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Tutor: Stefano Avallone
XXXI Cycle - III year presentation

Network Traffic Control Design and Evaluation

Background

- MSc Cum Laude in Computer Engineering at University of Naples Federico II
- COMICS Research Group
- Fellowship by University of Naples Federico II

Credits Summary

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Cycle XXXI

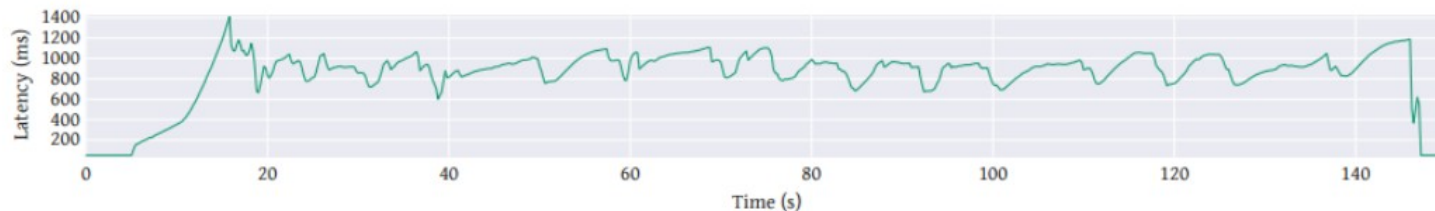
	Credits year 1							Credits year 2							Credits year 3							Total	Check			
	Estimated	1	2	3	4	5	6	Summary	Estimated	1	2	3	4	5	6	Summary	Estimated	1	2	3	4			5	6	Summary
Modules	20			3	5	6	8	22	10	6			4			10	0							0	32	30-70
Seminars	5	1.6	1	1	1.6		3	8.2	5	3.5	0.3	1.5			0.3	5.6	0							0	13.8	10-30
Research	35	4	7	7	4	4	4	30	45	3	9	5	10	10	9	46	60	9	10	10	10	10	10	59	135	80-140
	60	5.6	8	11	10.6	10	15	60.2	60	12.5	9.3	10.5	10	10	9.3	61.6	60	9	10	10	10	10	10	59	180.8	180

- Period abroad at Centre Tecnològic de Telecomunicacions de Catalunya (CTTC) in Castelldefels (Barcelona)
- European Space Agency (ESA) Summer of Code in Space (SOCiS)



Problem

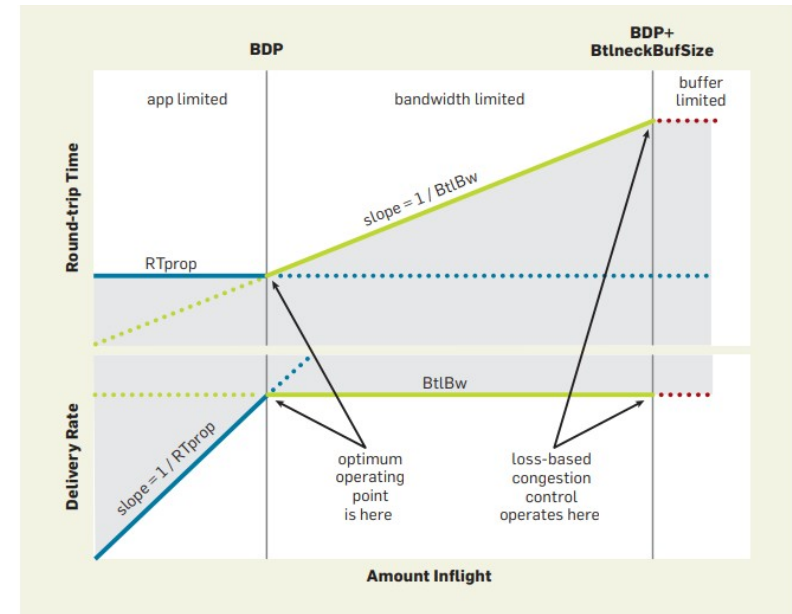
- Relevance: the uncontrolled growth of the delay in communication networks
 - the term *bufferbloat*¹ has been coined to indicate such phenomenon
- Approach: simulation and emulation to study the bufferbloat problem, to design and to evaluate solutions



¹ Vinton G. Cerf, "Bufferbloat and Other Internet Challenges", IEEE Internet Computing, vol. 18, no. , pp. 80, Sept.-Oct. 2014.

Context: network traffic control 1/2

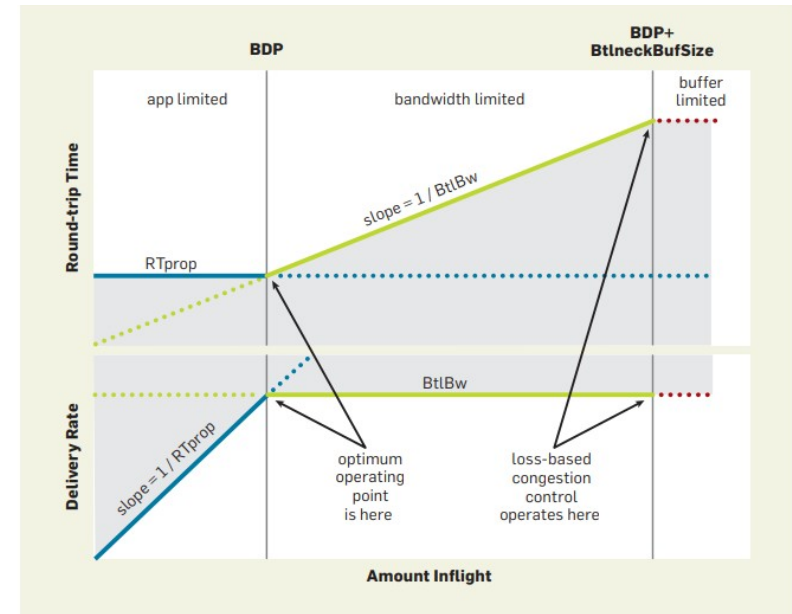
- High network resource utilization with low network delay
- Transport protocols, e.g., TCP, send as much data as possible to keep high network utilization
- Network buffers aim to store packets waiting for transmission avoiding packet losses



