matthias Wichtlhuber, Juan Tapiador, Narseo Vallina-Rodriguez, Oliver Hohlfeld, and Georgios Smaragdakis. 2021. A year in lockdown: how the waves of COVID-19 impact internet traffic. Commun. ACM 64, 7 (July 2021), 101–108. DOI: https://doi.org/10.1145/3465212*
2. *3rd Generation Partnership Project (3GPP), \NR; NR and NG-RAN Overall description; Stage-2," Technical Specication (TS) 38.300, Mar. 2021, release 16.5.0.*
3. *M. Devera, "Hierarchical token bucket," http://luxik.cdi.cz/~devik/qos/htb/, February 2002.*
4. *HTB Linux source code, https://github.com/torvalds/linux/blob/master/net/sched/sch_htb.c*
5. *Documentation of the ContentBasedClassifier, https://doc.omnetpp.org/inet/api-current/neddoc/inet.queueing.classifier.ContentBasedClassifier.html*