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Circuit Breakers for Multimedia Congestion Control

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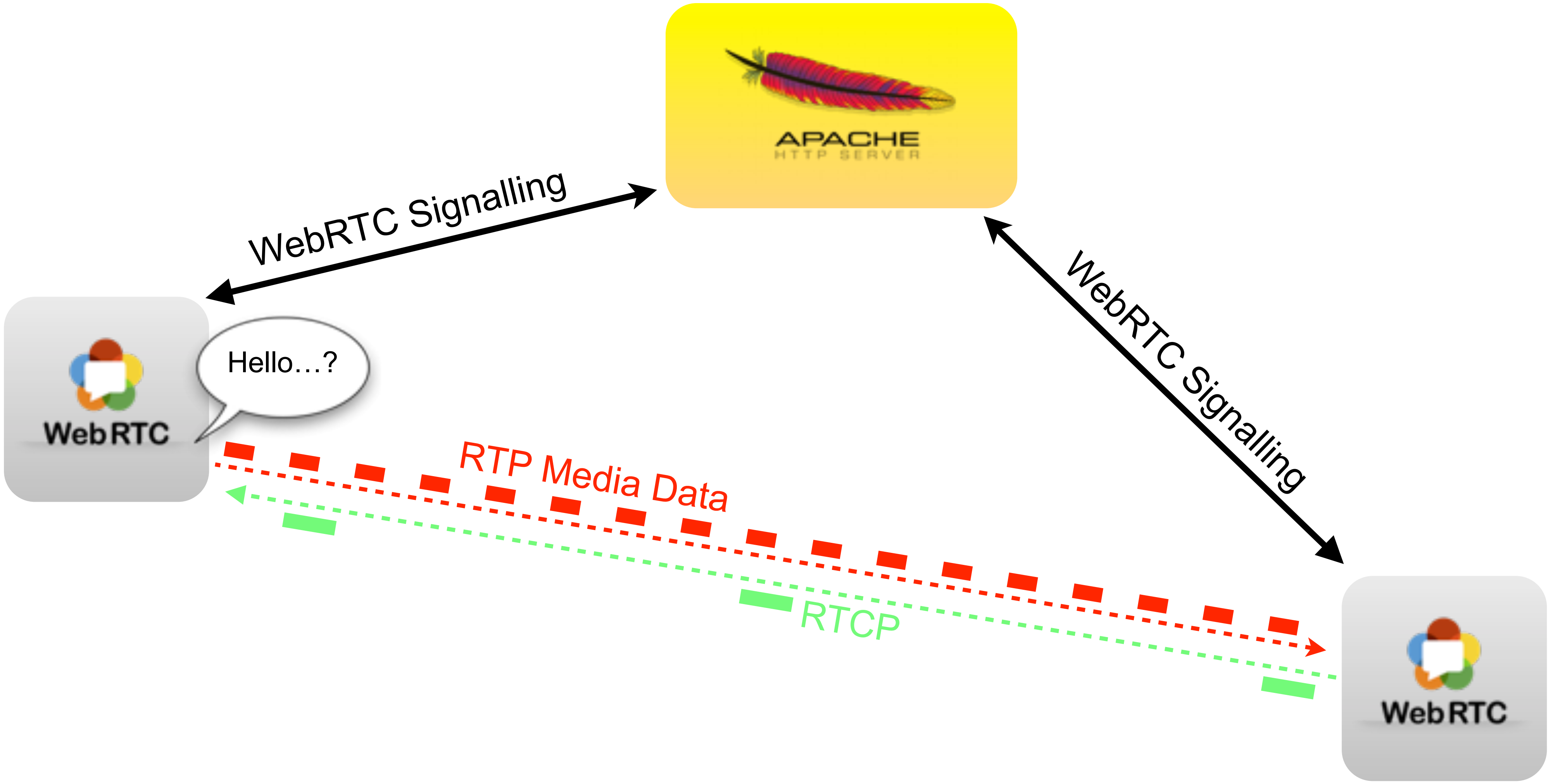
Context

- Video conferencing seeing increasing deployment

- Still no standard congestion control algorithm for RTP traffic running over UDP/IP
  - Various proprietary algorithms
  - IETF RMCAT working group
  - Potential congestion collapse

- Circuit breaker algorithm wanted to stop errant flows

Example Scenario: WebRTC



- High-rate RTP media data flow
- Low-rate RTCP reception quality feedback

RTCP Reception Quality Feedback

- Reporting interval: O(seconds)
- Timing statistics
    - Inter-arrival jitter
    - One RTT estimate per reporting interval
- Packet loss statistics
    - Fraction packets lost in last interval
    - Cumulative number of lost packets
    - Highest sequence number received

```
        0                   1                   2                   3
        0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
header |V=2|P|    RC   |   PT=RR=201   |             length            |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                     SSRC of packet sender                     |
       +=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
report |                 SSRC_1 (SSRC of first source)                 |
block  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  1    | fraction lost |       cumulative number of packets lost       |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |           extended highest sequence number received           |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                      interarrival jitter                      |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                         last SR (LSR)                         |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                   delay since last SR (DLSR)                  |
       +=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
