Evaluation of PI Controller Queue Management Algorithm using ns-3

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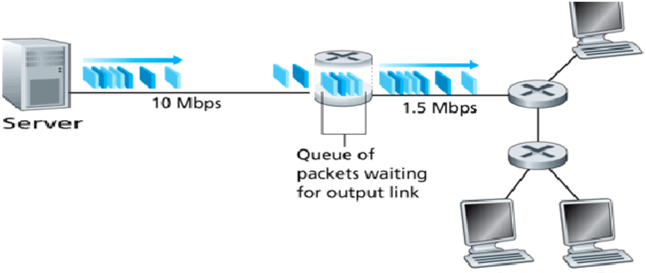
Network congestion

1. Network resources are limited, including router processing time and link throughput.
2. Network congestion occurs when a network node or link is carrying more data than it can handle.



source : https://www.researchgate.net/figure/Network-congestion-effects_fig1_258163957

Figure 1: Network Congestion

Importance of Queue Management Algorithm

1. The large buffer will increase queuing delay which will result in the Bufferbloat problem.
2. To maintain the queue size in the router, we have to use Queue Management Technique like PQM and AQM.
3. AQM algorithms is often based on queue length (RED, PI), packet loss (BLUE), queue delay (PIE, CoDel) etc.
4. PI Controller is one of the AQM which works on instantaneous queue length.

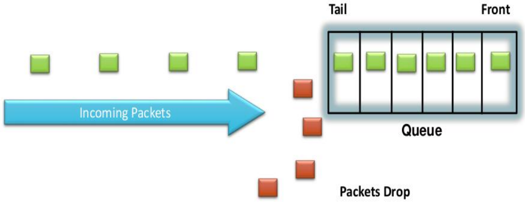


Figure 2: Buffer Overflow

Used System Parameters

Table 1: System Parameters

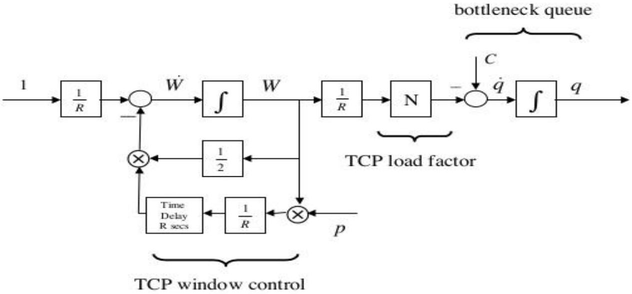
Notations	Explanation
W	TCP Congestion Window Size (packets)
q	Current Queue Length (packets)
N	Number of TCP flows
C	Link Capacity (packets/sec)
R	Round-trip time (secs)
T_p	Propagation delay (secs)
s	Laplace transfer complex function
W_0	Value of W at equilibrium point
q_0	Value of q at equilibrium point
p_0	Value of p at equilibrium point
R_0	Value of R at equilibrium point

Non-linear Dynamic Model for TCP congestion avoidance

Simplified version of TCP model ignoring the timeout mechanism based on fluid flow analysis,

$$\frac{dW(t)}{dt} = \frac{1}{R(t)} - \frac{W(t)W(t-R(t))}{2R(t)}p(t-R(t)) \tag{1}$$

$$\frac{dq(t)}{dt} = \frac{N(t)}{R(t)}W(t) - C \tag{2}$$

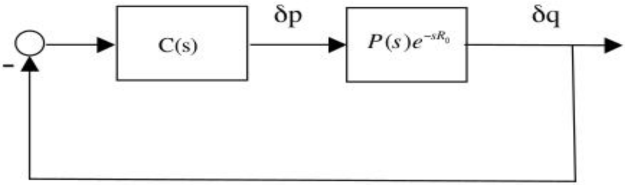


source : C.V. Hollot , V. Misra , D. Towsley , W.-B. Gong ,at al, "A Control Theoretic Analysis of RED "

Figure 3: Block-diagram of TCP's congestion avoidance flow control mode

Linearized control system of AQM

In Figure 4 the transfer function C(s) denotes an AQM control strategy such PI or RED.
The plant transfer function P(s)=$P_{tcp}(s)P_{queue}(s)$, where $P_{tcp}(s)$ and $P_{queue}(s)$ are poles of Laplace function.
Here e^{-sR_0} is the laplace time delay.