RTT and delivery rate in TCP loss based and model based.

Context: network traffic control 2/2

- The need of mitigation strategies arises to avoid unnecessary delay, in particular for interactive traffic
- Active Queue Management (AQM) algorithms have been proposed to drop packets before the queue becomes full



RTT and delivery rate in TCP loss based and model based.

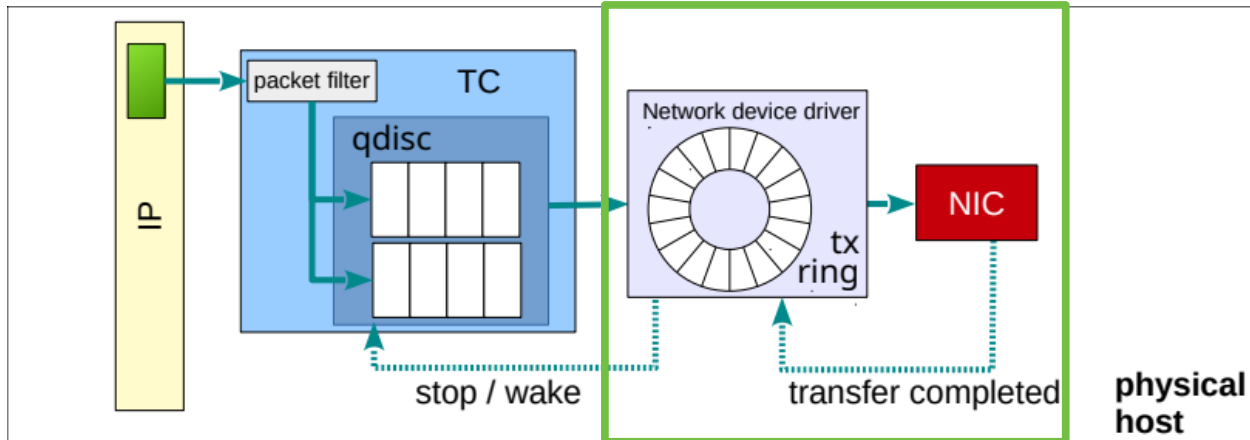
Context: network experimentation

- Simulation, emulation and testbed experiments are possible approaches to evaluate network performance
- Simulation allows *high flexibility* and has *low complexity*
- The challenge of using simulations is their *credibility*

Contributions

- Analysis of the Linux networking stack
- Design and implementation of an ns-3 traffic control module based on the Linux one
- Design and implementation of a new methodology to support network emulation
- Validation of the implemented modules
- A scheme of traffic control in LTE networks to reduce latency
- An alternative scheme of flow control to improve the effectiveness of AQM algorithms

Analysis of the Linux networking subsystem: architecture 1/2

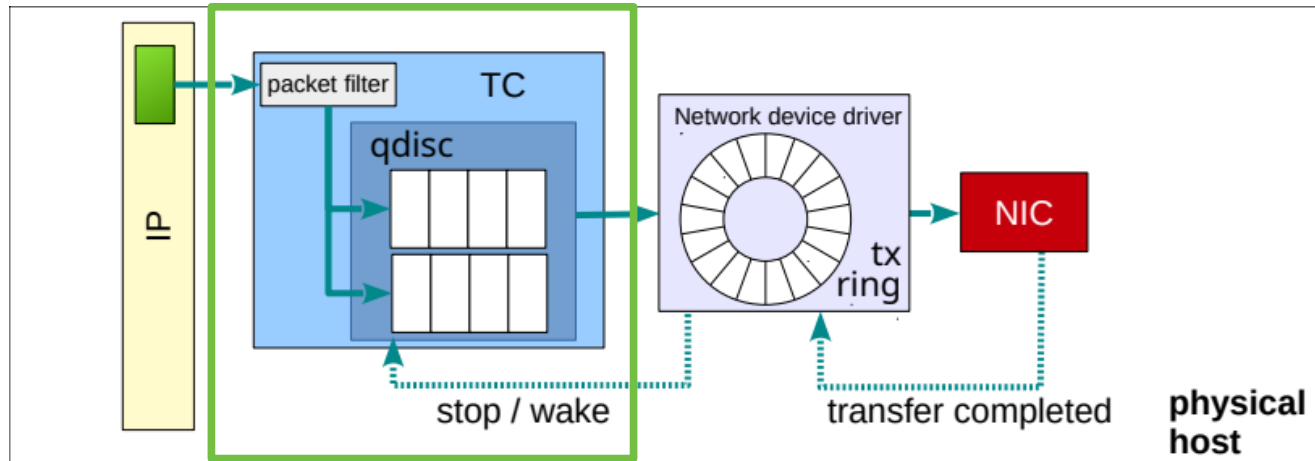


Representation of the transmission path of the Linux networking stack.