report |                 SSRC_2 (SSRC of second source)                |
block  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  2    :                               ...                             :
       +=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
       |                  profile-specific extensions                  |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

- Reception quality feedback is infrequent and highly aggregated

RTP Circuit Breaker Algorithms

- Monitor reception quality of RTP media traffic to detect excessive network congestion
  - Use standard RTP and RTCP mechanisms
  - Must work with unmodified RFC3550-compliant receivers
- Three circuit breakers:
  - Media timeout
  - RTCP timeout
  - Congestion

RTP Circuit Breaker Algorithms

- Circuit breaker #1: Media timeout
  - RTP data packets being sent, but corresponding RTCP RR packets report non-increasing extended highest sequence number received
  - Indication of significant forward-path connectivity problem if persistent for ≥ 2 reporting intervals → cease transmission

- Circuit breaker #2: RTCP timeout
  - RTP data packets being sent, but no corresponding RTCP RR packets returned for ≥ 2 consecutive reporting intervals → cease transmission
  - Indicates significant return-path connectivity problem

RTP Circuit Breaker Algorithms

- Circuit breaker #3: Congestion
  - RTP data sent, corresponding RR packets have increasing extended highest sequence number received, but non-zero packet loss fraction
  - Indication of network congestion – estimate equivalent TCP throughput:

$$T = \frac{s}{R\sqrt{\frac{2p}{3}} + (t_{RTO}(3\sqrt{\frac{3p}{8}})p(1+32p^2))}$$

R = round trip time, s = packet size
p = packet loss event rate

and cease transmission if RTP sending rate ≥ $10T$ for 2 reporting intervals

  - Poor quality inputs – simplify by setting highlighted term to zero

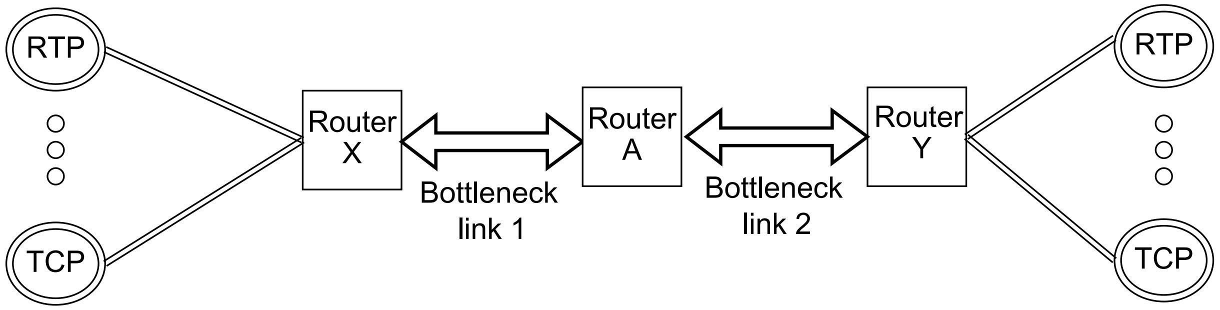
- Not a robust estimate of TCP throughput – is it good enough for a circuit breaker?

