Congestion Control, Active Queue Management & Bufferbloat

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CSE, UNSW, 2014-04-16

NICTA Funding and Supporting Members and Partners

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- Introduction
- Congestion Control
- Bufferbloat
- Active Queue Management
- Fighting Bufferbloat
- Conclusion

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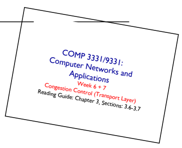
Introduction



Transport **end-to-end** congestion control adjusts throughput to fairly share available capacity[1]

Network **best effort** forwarding of all received packets

"Just works"
- ... does it?
- How much effort is best effort?
- Failure cases: Bufferbloat
  - Why does everything slow down during large file transfers?

This lecture
- Congestion signals/control model
- More network involvement in throughput control
- Bufferbloat and solutions

[1] Beware of "bandwidth": radio spectrum?

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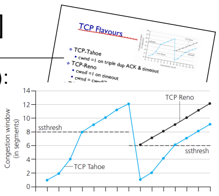
TCP NewReno reminder [3]



- **Slow-start** (*cwnd* $<$ *ssthresh*): *cwnd* $\leftarrow 2 \times$ *cwnd* every RTT (or *cwnd* $+ 1$ on every ACK)
- **Congestion avoidance** (*cwnd* $>$ *ssthresh*): *cwnd* $\leftarrow$ *cwnd* $+ 1/$*cwnd* on every ACK (or *cwnd* $+ 1$ every RTT)
- Losses
  - **Fast retransmit** *cwnd*, *ssthresh* $\leftarrow$ *cwnd*$/2$ on triple dup-ACK (a.k.a. losses … or something else?)
  - **Fast recovery** *cwnd* $\leftarrow$ *ssthresh* $+ n_{\text{dupack}}$ for isolated losses
  - *cwnd* $\leftarrow 1$, *ssthresh* $\leftarrow$ *cwnd*$/2$ on timeout
- Generalised $AIMD(a, b)$ [4]
  - CA: *cwnd* $\leftarrow$ *cwnd* $+ a$
  - **Loss**: *cwnd* $\leftarrow (1 - b)$*cwnd*
  - NewReno: $a = 1, b = 1/2$

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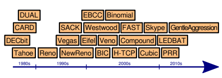
Congestion Control
TCP Variants

- World of TCP CC not uniform
- Default implementations in OSes vary
  - Mac OS X, FreeBSD, OpenBSD: NewReno
  - Linux: CUBIC ($\geq$ 2.6.19)
  - Windows: Compound ($\geq$Vista), Westwood+
  - Many more options in research

- Other congestion control: Vegas, HSTCP, Hybla, TFRC…
- Other transports: DCCP, SCTP, LEDBAT, …



Source: K. Winstein, N. Sivaraman, P. Thaker and H. Balakrishnan. **Transport Architectures for an Evolving Internet**. Mar. 2014. URL: http://www.ietf.org/proceedings/89/slides/slides-89-irtfopen-0.pdf

- Let's stick to TCP CC here!

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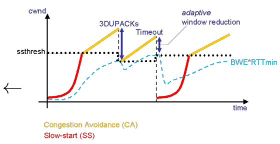
Congestion Control
TCP Variants

Westwood+ use capacity estimate on loss *cwnd*, *sshthresh* $\leftarrow$ $RTT \times BWE$



Source: http://c3lab.poliba.it/index.php/Westwood, [6]

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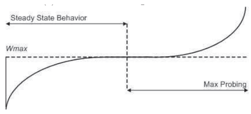
Westwood+ use capacity estimate on loss

CUBIC cubic equation flattening around last $cwnd = W_{\max}$, $cwnd \leftarrow C(t-K)^3 + W_{\max}$



S. Ha, I. Rhee and L. Xu. "CUBIC: A New TCP-friendly High-speed TCP Variant". In: **ACM SIGOPS Operating Systems Review** 42.5 (July 2008)

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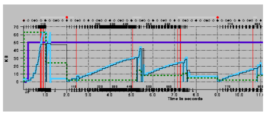
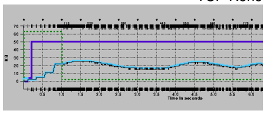
Vegas react to changes in delay



