Router participation in Congestion Control

Techniques
- Random Early Detection
- Explicit Congestion Notification
Early congestion notifications

“Early” notifications inform end-systems that the network is “congested” before buffers overflow in network elements (routers).

- Excessive delay may be considered to reflect congestion, not just packet loss
- Sources will take some time to respond to notifications
  ⇒ early notifications may enable congestion (buffer overflow) “avoidance”

Two forms of early notifications:
- Discard: “Active Queue Management (AQM)”
- Explicit Congestion Notifications
Active Queue Management (AQM)

- **Switches drop packets** to notify ends of imminent congestion.
  - Notification has same form as buffer overflow ⇒ can exploit existing end-system responses.
- **The hope** is that the early discard causes sources to slow down before the buffer overflows (causing high loss rates).
- **This assumes** that sources slow down in response to packet loss.
  - i.e. layer interdependence: the network layer depends on certain transport protocols being used.

Details in RFC 2309
Random Early Detection† (RED)

Discard arriving packets with a probability that increases\(^1\) linearly with the average\(^2\) queue length.

1. **Increasing** discard rate with queue length indicates severity of congestion and penalises sources that don’t slow down.

2. **Averaging** the queue length rather than using instantaneous measurement allows limited bursts to pass, accommodating TCP’s Slow Start

\[\text{Discard probability} = \begin{cases} 0 & \text{for } \text{min}_\text{th} \leq \text{Average queue length} < \text{max}_\text{th} \\ 1 & \text{for } \text{Average queue length} \geq \text{max}_\text{th} \end{cases}\]

† A form of AQM. Sometimes called “Random Early Discard”/drop
Slow Start produces bursts

⇒ Router buffering strategies must accommodate short bursts (else source will never reach steady state) ⇒ RED

Figure from S. Seshan
RED variant references

T. Ott, T. Lakshman and L. Wong: “SRED: Stabilized RED,”

J. Aweya, M. Ouellette and D. Montuno: “A Control
Theoretic Approach to Active Queue Management,”

B. Wydrowski and M. Zukerman: “GREEN: an active queue
management algorithm for a self managed Internet”,
Proc. ICC, pp. 2368-72, May 2002

W. Feng, A. Kapadia and S. Thulasidasan: “GREEN:
proactive queue management over a best-effort

W. Feng et al., “BLUE: A New Class of Active Queue
Management Algorithms,” Technical Report CSE-TR-

G. Chatranon, M. A. Labrador, and S. Banerjee, “BLACK:
Detection and Preferential Dropping of High Bandwidth
664–668.
Outline
Explicit Congestion Notification

Motivation:
- Early discard is crude:
  - wastes bandwidth: packets propagate from source to congested router, only to be discarded.
  - increases packet loss
- May be better for routers to explicitly inform sources (through an ECN signal rather than packet loss) that they are getting congested.

Limitation of ECN:
- Presence of ECN indicates congestion
- Absence of ECN doesn’t prove non-congestion (congestion might have resulted in ECN signal being lost)
  ⇒ sources still have to treat loss as a congestion indicator
  ⇒ sources still can’t determine cause (congestion/transmission error) of loss
ECN mechanisms

Router could directly tell the source:
- Send a new packet to the source
  But that would create extra network traffic during times of congestion (Early Internet had “Source quench”, but that has been deprecated.)
- Set a field in a packet already going to the source ("Backward ECN")
  Router has to remember which sources are contributing to its congestion (⇒ scalability problem), while waiting to observe packets being sent to those sources (to piggyback signal on)
  ⇒ Used by Frame Relay, but not the Internet
Router could tell destination, and destination (if it receives the packet) tells source.
  "Forward ECN", used by Frame Relay, and now the Internet.
ECN in the Internet

IP header was: (CU=Currently Unused)

Becomes:

<table>
<thead>
<tr>
<th>ECT</th>
<th>CE</th>
</tr>
</thead>
</table>
| 0   | 0  | Not-ECT
| 0   | 1  | ECT(1)
| 1   | 0  | ECT(0)
| 1   | 1  | CE
2 ECN bits

Ends support ECN?

Yes

Congestion experienced?