Testbed Experiments

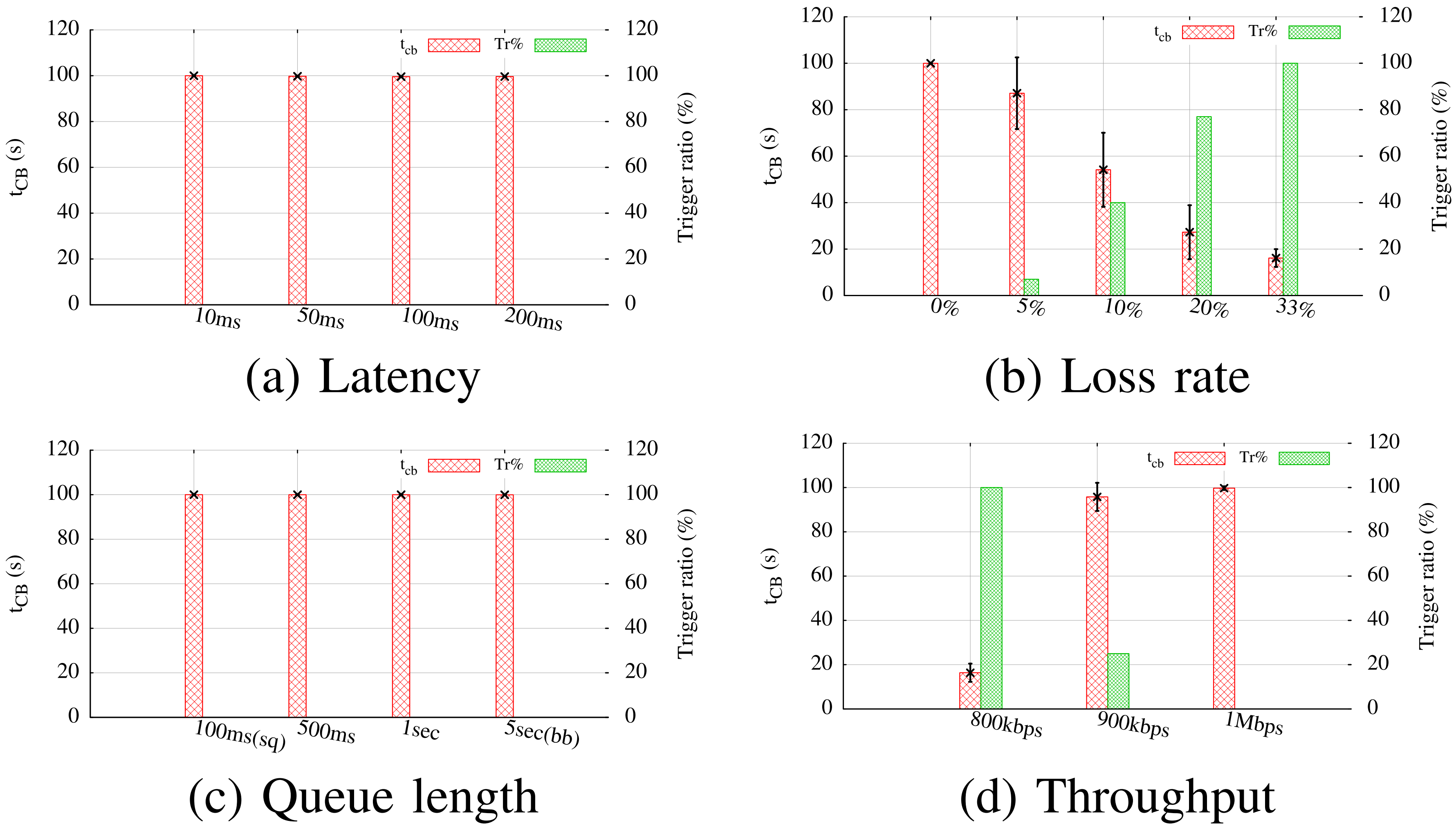
- Initial experiments: does circuit breaker behave as expected in simple environments?

