

11 Conclusions

In this dissertation, we have studied the performance of a class of TCP end-to-end congestion avoidance algorithms (i.e., DCA algorithms) which use an increase in a packet RTT as an indicator of congestion and future packet loss. We have provided significant evidence that supports our claim that DCA cannot be incrementally deployed over high speed Internet paths.

An incrementally deployable enhancement to TCP must reflect the following attributes:

- It must improve the throughput of the TCP connection that employs the enhancement.
- It should not reduce the performance of other competing TCP flows on the same path where the “enhanced” TCP flow travels.
- Ideally it requires changes only to a TCP sender.

Due to the economics associated with deploying change within an existing network, we assume that an incrementally deployable change must provide benefits for a single deployment. If this is not true, the chances of deployment drop drastically. We have presented strong evidence suggesting that there are no benefits to deploying a single DCA flow. In fact, we have shown that, for at least one simulated Internet environment, DCA must contribute greater than 10% of the total traffic at a congested link in order to significantly reduce the loss rate at the router. We also saw that in the same congested environment, even when 95% of all the traffic is DCA, DCA is not able to significantly reduce the average queue level.

In our analysis, we set the TCP maximum receiver’s advertised window to a maximum of 16Kbytes. The average throughput for the best performing path in our analysis was less than 1.5 Mbps. Based on measurements, we have deduced that the link capacity at the bottleneck link is at least 45 Mbps. This implies that we have studied DCA for flows that consume at most 3% of the bandwidth. In fact, we found that the DCA flow under observation generally contribute less than .5% of the total traffic that arrives at any given router.

Through measurement analysis and simulation, we have found that:

- DCA will not improve the throughput of the connection (as compared to an unmodified TCP/Reno connection). The fundamental problem is that increases in RTT cannot be used to reliably predict future packet loss events. There are two reasons for this.
 - ◆ A TCP constrained RTT congestion probe is too coarse to accurately track the bursty congestion associated with packet loss over high speed paths.
 - ◆ A DCA algorithm cannot differentiate between the significant number of increases in RTT that are not associated with packet loss from those increases that do lead to packet loss.
- The congestion reactions of a DCA flow will not significantly reduce the congestion level at the bottleneck links. This is mainly because the contribution of the flow is a fraction of the total traffic level at the congested link.

The major contribution of this dissertation is to provide evidence that DCA is not able to reliably avoid packet loss. As a result, we claim that DCA will usually lead to degraded throughput. The dynamics associated with many aggregate, ON/OFF TCP connections leads to highly bursty traffic arrival processes with time scales that span several orders of magnitude. The switches that are deployed throughout the Internet are generally provisioned with a large amount of memory (i.e., buffers) to handle the tremendous variation associated with the traffic arrival processes. The result is that RTT variations are quite common over the Internet and in fact generally are not associated with packet loss. Therefore, even though we have seen that loss is generally accompanied by some level of increase in RTT, the loss in throughput caused by frequent DCA reactions to RTT increase outweighs the benefits of fewer dropped packets.

In summary, when running under high speed networks and the traffic associated with a flow consumes only a fraction of total bandwidth, DCA does not reduce packet losses nor the congestion level. Instead, the result is throughput degradation. Although proposed DCA algorithms may satisfy the second and third requirements of incremental deployability, it does not satisfy the first condition. Thus, we hereby present our thesis.

The work of [BIAZ98] attempts a similar study but focuses on set of particular algorithms in a limited environment (i.e., a wireless environment). In order to evaluate the effectiveness of the fundamental congestion control properties of DCA, we studied the relationship between increases in RTT and loss events. We focused on a TCP constrained RTT sampling process and the effectiveness of a DCA algorithm to be able to react to the congestion indications in time to prevent loss.

The work of [MOON99] also focuses on understanding the level of correlation between increases in packet delays and loss events. Their intent was to explore if a loss could be predicted by an end-to-end probe. The loss conditioned delay correlation metric results shown in [MOON99] illustrate a higher level of correlation than our results. The difference between our methodology and that used by [MOON99] explains the different results:

- In our analysis, the reference point used in the calculation of the loss conditioned delay correlation (i.e., lag 0) is the time that the dropped packet is originally transmitted. In [MOON99], lag 0 is the time of the actual loss. Our results become more similar to those of [MOON99] when we move the reference point forward in time so that lag 0 is the time that the dropped packet is retransmitted.
- Our probe is based on TCP-constrained RTT-based samples while the probe used in [MOON99] was much finer grained sampling process (probes emitted every 20 milliseconds). We conjecture that during times of congestion, the [MOON99] probe packets will accumulate and bunch up at the points of congestion. The resulting level of loss conditioned delay correlation surrounding the loss event can lead to misleading data that can indicate a higher level of correlation than what really exists.

The work done in [BRAK94, AHN95] focuses on low speed paths while we are interest was high speed Internet paths. Furthermore, these studies have not studied the contribution of the CAM algorithm compared to the enhanced loss recovery algorithm. While the studies of Vegas confirm that the behavior of Vegas digresses to that of Reno as congestion levels build, no one has supplied the intuition that completely explains this as we have in our simulation analysis.

12 Future Work

We identify the following research issues that are required to complete the study of DCA:

- Our definition of DCA was limited to a congestion detection mechanism based on TCP RTT samples. We conjecture that our results also hold for one-way probe mechanisms, but this needs to be proven.
- We have not studied the behavior of DCA when the flow is high bandwidth and consumes a significant amount of resources at the bottleneck router.
- Similarly, we have not studied low speed links. We conjecture that DCA would be much more effective over paths where there is a single, low speed bottleneck link. For example, it would be interesting to study the benefits of DCA in either a branch office environment where the Internet access link is either a T1 leased line or a DSL service.
- We have presented evidence that enhanced loss recovery algorithms, such as NewReno, can be effective at improving TCP throughput. A thorough study of such a change is necessary. The study needs to consider the impact of making all TCP flows “more effective” at utilizing available bandwidth. A concern is that during times of congestion, algorithms such as NewReno essentially become more aggressive. Fairness and stability issues needs to be studied.
- We have not studied DCA from a “global” performance perspective. For example, we might modify the objective of DCA such that the goal is to minimize the queue levels within the network. The interesting research issue becomes, if we assume that the majority of traffic flowing over the Internet consists of DCA flows, can DCA improve Internet QoS ?
- The future of the Internet appears to be Differentiated Services possibly incorporating explicit feedback. A complete study of DCA must include a comparison to alternatives such as RED/ECN. We conjecture that RED/ECN solves the many of the problems that limit the effectiveness of DCA over high speed paths. However, we also conjecture that the feedback loop delays and the bursty nature of congestion over the Internet are still significant problems for RED/ECN.

Aside from the issues directly related to DCA and protocol performance, our work has raised interesting questions in the area of protocol analysis and modeling. The methodology we utilized is based on a

combination of measurements and simulation. Our simulation models are based on carefully designed background traffic flows designed to create end-to-end dynamics that match the dynamics of traced TCP connections over the Internet paths that were being modeled. It is unclear how accurate the models actually are. There is a need for a better understanding of the congestion dynamics that occur at high speed Internet switches.