LEDBAT++: Low priority TCP Congestion Control in Windows

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Background

- Software updates, telemetry, or error reporting
- Should not interfere with Skype call, interactive web browsing, etc.
- Four solutions to “lower than best effort” service:
  - Delay based transport protocols
  - Congestion window update algorithm designed to be “less aggressive”
  - Application level solutions such as BITS, monitor network usage
  - Network assisted solutions flag the packets as low priority
- In 2016, started exploring LEDBAT
  - Easier to deploy and maintain than app layer alternatives e.g. BITS
  - Versus waiting for hypothetical universal support in the network
- Literature survey and our own experiments found issues with LEDBAT as described in the RFC

LEDBAT (RFC 6817) Brief Recap

- Low Extra Delay Background Transport
- Minimize the impact of “lower than best effort” connections on the latency and bandwidth of other connections
- Compare measured delay with the base delay
- If delay is less than target, additive increase
- If delay is higher than target, additive decrease
- No strict requirements on slow start (with a suggestion to avoid)
- React to packet loss and ECN like standard TCP

Problems with LEDBAT

- One-way delay measurements are hard with TCP
  - No standard clock frequency or synchronization
  - Clock skew
- Latecomer advantage
  - Reliance on inherent burstiness of network traffic to detect base delay
- Inter-LEDBAT fairness
  - Proportional feedback uses both additive increases and decreases, stable queue but no fair sharing
  - Carofiglio, G. et al. “Rethinking the LEDBAT Protocol”
- Somewhat vague recommendations regarding slow start
- Latency drift
  - Impacts long running LEDBAT connections
- Low latency competition
  - If bandwidth is large, queueing delay never exceeds the fixed target

Introducing LEDBAT++

- LEDBAT++ comprises of the following
  - Round trip latency measurements
  - Slower than Reno cwnd increase with adaptive gain factor
  - Multiplicative cwnd decrease with adaptive reduction factor
  - Modified slow start
  - Initial and periodic slowdown
- Part of Windows 10 since Anniversary Update
- Internal API currently in use by WER (Windows Error Reporting) and Windows Update Delivery Optimization
- Working on making the API and config public in future releases

Round trip latency

- Advantages
  - Already available in TCP
  - No need for clock synchronization
- Disadvantages
  - Incorporates queuing delay in both directions
  - Receiver delays and delayed ACKs
- Mitigations
  - Erring on the side of higher latency estimation is acceptable
  - Enable TCP timestamp option implicitly for LEDBAT connections
  - Filter the RTT samples (minimum of the 4 most recent samples)
  - Use a TARGET delay of 60 ms
    - Larger than typical* server ACK delay (50ms)
    - 100 msec consumes 2/3rd of budget for 150 msec maximum acceptable delay for VoIP

Slower than Reno

- Reno
  - On packet loss: W -= W/2
  - On packet acknowledgement: W += 1/W
- Introduce a reduction factor F:
  - On packet loss: W -= W/2
  - On packet acknowledgement: W += 1/(F*W)
- Throughput of LEDBAT++ connection will be a fraction (1/SQRT(F)) of the throughput of regular TCP connection
- Based on experimentation we picked an adaptive scheme for F
  - F = min (16, CEIL (2*TARGET/base))
  - 16 is a good tradeoff between responsiveness and performance
- Solves low latency competition problem

Multiplicative Decrease

- Carofiglio, G. et al "Rethinking the Low Extra Delay Background Transport (LEDBAT) Protocol" suggest multiplicative decrease

	Standard LEDBAT, per RTT	Multiplicative decrease, per RTT
Delay lower than target	W += Gain * (1 – delay/target)	W += Gain
Delay larger than target	W -= Gain * (delay/target - 1)	W += Gain – Constant * W * (delay/target - 1)

- Only works when all connections measure same base delay, so
  - Use constant value of 1 and cap the multiplicative decrease coefficient to be at least 0.5
  - Ensure that cwnd never decreases below 2 packets
- Solves the Inter-LEDBAT fairness problem