- The device driver manages the device buffer (*tx ring*)
 - stops/wakes the queue
 - notifies the kernel about enqueue/dequeue events to support dynamic ring sizing through BQL

An analysis of the impact of network device buffers on packet schedulers through experiments and simulations, P. Imputato and S. Avallone, Simulation Modelling Practice and Theory (SIMPAT), 2018.

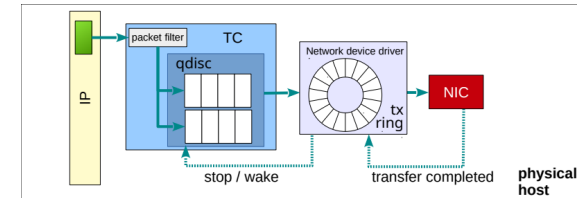
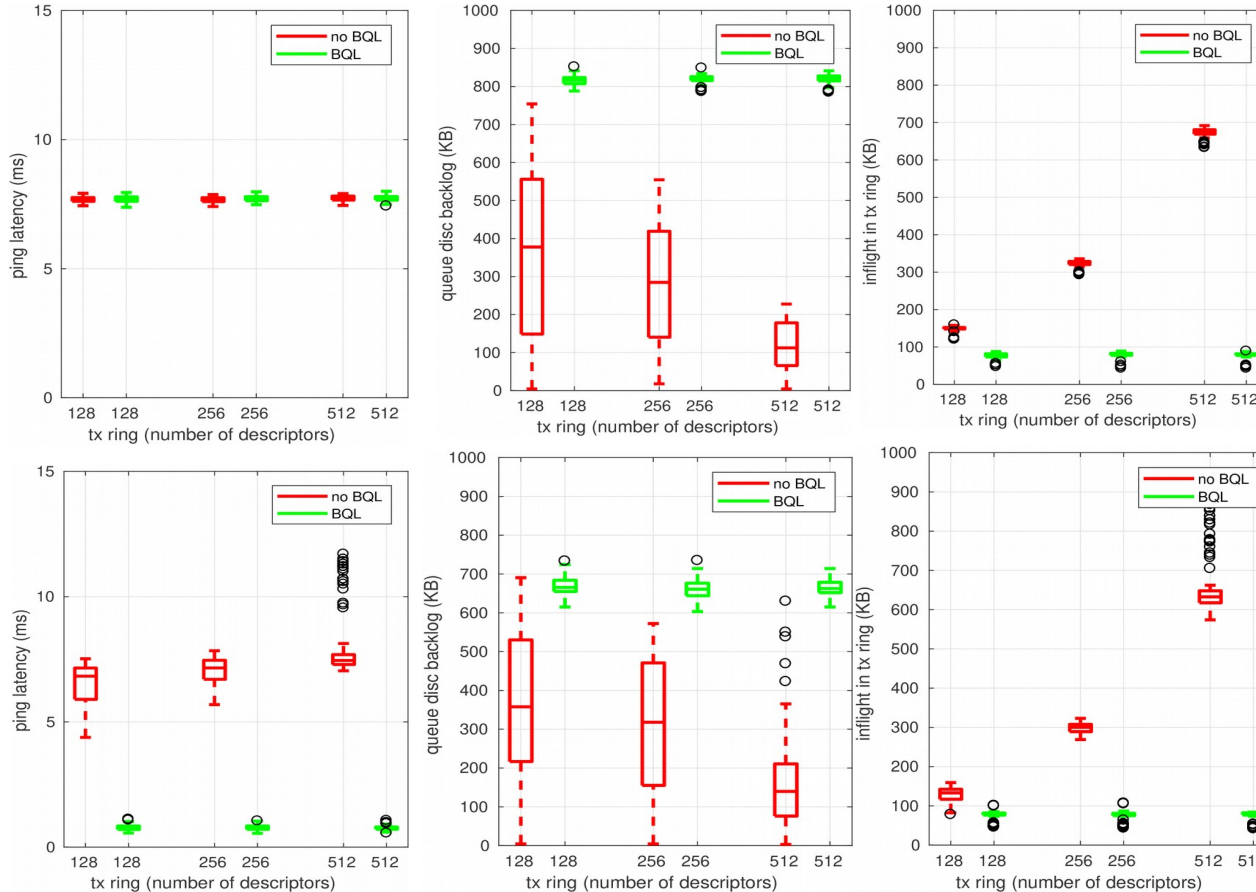
Analysis of the Linux networking subsystem: architecture 2/2



Representation of the transmission path of the Linux networking stack.