- Evaluate using gstreamer + x264, Akiyo video sequence, VGA size video at 15fps with 1Mbps target rate; multiple 100 second runs

- Basic network testbed: simple bottleneck with variable queue, latency, available bandwidth



Impact of Bottleneck Link Parameters



(a) Latency

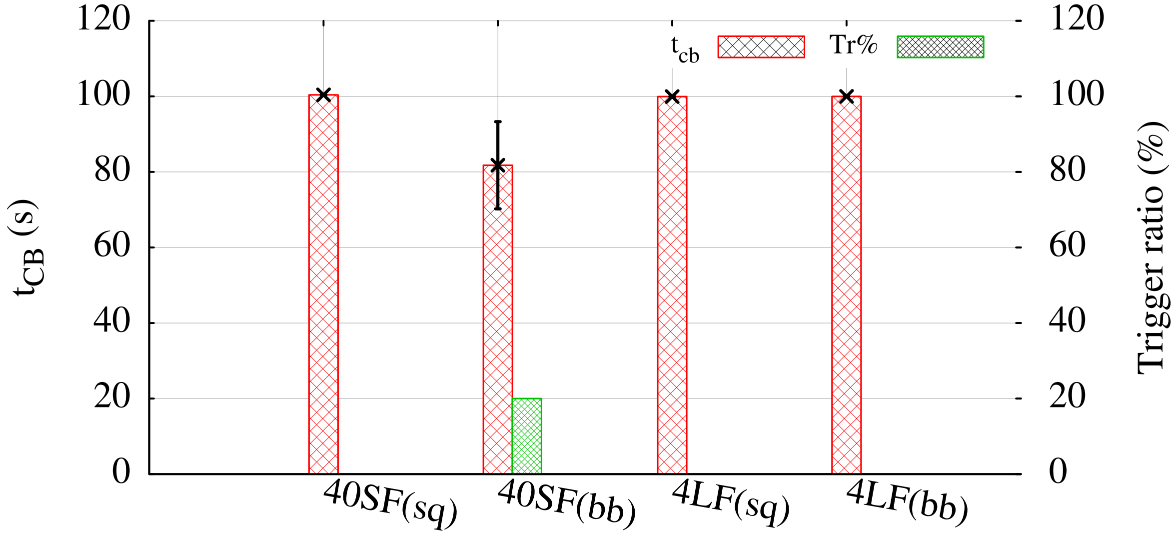
(b) Loss rate

(c) Queue length

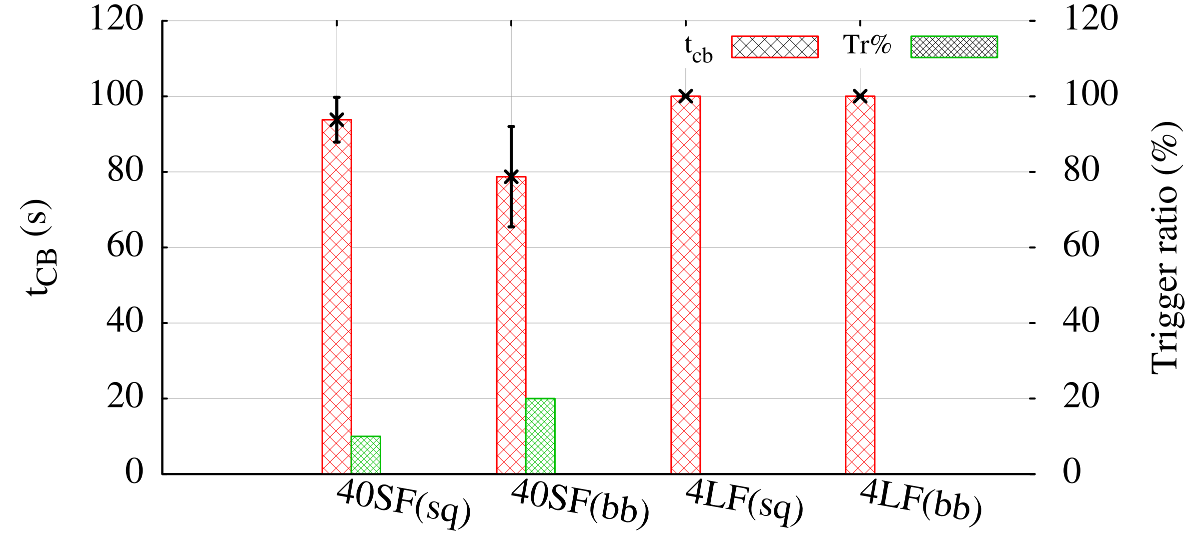
(d) Throughput

- See paper for full details – circuit breaker behaves as expected with changing bottleneck link characteristics

Impact of TCP Cross Traffic



(a) TCP and RTP flows start together



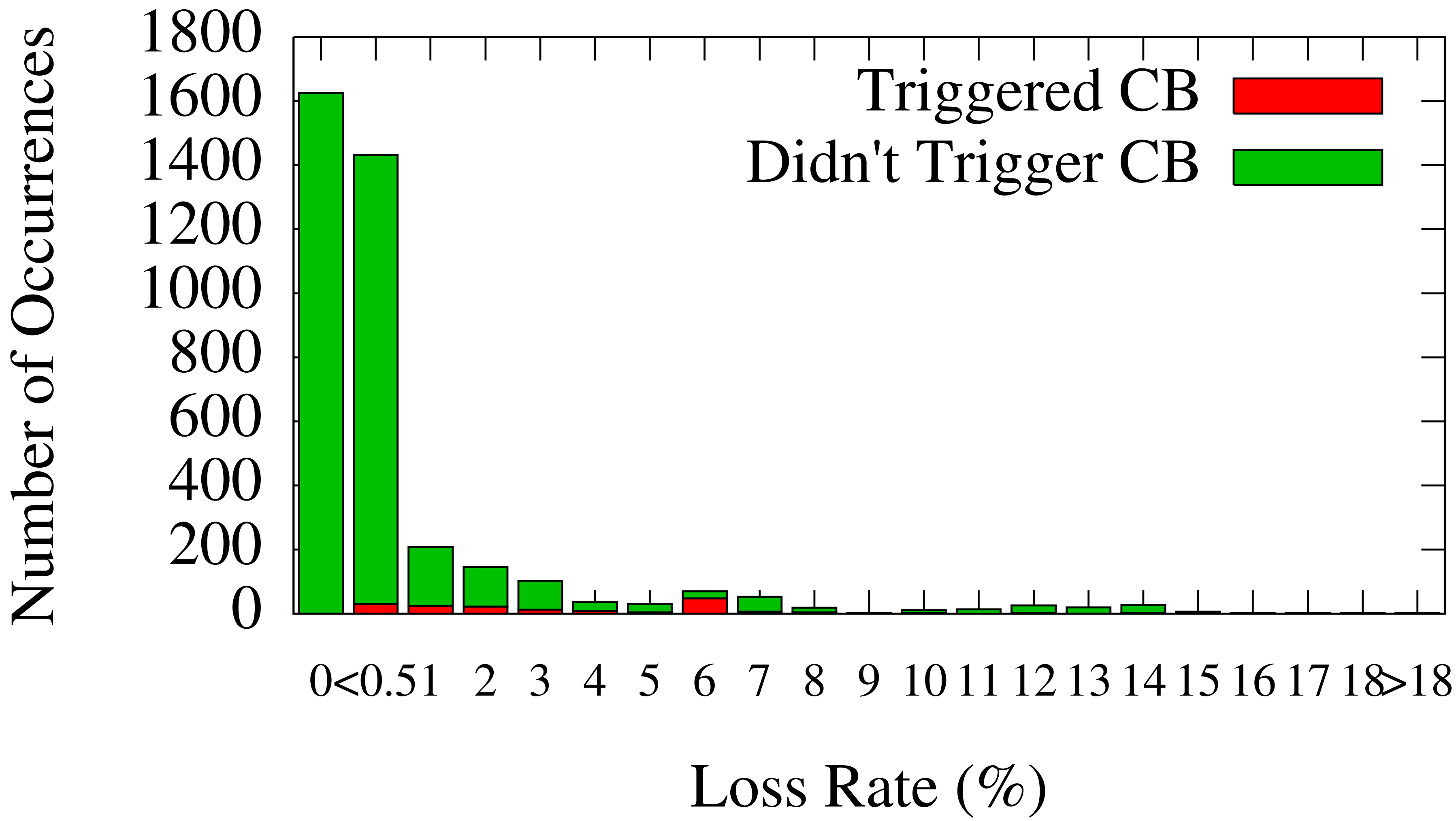
(b) TCP starts 20s before the RTP

- 3Mbps bottleneck, 1 RTP flow at 1Mbps, short (sq) or bloated (bb) 5s queue
- 40 short TCP flows modelling web traffic *or* 4 long duration TCP flows
- Short TCP flows aggressive due to slow start; buffer bloated queues decrease responsiveness, trigger circuit breaker – as expected, over-buffering affects TCP dynamics

Performance on Residential Links

- Captured RTP packet traces to residential users
  - CBR traffic flows; range of bit rates (1–8.5Mbps); 1–10 minute duration
  - Well-connected server; clients on standard home ADSL and cable modem links in the UK and Finland