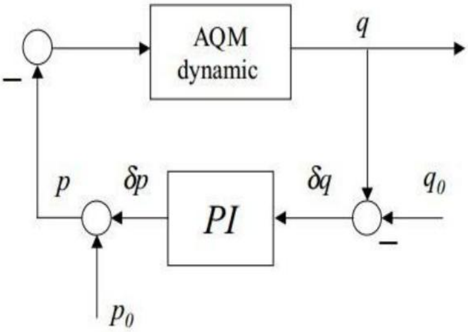


source : C.V. Hollot , V. Misra , D. Towsley , W.-B. Gong ,at al, "A Control Theoretic Analysis of RED "

Figure 4: AQM as feedback control.

Proportional Integral Controller

Proportional Integral Controller



Source : C.V. Hollot, Vishal Misra, Don Towsley and Wei-Bo Gong, at el,"On Designing Improved Controllers for AQM Routers Supporting TCP Flows"

Figure 5: Implementation of PI controller emphasizing the role of operating point q_0

Class Diagram of PI Queue Disc in traffic control layer of ns-3

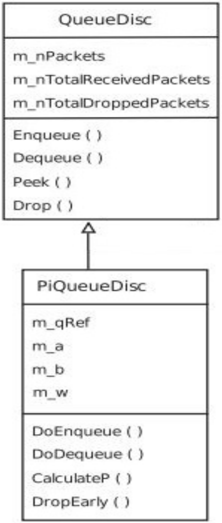
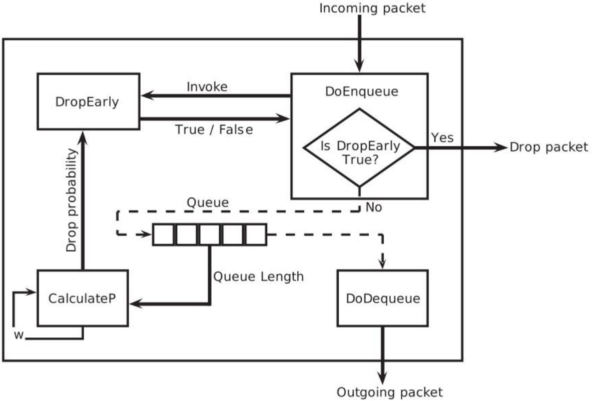


Figure 6: PI Queue Disc Class Diagram

Implementation of PI Controller in ns-3



Source : Vivek Jain, Viyom Mittal, Shravya K. S., Mohit P. Tahiliani , Wireless Information Networking Group (WiNG),at el, "Implementation and validation of BLUE and PI queue disciplines in ns-3"

Figure 7: Interaction between different methods of PI algorithm.

Implementation of PI Controller in ns-3 (Contd..)

PI Controller calculates the packet drop probability (p) at a sampling frequency represented by w. The parameters involved in the calculation of drop probability are:

$$p = \alpha * (q - qRef) - \beta * (qOld - qRef) + pOld \tag{3}$$

The queue reaches a steady state when α * (q - qRef) - β * (qOld - qRef) becomes zero, implying that the queue length has reached the desired value.

Table 2: System Parameters

Notations	Explanation
w	Sampling Frequency
p	Probability of packet mark/drop
qOld	Queue Length during the previous sample
qRef	Desired Queue Length
q	Current Queue Length
pOld	Drop probability during the previous sample
α and β	Scaling Factors for adjusting the controller response

Drop Early function in PiQueueDisc class

❒ When to drop a packet?

1. Unforced Drop : When Router buffer will be full.
2. Forced Drop : When Drop Early function returns true.

❒ When Early Drop function returns true?

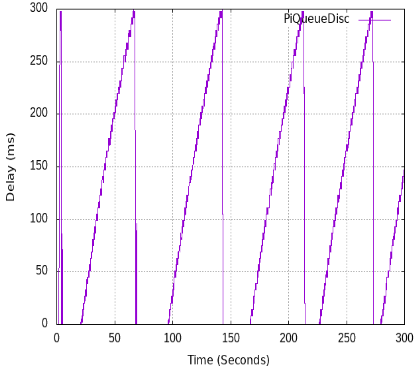
1. When value of drop probability is greater than equal to uniform random variable.

❒ How to Mark a packet?

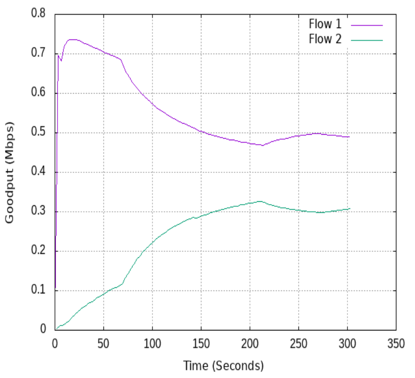
1. Forced Mark : To mark a packet we have to set the ECN bit.

