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TCP Alternative Backoff with ECN (ABE)  
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## Abstract

This memo provides an experimental update to RFC3168. It updates the TCP sender-side reaction to a congestion notification received via Explicit Congestion Notification (ECN). ECN-marking can allow a network device to signal congestion at a point before a transport experiences congestion loss or additional queueing delay. The updated method is less conservative than the TCP reaction in response to loss. The intention is to achieve good throughput when the queue at the bottleneck is smaller than the bandwidth-delay-product of the connection. This is more likely when an Active Queue Management (AQM) mechanism has used ECN to CE-mark a packet, than when a packet was lost. Future versions of this document will discuss SCTP as well as other transports using ECN.

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## Table of Contents

1. Introduction . . . . .	2
2. Discussion . . . . .	3
2.1. Why use ECN to vary the degree of backoff? . . . . .	4
2.2. Choice of ABE multiplier . . . . .	5
3. Updating the Sender-side ECN Reaction . . . . .	6
3.1. RFC 2119 . . . . .	6
3.2. Update to RFC 3168 . . . . .	6
3.3. Status of the Update . . . . .	6
4. Acknowledgements . . . . .	7
5. IANA Considerations . . . . .	7
6. Security Considerations . . . . .	7
7. References . . . . .	8
7.1. Normative References . . . . .	8
7.2. Informative References . . . . .	8
Authors' Addresses . . . . .	9

## 1. Introduction

Explicit Congestion Notification (ECN) is specified in [RFC3168]. It allows a network device that uses Active Queue Management (AQM) to set the congestion experienced, CE, codepoint in the ECN field of the IP packet header, rather than to drop ECN-capable packets when incipient congestion is detected. When an ECN-capable transport is used over a path that supports ECN, it provides the opportunity for flows to improve their performance in the presence of incipient congestion [I-D.AQM-ECN-benefits].

[RFC3168] not only specifies the router use of the ECN field, it also specifies a TCP procedure for using ECN. This states that a TCP sender should treat the ECN indication of congestion in the same way as that of a non-ECN-Capable TCP flow experiencing loss, by halving

the congestion window "cwnd" and by reducing the slow start threshold "sssthresh". [RFC5681] stipulates that TCP congestion control sets "sssthresh" to  $\max(\text{FlightSize} / 2, 2 * \text{SMSS})$  in response to packet loss. Consequently, a non-ECN enabled standard TCP flow using this reaction needs significant network queue space: it can only fully utilize a bottleneck when the length of the link queue (or the AQM dropping threshold) is at least the bandwidth-delay product (BDP) of the flow.

A backoff multiplier of 0.5 (halving cwnd and sssthresh after packet loss) is not the only available strategy. As defined in [ID.CUBIC], CUBIC multiplies the current cwnd by 0.8 in response to loss (although the Linux implementation of CUBIC has used a multiplier of 0.7 since kernel version 2.6.25 released in 2008). Consequently, CUBIC flows more fully utilize paths even when the bottleneck queue is slightly shorter than the bandwidth-delay product of the flow. However, in the case of a DropTail (FIFO) queue without AQM, such less-aggressive backoff increases the risk of creating a standing queue [CODEL2012].

Devices implementing AQM are likely to be the dominant (and possibly only) source of ECN CE-marking for packets from ECN-capable senders. AQM mechanisms typically strive to maintain a small queue length, regardless of the bandwidth-delay product of flows passing through them. Receipt of an ECN CE-mark might therefore reasonably be taken to indicate that a small bottleneck queue exists in the path, and hence the TCP flow would benefit from using a less aggressive backoff multiplier.

Results reported in [ABE2015] show significant benefits (improved throughput, resulting in reduced completion times for short flows) when reacting to ECN-Echo by multiplying cwnd and sssthresh with a value in the range [0.7..0.85]. Section 2 describes the rationale for this change. Section 3 specifies a change to the TCP sender backoff behaviour in response to an indication that CE-marks have been received by the receiver.