TCP Reno



TCP Vegas

Source: https://www.cs.arizona.edu/projects/protocols/

$RTT_{\text{base}} = \min(RTT)$

$Expected = cwnd / RTT_{\text{base}}$

$Diff = Expected - transferred / RTT_{\text{current}}$

$$cwnd \leftarrow \begin{cases} cwnd + 1, & \text{if } Diff < \alpha \\ cwnd - 1, & \text{if } Diff > \beta \\ cwnd, & \text{otherwise} \end{cases}$$

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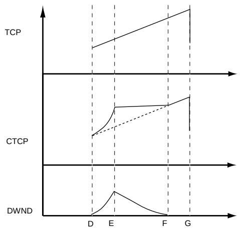
Vegas react to changes in delay

Compound loss-based AIMD & delay-based



K. Tan, J. Song, Q. Zhang and M. Sridharan. "A Compound TCP Approach for High-Speed and Long Distance Networks". In: **INFOCOM 2006**. Apr. 2006

$cwnd \leftarrow cwnd + dwnd$

$$dwnd \leftarrow \begin{cases} dwnd + \begin{cases} \alpha dwnd^k - 1, & \text{if } Diff < \gamma \\ \eta Diff, & \text{if } Diff \geq \gamma \end{cases} \\ dwnd(1-\beta), & \text{on loss } (\ldots\text{MD}) \end{cases}$$

Vegas-ish "AI. . . "

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Vegas react to changes in delay

Compound loss-based AIMD & delay-based

- Three main CC classes
  - loss-based
    - $AIMD(a, b), \forall a, b$
    - quadratic, cubic laws instead of AI. . .
    - estimates instead of . . . MD
  - delay-based
    - compare actual throughputs (ACKs) to expected ($cwnd/RTT$)
    - may reduce *cwnd* without loss
  - hybrids
    - kitchen sink

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Congestion Control
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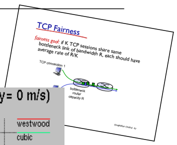
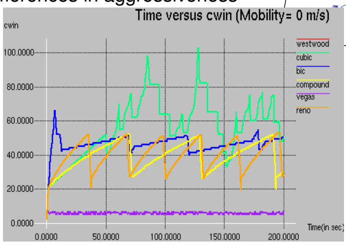
- Not all CC are equal: fairness
- Differences in aggressiveness





Source: M. Jehan, G. Radhamani and T. Kalakumari. "VEGAS: Better Performance Than Other TCP CongestionControl Algorithms on MANETs". In: **International Journal of Computer Networks** 3.2 (May 2011)

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Congestion Control
TCP Variants

- Bottomline: fill the pipe as much as possible
  - *i.e.*, put as many packets in flight as the network can buffer
  - until a loss occurs
  - except for Vegas (delay-based)
- Sounds reasonable: make sure the resource is used fully
- Worked since the 90s

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Bufferbloat
Router design 90s–2011[2]

- Best-effort
- Losses are bad
- Buffers avoid losses during bursts
- Memory is cheap
- Increase buffer size so losses never happen
- Rule-of-thumb: Bandwidth × Delay Product (BDP)

[2] This is slightly caricatured

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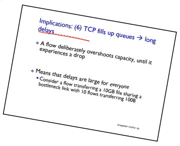
Bufferbloat
Router design 90s–2011

- Are losses really that bad?
- Could they be useful for something?
- How does loss-based CC behave without losses?



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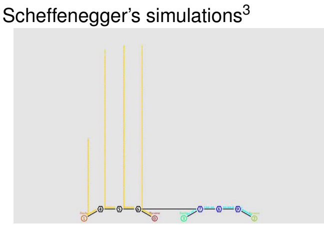
Bufferbloat
Too much buffering is not necessarily best

- Heavy download vs. interactive traffic
- Richard Scheffenegger's simulations[3]



Left: large buffers; Right: small buffers

  - CC doesn't get needed feedback until much later
- Delay (from BDP) at **every** hop

[3] https://lists.bufferbloat.net/pipermail/bloat/2011-February/000082.html

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Bufferbloat[5]
When does it happen?