Evaluation of PI Queue Disc : Mild Congestion in AQM suite

Delay vs Time

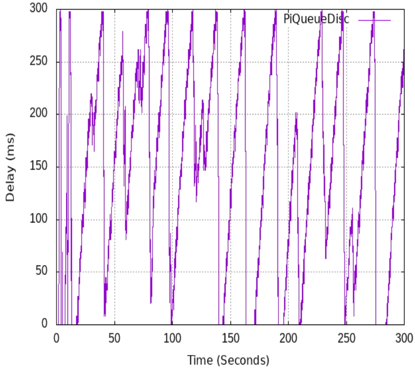


Good put vs Time



Evaluation of PI Queue Disc : Medium Congestion in AQM suite

Delay vs Time



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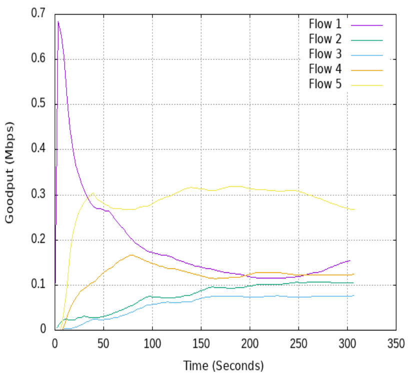
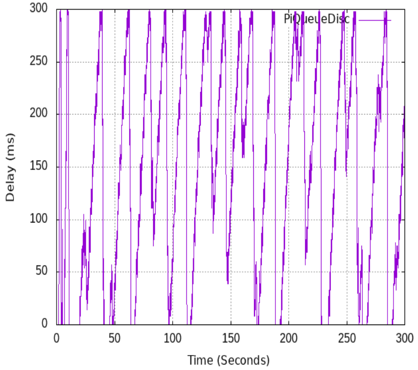
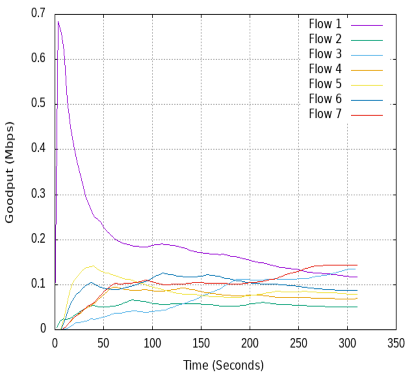


Evaluation of PI Queue Disc : Heavy Congestion in AQM suite

Delay vs Time



Good put vs Time



Conclusion

- How PI queue disc provides a solution to the congestion.
- It works well for some network condition but does not perform well in some other network condition.
- It usuages some constant scaling factor like α and β for adjusting the controller response .
- Self Tuning PI controller indeed needed.

Bibliography

- Vivek Jain, Viyom Mittal, Shravya K. S., Mohit P. Tahiliani , Wireless Information Networking Group (WiNG), Department of Computer Science and Engineering NITK Surathkal, Mangalore, Karnataka 575025, India et al, BLUE and PI :" Implementation and validation of BLUE and PI queue disciplines in ns-3",Simulation Modelling Practice and Theory 84 (2018) 19–37.
- Dynamic Video Content Streaming, Adnan Shaout : https://www.researchgate.net/figure/Network-congestion-effects_fig1_258163957
- B. Braden , D. Clark , J. Crowcroft , B. Davie , S. Deering , D. Estrin , S. Floyd , V. Jacobson , G. Minshall , C. Partridge , et al. , Recommendations on Queue Management and Congestion Avoidance in the Internet, Technical Report, IETF, 1998 .
- PID controller from wiki pedia : https://en.wikipedia.org/wiki/PID_controller
- C.V. Hollot , V. Misra , D. Towsley , W.-B. Gong , "On designing improved controllers for AQM routers supporting TCP flows ", in: Proceedings of the Twen- tieth Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2001), 3, IEEE, 2001, pp. 1726–1734 .
- Honggang Zhang, C. V. Hollot, Don Towsley ,Department of Computer Science ,University of Massachusetts at Amherst and Vishal Misra ,Department of Computer Science, Columbia University, USA. et al. Self Tuning PI :"A Self-Tuning Structure for Adaptation in TCP/AQM Networks.",IEEE, 2013, pp. 148–155 .
- My Gitlab Repository : https://gitlab.com/PranabNandy/ns-3-dev/-/commits/PI

Thank You