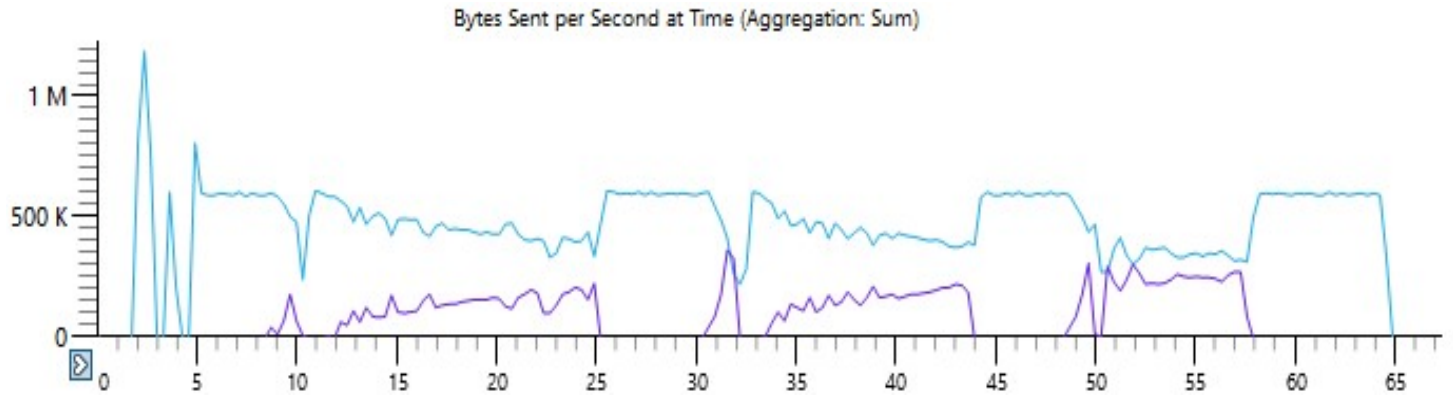
Modified slow start

- Skipping slow start results in really poor performance on long delay links
- Slower than Reno ramp up
  - Apply the adaptive reduction factor F to the congestion window increases
  - Limit the initial cwnd to 2 packets
- If queuing delay is larger than 3/4^{ths} of the TARGET, exit slow start
  - Immediately move to the “congestion avoidance” phase
- Only apply the “exit on excessive delay” during the initial slow start
  - Subsequent slow starts capped by recorded ssthresh

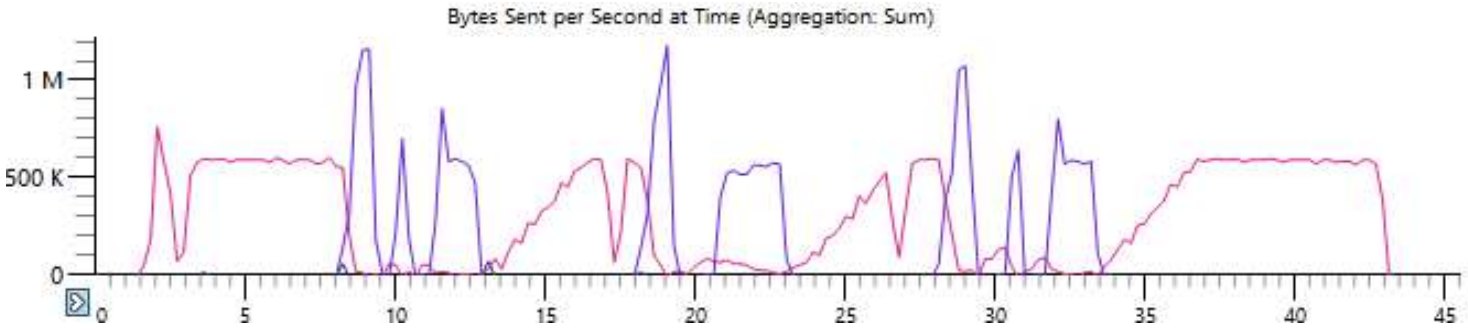
Initial and periodic slowdown

- Traffic is sustained for long periods
  - Inaccurate base delay estimates
  - Causes latency drift as well as the lack of inter-LEDBAT fairness
- Force gaps for measuring base delay, or “slowdown” periods
  - “slowdown” is an interval during which the LEDBAT++ connection voluntarily reduces its traffic
  - Upon entering slowdown, set ssthresh = cwnd, and reduce cwnd to 2 packets
  - Keep CWND frozen at 2 packets for 2 RTT
  - After 2 RTT, ramp up according to “slow start” until cwnd reaches ssthresh
- Initial slowdown 2*RTT after first slow start exit
- Periodic slowdown – not more than 10% drop in throughput
  - Measure duration of slowdown from entry to ramp up to ssthresh
  - Schedule next slowdown 9 times this duration
- Solves the latency drift problem