- Traffic control stores packets waiting for transmission
- Packet schedulers and AQM algorithms implemented as queueing disciplines (qdisc)
 - pfifo_fast is a three band discipline and separates flows based on the IP Type of Service (ToS) field of packets
 - fq_codel separates flows through hashing of the five-tuple of packet and manages the queues with CoDel

Analysis of the Linux networking subsystem: performance



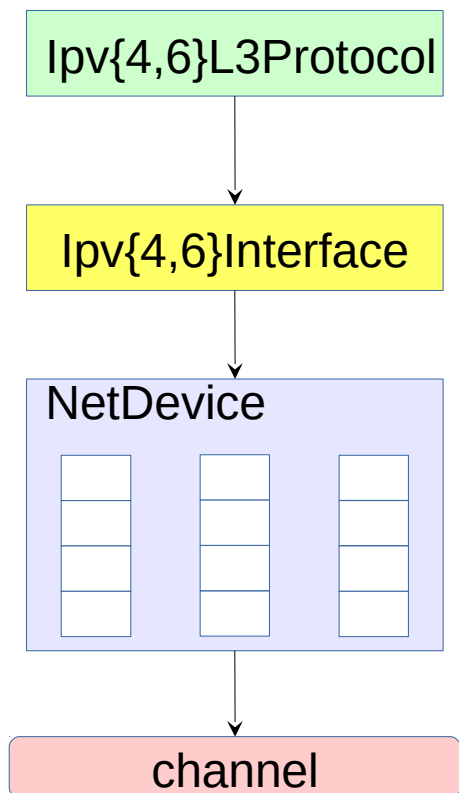
- Scenario with pfifo_fast or fq_codel qdisc
- BQL reduces inflight and increases backlog and AQM effectiveness

RTT, qdisc backlog and tx ring inflight in host scenario in case pfifo_fast and fq_codel qdiscs.

The ns-3 network simulator

- Full-stack simulation and emulation of multiple network technologies (e.g., 3GPP LTE, IEEE 802.11ac)
- Design inspired to Linux networking stack
- **Lacked** an equivalent of the Linux traffic control
- **Limitations** in the emulation support

A traffic control module in ns-3 1/2

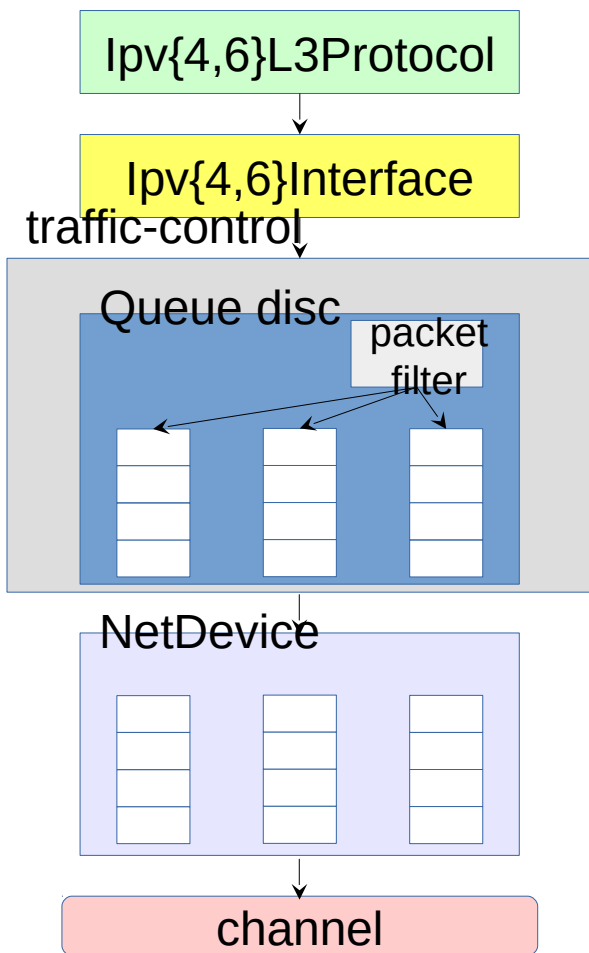


ns-3 stack before the introduction of traffic control module.

- Single level of queue inside the device
- Limited AQM support

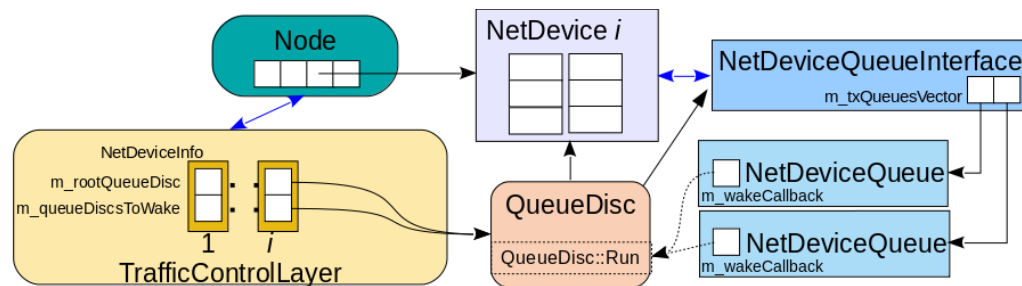
Design and implementation of traffic-control module in ns-3, P. Imputato and S. Avallone, Workshop on ns-3 (WNS3), 2016.

A traffic control module in ns-3 2/2



ns-3 stack with traffic control module.