## 2. Discussion

Much of the background to this proposal can be found in [ABE2015]. Using a mix of experiments, theory and simulations with standard NewReno and CUBIC, [ABE2015] recommends enabling ECN and "...letting individual TCP senders use a larger multiplicative decrease factor in reaction to ECN CE-marks from AQM-enabled bottlenecks." Such a change is noted to result in "...significant performance gains in lightly-multiplexed scenarios, without losing the delay-reduction benefits of deploying CoDel or PIE."

### 2.1. Why use ECN to vary the degree of backoff?

The classic rule-of-thumb dictates a BDP of bottleneck buffering if a TCP connection wishes to optimise path utilisation. A single TCP connection running through such a bottleneck will have opened cwnd up to  $2 \times \text{BDP}$  by the time packet loss occurs. [RFC5681]'s halving of cwnd and ssthresh pushes the TCP connection back to allowing only a BDP of packets in flight -- just enough to maintain 100% utilisation of the network path.

AQM schemes like CoDel and PIE use congestion notifications to constrain the queuing delays experienced by packets, rather than in response to impending or actual bottleneck buffer exhaustion. With current default delay targets, CoDel and PIE both effectively emulate a shallow buffered bottleneck (section II, [ABE2015]). This interacts acceptably for TCP connections over low BDP paths, or highly multiplexed scenarios (many concurrent TCP connections). However, it interacts badly with lightly-multiplexed cases (few concurrent connections) over high BDP paths. Conventional TCP backoff in such cases leads to gaps in packet transmission and underutilisation of the path.

In an ideal world, the TCP sender would adapt its backoff strategy to match the effective depth at which a bottleneck begins indicating congestion. In the practical world, [ABE2015] proposes using the existence of ECN CE-marks to infer whether a path's bottleneck is AQM-enabled (shallow queue) or classic DropTail (deep queue), and adjust backoff accordingly. This results in a change to the requirements of [RFC3168], which required TCP senders to respond the same following indication of a received ECN CE-mark and a packet loss, making these equivalent signals of congestion. (The idea to change this behaviour pre-dates ABE. [ICC2002] also proposed using ECN CE-marks to modify TCP congestion control behaviour, using a larger multiplicative decrease factor in conjunction with a smaller additive increase factor to deal with RED-based bottlenecks that were not necessarily configured to emulate a shallow queue.)

[RFC7567] states that "deployed AQM algorithms SHOULD support Explicit Congestion Notification (ECN) as well as loss to signal congestion to endpoints" and [I-D.AQM-ECN-benefits] encourages this deployment. Apple recently announced their intention to enable ECN in iOS 9 and OS X 10.11 devices [WWDC2015]. By 2014, server-side ECN negotiation was observed to be provided by the majority of the top million web servers [PAM2015], and only 0.5% of websites incurred additional connection setup latency using RFC3168-compliant ECN-fallback mechanisms.

## 2.2. Choice of ABE multiplier

ABE decouples a TCP sender's reaction to loss and ECN CE-marks. The description respectively uses  $\beta_{\text{loss}}$  and  $\beta_{\text{ecn}}$  to refer to the multiplicative decrease factors applied in response to packet loss and in response to an indication of a received CN CE-mark on an ECN-enabled TCP connection (based on the terms used in [ABE2015]). For non-ECN-enabled TCP connections, no ECN CE-marks are received and only  $\beta_{\text{loss}}$  applies.

In other words, in response to detected loss:

$$\text{cwnd}_{(n+1)} = \text{cwnd}_n * \beta_{\text{loss}}$$

and in response to an indication of a received ECN CE-mark:

$$\text{cwnd}_{(n+1)} = \text{cwnd}_n * \beta_{\text{ecn}}$$

The higher the values of  $\beta_{*}$ , the less aggressive the response of any individual backoff event.

The appropriate choice for  $\beta_{\text{loss}}$  and  $\beta_{\text{ecn}}$  values is a balancing act between path utilisation and draining the bottleneck queue. More aggressive backoff (smaller  $\beta_{*}$ ) risks underutilising the path, while less aggressive backoff (larger  $\beta_{*}$ ) can result in slower draining of the bottleneck queue.

The Internet is already running with at least two different  $\beta_{\text{loss}}$  values, [RFC5681]'s 0.5, and Linux CUBIC's 0.7. ABE proposes no change to  $\beta_{\text{loss}}$  used by any current TCP implementations.