  - 3833 traces containing ~230,000,000 packets
- Simulated RTCP matching the RTP packet traces
  - Assume reliable delivery of RTCP
- Explore effectiveness of congestion circuit breaker

Distribution of Traces by Loss Rate



- Circuit breaker triggers in 164 traces out of 3833
- Overall packet loss rate a poor predictor of whether circuit breaker will trigger

Circuit Breaker Triggers by Loss Pattern

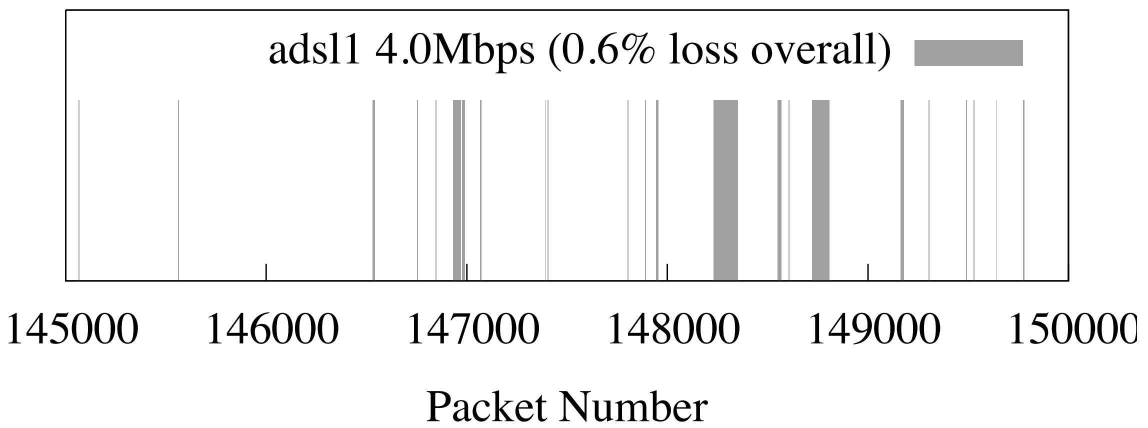
- Categorised packet traces according to RFC 3611 burst loss metric
  - 42% traces are loss free
  - 23% traces have non-bursty loss
  - 35% traces have bursty loss

> "A burst is a period during which a high proportion of packets are either lost or discarded due to late arrival. A burst is defined, in terms of a value Gmin, as the longest sequence that (a) starts with a lost or discarded packet, (b) does not contain any occurrences of Gmin or more consecutively received (and not discarded) packets, and (c) ends with a lost or discarded packet." – where the recommended value of Gmin = 16

- All packet traces triggering the RTP circuit breaker have bursty loss

Loss Pattern	Triggered	Did not trigger
Loss free	0.0%	100.0%
Non-bursty loss	0.0%	100.0%