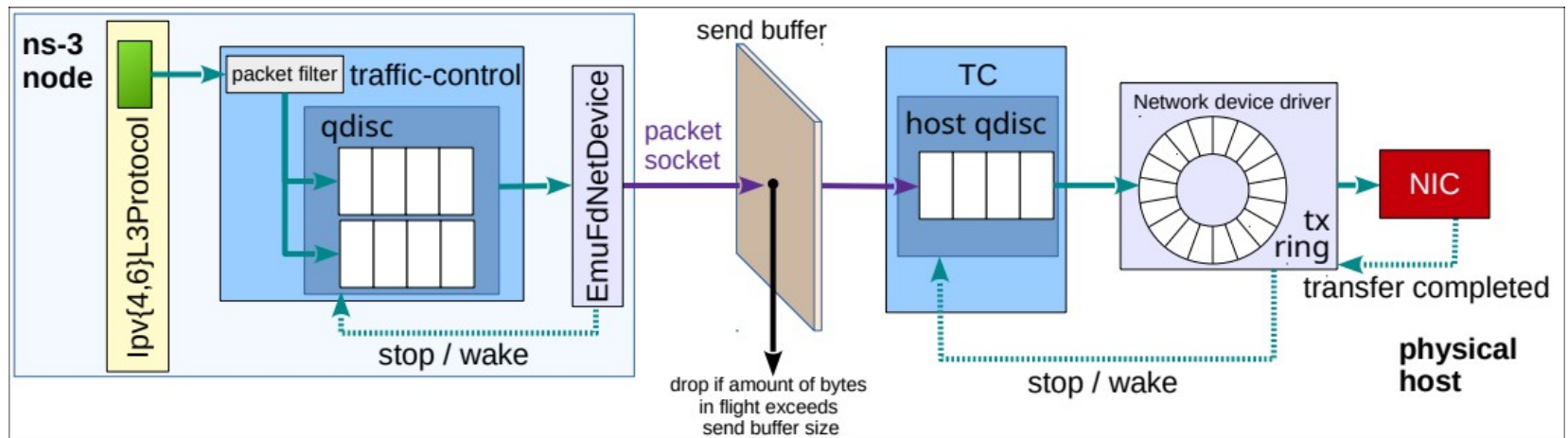
- Traffic control between IP and device layers
- Packet schedulers and AQM algorithms implemented as qdisc



Implementations details about the introduction of traffic control module.

Network emulation through kernel networking bypass 1/2

- Sockets have no access to the device tx ring status

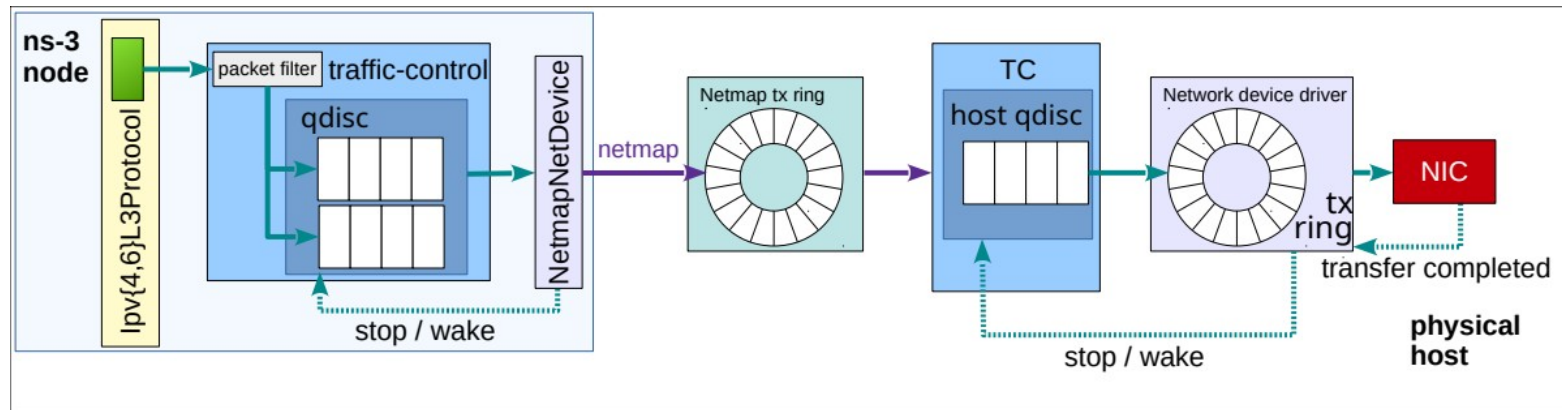


Emulation support through standard socket mechanism.

Enhancing the fidelity of network emulation through direct access to device buffers, P. Imputato and S. Avallone.

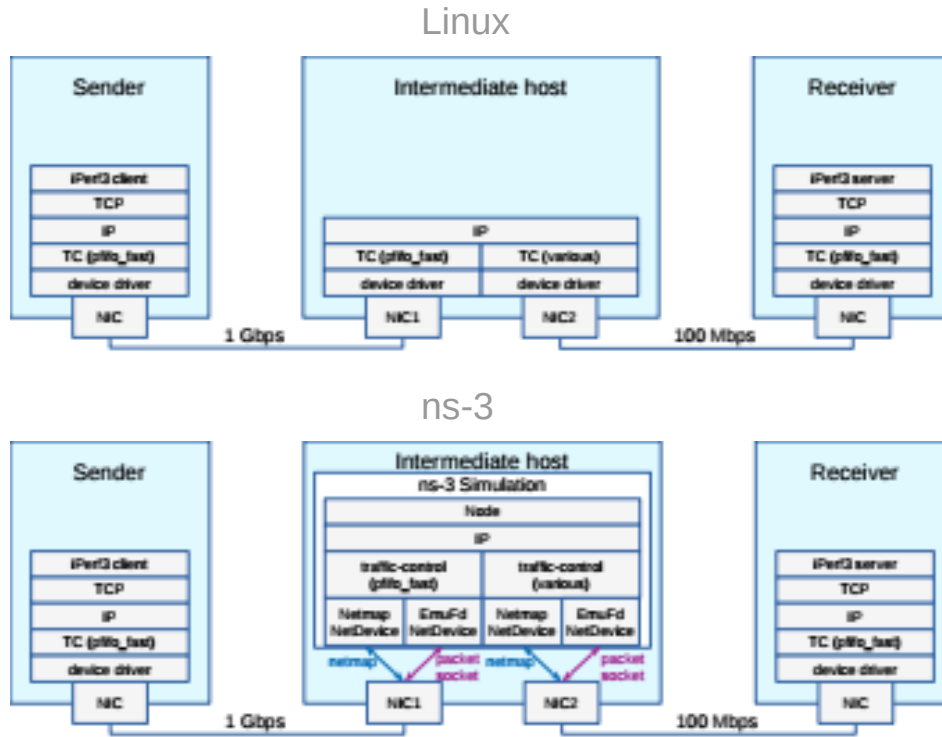
Network emulation through kernel networking bypass 2/2