$\beta_{\text{ecn}}$  depends on how we want to optimise the response of a TCP connection to shallow AQM marking thresholds.  $\beta_{\text{loss}}$  reflects the preferred response of each TCP algorithm when faced with exhaustion of buffers (of unknown depth) signalled by packet loss. Consequently, for any given TCP algorithm the choice of  $\beta_{\text{ecn}}$  is likely to be algorithm-specific, rather than a constant multiple of the algorithm's existing  $\beta_{\text{loss}}$ .

A range of experiments (section IV, [ABE2015]) with NewReno and CUBIC over CoDel and PIE in lightly multiplexed scenarios have explored this choice of parameter. These experiments indicate that CUBIC connections benefit from  $\beta_{\text{ecn}}$  of 0.85 (cf.  $\beta_{\text{loss}} = 0.7$ ), and NewReno connections see improvements with  $\beta_{\text{ecn}}$  in the range 0.7 to 0.85 (c.f.,  $\beta_{\text{loss}} = 0.5$ ).

### 3. Updating the Sender-side ECN Reaction

This section specifies an experimental update to [RFC3168].

#### 3.1. RFC 2119

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

#### 3.2. Update to RFC 3168

This document specifies an update to the TCP sender reaction that follows when the TCP receiver signals that ECN CE-marked packets have been received.

The first paragraph of Section 6.1.2, "The TCP Sender", in [RFC3168] contains the following text:

"If the sender receives an ECN-Echo (ECE) ACK packet (that is, an ACK packet with the ECN-Echo flag set in the TCP header), then the sender knows that congestion was encountered in the network on the path from the sender to the receiver. The indication of congestion should be treated just as a congestion loss in non-ECN-Capable TCP. That is, the TCP source halves the congestion window "cwnd" and reduces the slow start threshold "ssthresh"."

This memo updates this by replacing this with the following text:

"If the sender receives an ECN-Echo (ECE) ACK packet (that is, an ACK packet with the ECN-Echo flag set in the TCP header), then the sender knows that congestion was encountered in the network on the path from the sender to the receiver. The indication of congestion SHOULD induce a less conservative reaction than loss: the TCP source multiplies the congestion window 'cwnd' with 0.8 and reduces the slow start threshold 'ssthresh'."

#### 3.3. Status of the Update

XXX Author's note: Once ICCRG evaluation has been completed an appropriate outcome may be inserted here XXX

The congestion control behaviour specified in this update will be evaluated by the IRTF Internet Congestion Control Research Group (ICCRG), to determine whether it is thought safe for deployment in the general Internet.

XXX Author's note: If this is adopted for publication as an Experimental RFC we need to explain why this is not PS XXX

The present specification has been assigned an Experimental status, because this is common practice for first introduction of changes to the TCP protocol specification, where deployment experience is usually required prior to publishing a Standards-Track document.

This update is a sender-side only change. Like other changes to congestion-control algorithms it does not require any change to the TCP receiver or to network devices (except to enable an ECN-marking algorithm [RFC3168] [RFC7567]). If the method is only deployed by some TCP senders, and not by others, the senders that use this method can gain advantage, possibly at the expense of other flows that do not use this updated method. This advantage applies only to ECN-marked packets and not to loss indications. Hence, the new method can not lead to congestion collapse.

#### 4. Acknowledgements

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#### 5. IANA Considerations

XX RFC ED - PLEASE REMOVE THIS SECTION XXX

This memo includes no request to IANA.

#### 6. Security Considerations

The described method is a sender-side only transport change, and does not change the protocol messages exchanged. The security considerations of RFC 3819 therefore still apply.

This document describes a change to TCP congestion control that can make TCP senders more aggressive than flows using TCP as specified in RFC 3819. This could lead to a change in the capacity achieved by flows sharing a network bottleneck. If some flows use this method and share capacity with other flows using previous methods this could reduce fairness in the capacity allocation. Similar unfairness is also exhibited by other congestion control mechanisms that have been

in use in the Internet for many years (e.g., CUBIC [ID.CUBIC]). Unfairness may also be a result of other factors, including the round trip time experienced by a flow. This advantage applies only to ECN-marked packets and not to loss indications, and will therefore can not lead to congestion collapse.

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