Bursty loss	12.2%	87.8%

- Example circuit breaker trigger:
  - 10 second period with 4% avg. packet loss
  - 2–3 reporting intervals



Circuit Breaker Triggers by Sending Rate

- Likelihood of triggering circuit breaker increases with sending rate
- Most likely to trigger circuit breaker when sending rate is close to edge link capacity
- Results consistent with circuit breaker triggering due to edge congestion

	Sending Data Rate (Mbps)					
Link	1.0	2.0	4.0	5.0	6.0	8.5
adsl1	0%	0%	9%	-	38%	-
adsl2	0%	0%	-	-	-	-
adsl3	0%	0%	-	-	-	-
adsl4	0%	0%	0%	6%	0%	-
adsl5	0%	0%	0%	7%	27%	-
adsl6	0%	0%	19%	0%	52%	-
adsl7	2%	9%	-	29%	-	-
cable1	0%	20%	-	-	-	-
cable2	0%	0%	0%	4%	8%	17%
cable3	0%	0%	-	18%	-	-
cable4	0%	0%	-	2%	-	-
cable5	0%	0%	-	2%	-	-
finadsl0	0%	0%	-	2%	-	-
fincable0	0%	4%	-	100%	-	-

Fraction of traces triggering circuit breaker
(bars show negotiated rate of edge link)

Impact of Circuit Breaker Parameters

- Choice of TCP throughput model:
  - Use full TCP model, rather than the simplified TCP model
  - Num. flows triggering with bursty loss increases: 12.2% → 19.3%
  - Significant number of low-rate flows trigger this circuit breaker → overly sensitive to transient congestion