- Traffic sent from high-speed link to lower-speed link
  - Ethernet to Wi-Fi
  - Ethernet to ADSL
  - Fibre to Ethernet
- Oversized buffers are everywhere
  - Routers
  - Switches
  - Netwok interfaces
  - Network interface drivers
    - Patches for some Linux drivers
- Some CC unaffected: Vegas, LEDBAT[4]
  - Delay-based CC manages to avoid delay (shock!)
  - Get killed by the others, more aggressive, CC

[4] Low Extra Delay BAckground Transport
[5] http://www.bufferbloat.net/

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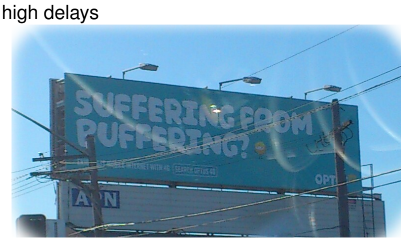
Bufferbloat

- Aggressive CC filling the pipes
- Buffers too large
- High throughput (eventually)
- But high delays



Source: myself (:

- Note: some buffering is good (*e.g.*, to absorb temporary bursts)
- Solutions?
  - Deployable?

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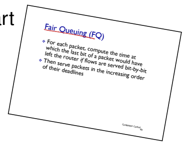
Active Queue Management

Different ways to control traffic rates

Congestion Control smart endpoints, dumb routers (with lots of memory!)

Packet-scheduling (*e.g.*, FQ) very smart routers which manage multiple queues, classify traffic, and distribute it



Active Queue Management smart-ish routers which don't always forward packets

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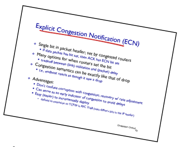
Active Queue Management

Techniques and Objectives

- Simple per-packet rules
  - Selective drops before queues are full
  - Packet-marking (*e.g.*, ECN)



- Variable goals
  - Fairly share limited network capacity
  - Keep queues short (longer $\simeq$ congestion)
  - Limit delays (mitigate Bufferbloat!)

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AQM variants

RED (Random Early Detection [5]) randomly drops/marks **arriving packets** depending on **current queue size**
- Initally hard to configure
- Well known [1]
- Adaptive RED (ARED [2]) automatically adjust most parameters

CoDel (Controlled Delay [10]) drops/marks **outgoing packets** depending on their **sojourn time** in the queue
- Designed for Bufferbloat
- Hardcoded target delay: 5 ms

PIE (Proportional Integral controller Enhanced [11]) randomly drops/marks **arriving packets** depending on their **queueing latency**

***-CoDel** Fair Queueing, SFQ, ...

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Impact of various CC and various AQMs[6]

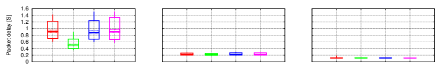
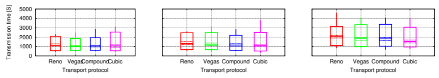


Figure 5: Packet transmission times



(a) DropTail (b) RED (c) CoDel

Figure 6: Time needed to transmit 10 MB

- Least delay introduced by Vegas
- Most delay introduced by CUBIC
- AQMs such as RED and CoDel provide an important reduction in delay
- RED allows to achieve a slightly better throughput

[6] N. Kuhn, E. Lochin and O. Mehani. "Revisiting Old Friends: Is CoDel Really Achieving What RED Cannot?" In: Under review

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- Mainly loss-based congestion control
  - Should we avoid losses...
  - ...or a new congestion collapse?
- Too big buffers lead to Bufferbloat

[7]

  - Rules-of-thumb ($C \times D$) sometimes smash the thumb
  - More is not always better
- Use smarter queue management (*e.g.*, ARED)
- Add some delay dependence

  Layer 4 Vegas, Compound, LEDBAT (w/o AQM!)
  Layer 3-ish Active Queue Management: CoDel, PIE
  - CeroWRT firmware with CoDel variants[8]
- **Consider the whole system you are working with**

Thanks. Questions?

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[7] Source: http://www.fg-a.com/clipart.html
[8] http://www.bufferbloat.net/projects/cerowrt

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Opportunities at Nicta
Come study with us!

- Various options with the Network Research Group
  - Internships
  - Projects (*e.g.*, Hons.)
  - PhD (w/ UNSW)
- Australian Technology Park, near Redfern
- http://nrg.nicta.com.au/internships/

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