Yes

Code from source

0

No

4 code points = 2 ECN bits

No
ECN in the Internet Protocol

The 2 ECN bits indicate:

- **Traditional Not-ECT**
  - Router only changes ECN field if set to ECT(1) or ECT(0)
  - Traditional receivers check that reserved bits are set to 0

- **Congestion Experienced (CE)**

- **ECN-Capable Transport (ECT)**
  - If ECT is set and router is experiencing congestion, router may change ECN field to CE, rather than discarding the packet.
  - Why 2 codepoints? See slide “Detect lying with 2 ECT values”

<table>
<thead>
<tr>
<th>ECN FIELD</th>
<th>ECT</th>
<th>CE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not-ECT</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ECT(1)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>ECT(0)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>CE</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

RFC 3168 (obsoletes RFC 2481)
Details: Transport reaction to ECN

Routers set only if ends sure to detect: “an ECT codepoint MUST NOT be set in a packet unless the loss of that packet in the network would be detected by the end nodes and interpreted as an indication of congestion.” [3168]

e.g. don’t set it in pure (not piggybacked) ACKs, since ACKs are cumulative: loss of one may escape notice if next one comes soon

Source reacts once per RTT to ECN: “end-systems should react to congestion at most once per window of data (i.e., at most once per round-trip time), to avoid reacting multiple times to multiple indications of congestion within a round-trip time.” [3168]

Source reacts to CE as if a single packet were lost:
“the congestion control algorithms followed at the end-systems MUST be essentially the same as the congestion control response to a *single* dropped packet.” [3168]

Traditional sources could receive unfair treatment if routers perform early discard to signal congestion rather than marking CE

End systems need to negotiate whether to use ECN.
Source that mistakenly thinks that destination is ECN-capable may penalise dest’n for making false reports about no CE
TCP’s Reserved field shrinks by 2 bits to indicate:

- **ECN-Echo (ECE):** Echoes to source receipt of CE. Destination continues setting ECE in ACKs until it receives CWR from source (in case ACKs are lost).

- **Congestion Window Reduced (CWR):** Source informs destination that window has been reduced. Destination need no longer echo previous CE.

In SYN segments: ECE&CWR ⇒ ECN capable
Typical series of events

1. Source establishes connection with destination, and negotiates to use ECN.
2. Source sends segments with IP=ECT, CWR=0
3. “congested” router changes IP=ECT to CE. Router:
   - Doesn’t process TCP fields
   - Likely marks all segments received while congested with IP=CE. Source will only reduce rate for one segment, but marking all segments expedites signal when segments get lost.
4. TCP destination receives segment, sends ACK, ECE=1 Keeps setting ECE=1 for all acks until step 6.
5. Source receives ACK with ECE=1, reduces congestion window. Sends segment with CWR=1 (IP=ECT).
6. Destination receives segment with CWR=1, and sends ACK with ECE depending on IP field of segment:
   1. IP=CE ⇒ router still congested ⇒ ECE=1
   2. IP=ECT ⇒ router no longer congested ⇒ ECE=0
Detect lying with 2 ECT values

- One ECT value allows a router to determine whether end-systems support CE markings.
- But uncooperative routers/destinations might suppress CE markings (e.g. greedy destination that wants to maximise its rate without regard to network congestion)
- Two ECT values allow a source to check the destination’s reporting of CE markings.
  - Source varies ECT 0/1 value according to a pattern that it alone knows (e.g. pseudorandom) – “nonce”
  - Destination must return the pattern back to the source, e.g. using a new “Nonce Sum” TCP header field (sum of ECT(x) fields received).
  - Routers overwrite ECT when setting CE, preventing receiver from returning pattern to source ⇒ source can detect CE, despite lying/uncooperative nodes

For details, see RFC 3540
ECN summary

- Reduces waste from loss
- Can’t entirely replace loss as a congestion indicator, since during extreme congestion loss may prevent ECN carriage.
- Router marks packets as having experienced congestion; destination signals to source to reduce rate.
- IP’s coding (using 2b)
  - provides backwards compatibility with non-ECN capable transport.
  - enables a source to detect false reporting.