- Netmap provides an image of the device tx ring
 - flow control between the netmap tx ring and traffic control



Emulation support through netmap.

Validation: testbed



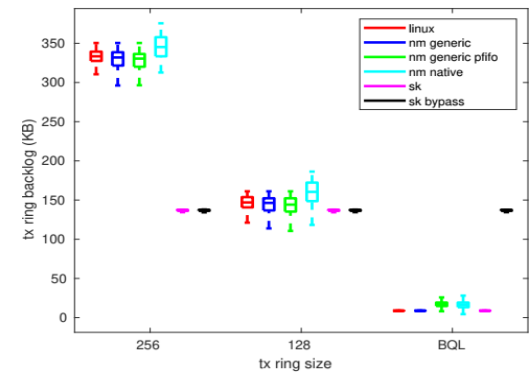
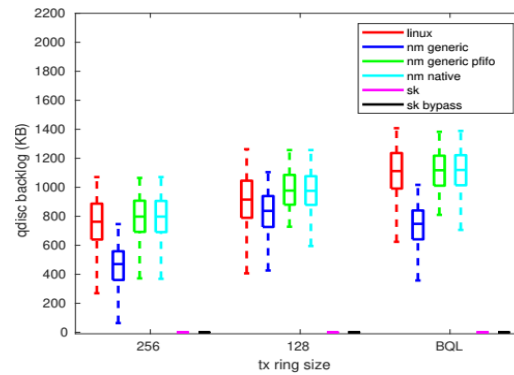
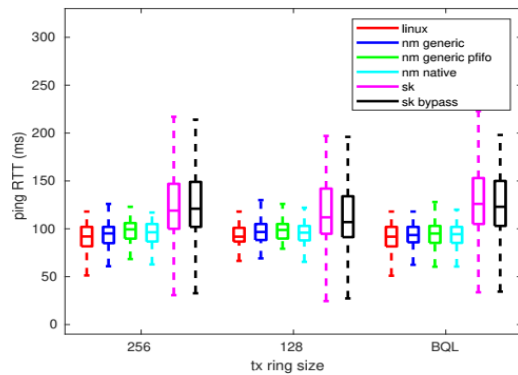
- 3 nodes on 2 subnets
- Fixed sender/receiver configuration
- Bottleneck causes queueing delay

Testbed with intermediate host configured with Linux (top part) and ns-3 (down part) traffic control in emulation mode.

Enhancing the fidelity of network emulation through direct access to device buffers, P. Imputato and S. Avallone.

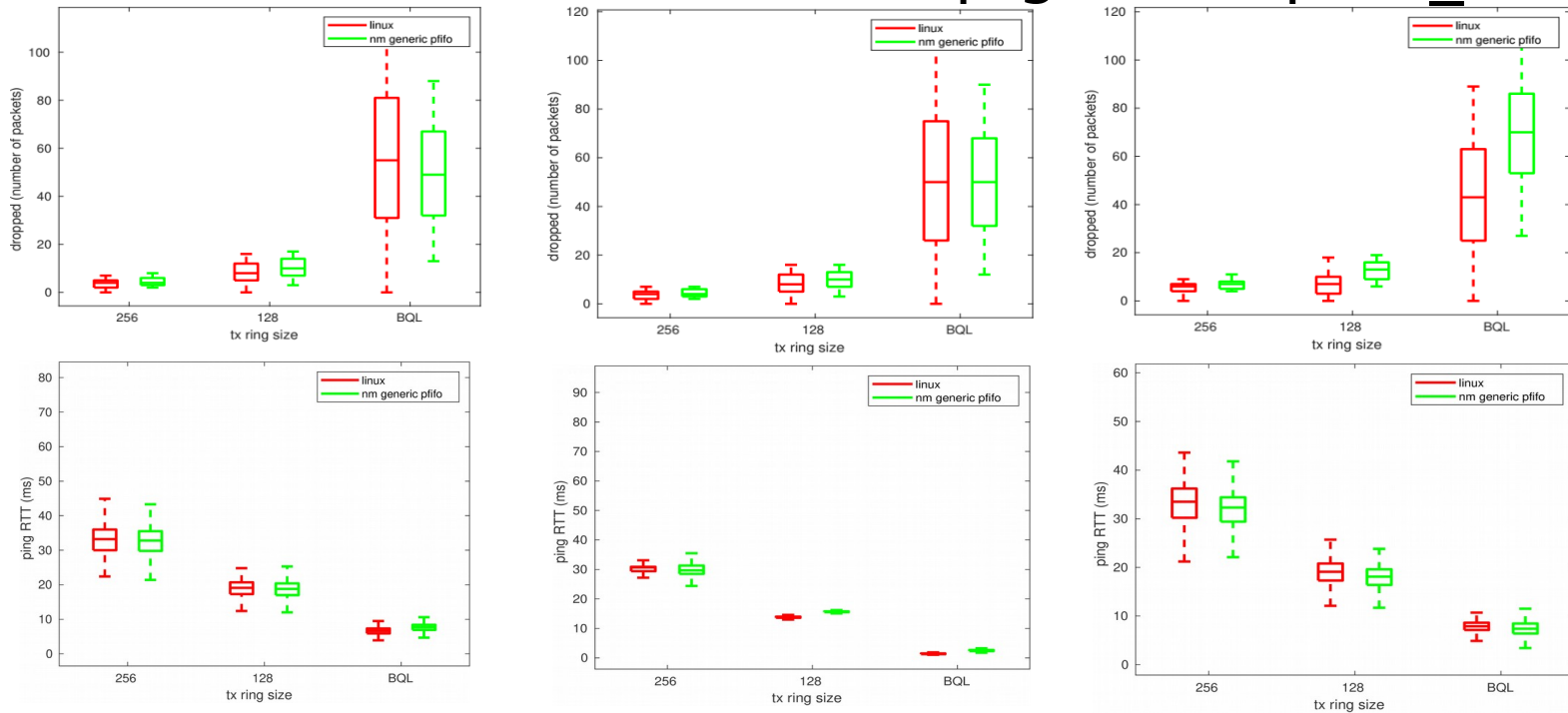
Validation: traffic control and emulation methodology

