ABSTRACT

KEYWORDS: Random Early Detection, Proportional Integral policy, Compound TCP, FAST TCP, stability, bifurcation

Bufferbloat–large and persistently full buffers–is leading to an increase in queueing delays across the Internet. Today's routers employ the Drop-Tail policy, which drops packets only after the buffer is full. Transmission Control Protocol (TCP), a fundamental transport protocol of the Internet, sends packets until packet loss is detected, and reduces its sending rate upon detecting a packet loss. With Drop-Tail at the routers, packets from TCP sources end up occupying the entire buffer, as TCP is likely to encounter packet loss only after the buffer is full. Such filling of buffers leads to large queueing delays. This problem necessitates the study of TCP in the end systems, and queue management at the routers.

Recent studies emphasise the need for an effective Active Queue Management (AQM) strategy to mitigate bufferbloat. Many AQM strategies have been proposed for deployment at the routers. Prior to their deployment, these AQM proposals must be evaluated with respect to currently deployed protocols. We consider two queue policies, namely (i) Random Early Detection (RED), and (ii) Proportional Integral (PI) queue policy. RED, one of the earliest AQM proposals, is implemented in Internet routers. However, owing to the lack of design guidelines, RED has not been deployed so far. The PI policy is inspired from the classical PI controller, which is used in various applications. We study the performance of these two AQMs with Compound TCP (default in Windows).

AQMs are required to provide congestion feedback to TCP, such that queueing delay is minimised while not dropping too many packets. This must be ensured despite variations in other parameters, such as the feedback delay. This requires the TCP-AQM systems to be stable. Hence, performance evaluation must incorporate the study of system stability. We begin by analysing the stability of the Compound TCP-AQM systems. We outline a non-linear time-delayed model for these systems by combining the (i) fluid model for Compound TCP, (ii) relevant queueing model, and (iii) a model for packet-drop probability decided by the AQM. Local stability of this model is seen to be

dependent on the feedback delay, as well as protocol and AQM parameters. The stability results yield design guidelines. In particular, we highlight that small packet-dropping thresholds could aid stability. Due to the non-linear nature of TCP-AQM systems, loss of stability could lead to limit cycles that could manifest as queue size oscillations, that can cause synchronisation of TCP flows and impact network performance. Thus, it is important to study the transition of the system into instability. We use bifurcation theory to study the loss of local stability, and analyse the system dynamics in the unstable regime. Our study reveals some basic limitations of the two AQMs we consider. The analytical insight is corroborated with packet-level simulations, which indeed depict queue size oscillations and loss of link utilisation as stability conditions are violated.

Analysis and simulations of Compound TCP-AQM systems predict that small packet-dropping thresholds could aid stability. Thus, we propose a simple threshold-based queue policy, that can be tuned to ensure small queues. We establish that local stability, of Compound TCP with this policy, does not depend explicitly on the feedback delay, and can be ensured by the co-design of protocol parameters and queue threshold. We also conduct a simulation-based performance evaluation to compare RED and PI with the threshold policy. The threshold-based policy outperforms both RED and PI, in terms of queueing delay, packet loss, throughput and flow completion time.

If the threshold-based policy is to be deployed at the routers, it must guarantee stable operation with new TCP proposals as well. FAST TCP is a new proposal for delay-based TCP, that has attracted significant research interest. Notably, it is not specifically designed for a regime of small queues, that the threshold policy ensures. Thus, we investigate how FAST TCP would operate in this regime. We begin by analysing various models for FAST TCP with Drop-Tail (currently deployed). Large feedback delay is shown to destabilise the system. We then propose a fluid model for FAST TCP in the regime of small queues–applicable when the threshold policy is deployed. We establish that, in this regime, stability of FAST TCP is independent of feedback delay and can be achieved by appropriate choice of queue threshold. Packet-level simulations reveal that FAST TCP, with small thresholds, is indeed stable. Through a combination of analysis and simulations, we thus establish that the threshold-based queue policy could guarantee stability, while mitigating queueing delays, when deployed at Internet routers.