	Sending Data Rate (Mbps)					
Link	1.0	2.0	4.0	5.0	6.0	8.5
adsl1	0%	1%	14%	-	42%	-
adsl2	0%	0%	-	-	-	-
adsl3	0%	0%	-	-	-	-
adsl4	3%	5%	0%	26%	0%	-
adsl5	0%	4%	7%	20%	31%	-
adsl6	0%	1%	26%	0%	56%	-
adsl7	10%	9%	-	29%	-	-
cable1	0%	33%	-	-	-	-
cable2	0%	0%	0%	6%	8%	21%
cable3	18%	13%	-	29%	-	-
cable4	2%	0%	-	2%	-	-
cable5	2%	0%	-	4%	-	-
finadsl0	0%	0%	-	6%	-	-
fincable0	16%	16%	-	100%	-	-

- Number of RTCP reporting intervals to trigger:
  - Trigger after 3 reporting intervals gives slight reduction in number of traces triggering circuit breaker: 12.2% → 10.1% of bursty traces
  - No significant impact on low-rate traces

Conclusions

- Proposed RTP circuit breaker based on reachability and TCP-friendly throughput
  - Baseline RTP provides insufficient information for accurate TCP-friendly rate estimation; RTCP XR extensions can correct this in future systems
  - Circuit breaker adopts low-complexity approximations
- Trace-drive simulations show RTP circuit breaker triggering correctly for streaming to residential links
  - Might consider increasing to three reporting intervals before triggering
  - Ongoing work considering other network environments, more detailed analysis of circuit breaker triggers in this environment