- ns-3 traffic control configured with pfifo_fast
- five emulation methodologies



Validation: CoDel, FQ-CoDel, RED

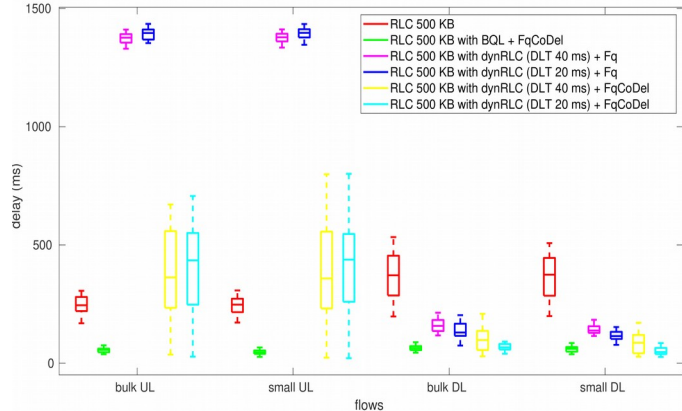
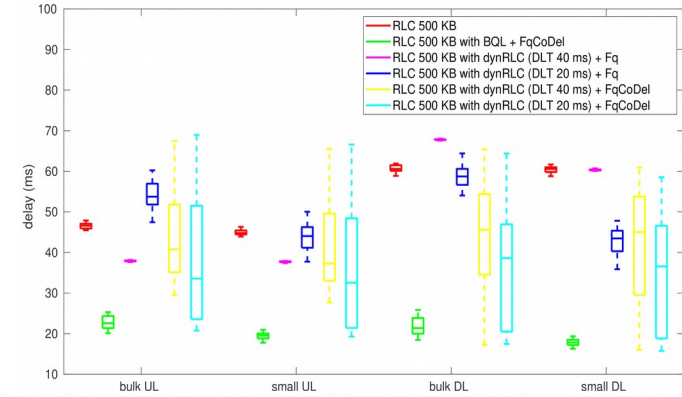
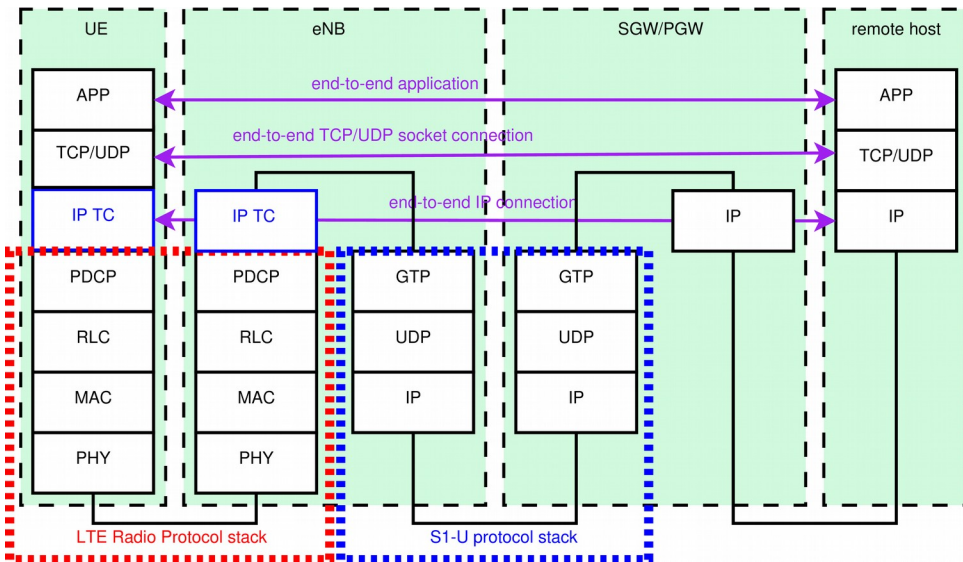
- ns-3 traffic control configured with AQMs
- Emulation mode with netmap generic pfifo_fast



Dropped and RTT with ns-3 qdisc CoDel, FQ-CoDel and RED.

A scheme of traffic control in LTE networks to reduce latency

- IP TC on top of LTE
- FQ-CoDel with BQL outperforms other schemes

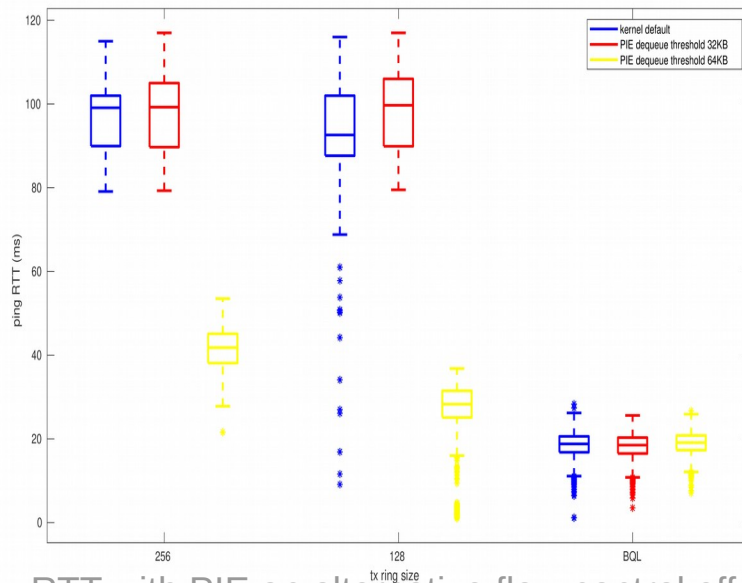


Flows RTT in single UE and multiple UE scenario.

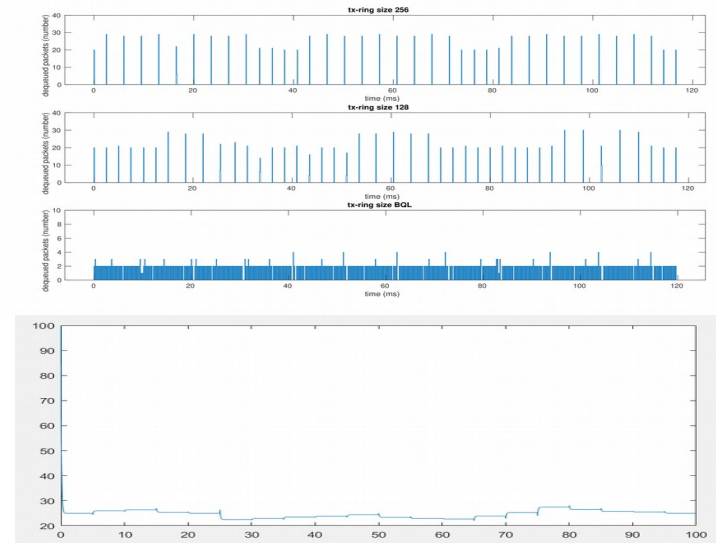
Smart backlog management to fight bufferbloat in 3GPP stacks, P. Imputato, N. Patriciello, S. Avallone, J. Mangues-Bafalluy.

An alternative scheme of flow control to improve the effectiveness of AQM algorithms

- Rate based AQM algorithms affected by specific flow control implementations



RTT with PIE an alternative flow control effect.



Avoiding AQM design flaws: the PIE case, P. Imputato, S. Avallone.

Conclusions

- In this work we aligned the ns-3 queueing system to the Linux one by introducing a traffic control module
- We devised a new methodology to support network emulation through bypass of the host networking stack
- We validated the emulation methodology and the modules introduced into ns-3
- Our work improves the accuracy of all the performance metrics affected by traffic control

Future works

- Future works include:
 - the design and evaluation of traffic control strategies in the context of 5G and WiFi networks
 - the validation of other ns-3 modules, e.g., TCP

Products

- Design and implementation of traffic-control module in ns-3, P. Imputato and S. Avallone, *Workshop on ns-3 (WNS3)*, 2016, **Best Paper Award**
- Traffic differentiation and multiqueue networking in ns-3, P. Imputato and S. Avallone, *Workshop on ns-3 (WNS3)*, 2017
- Network emulation support in ns-3 through kernel bypass techniques, P. Imputato, S. Avallone and T. Pecorella, *International Conference on Performance Evaluation Methodologies and Tools (VALUETOOLS)*, 2017
- An analysis of the impact of network device buffers on packet schedulers through experiments and simulations, P. Imputato and S. Avallone, *Journal on Simulation Modelling Practice and Theory (SIMPAT)*, 2018
- Smart backlog management to fight bufferbloat in 3GPP stacks, P. Imputato, N. Patriciello, S. Avallone, J. Manges-Bafalluy, *accepted for publication in Consumer Communications & Networking Conference (CCNC)*, 2019
- Enhancing the fidelity of network emulation through direct access to device buffers, P. Imputato, S. Avallone, *under review in Journal of Networks and Computer Applications (JNCA)*