Bandwidth sharing with normal priority traffic

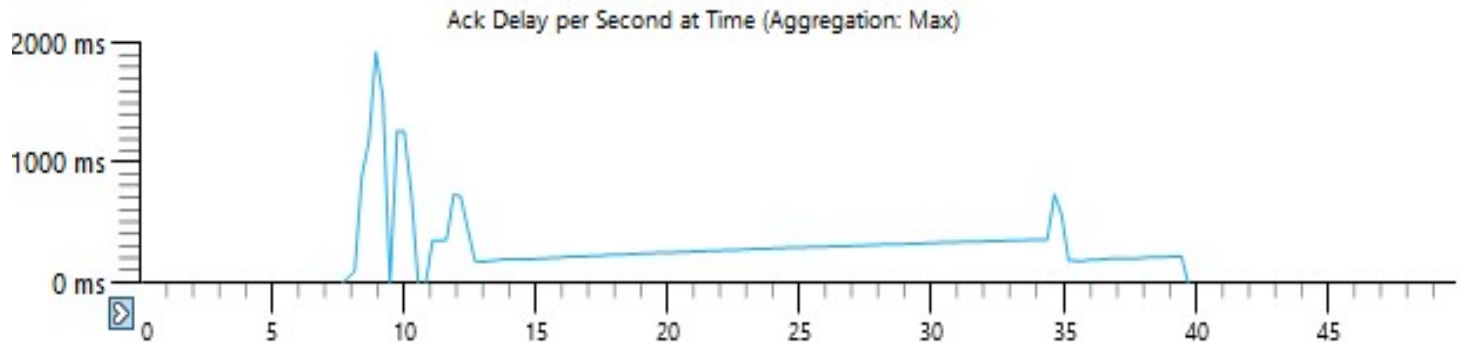


Blue: Standard TCP
Purple: Short flows

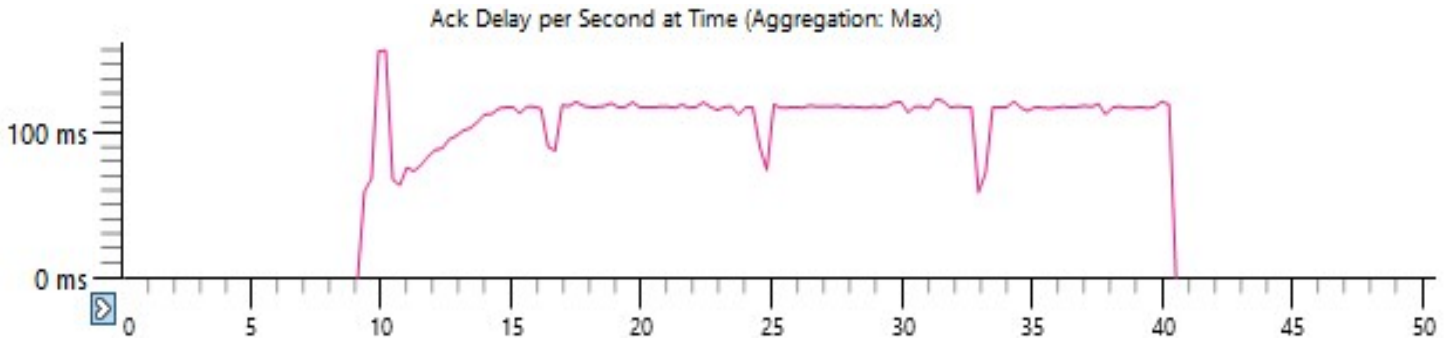


Red: LEDBAT++
Purple: Short flows

Reduced latency impact of LEDBAT++

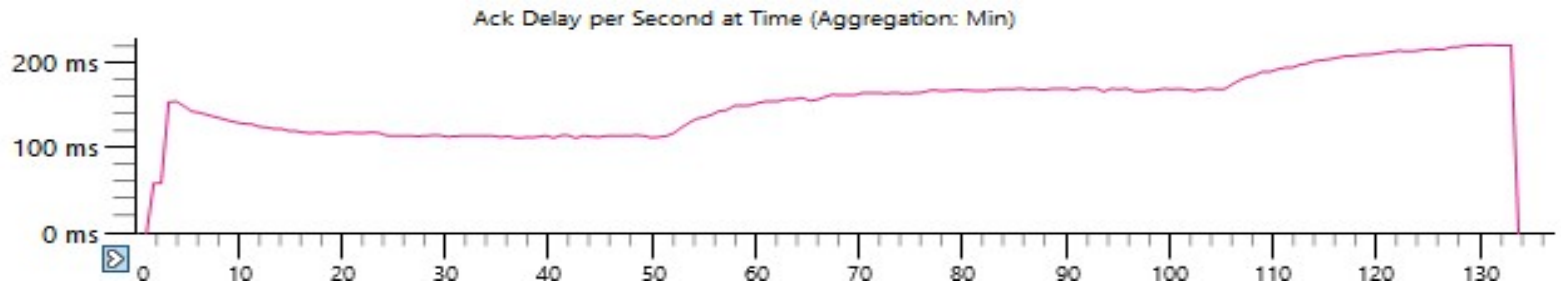


Standard TCP

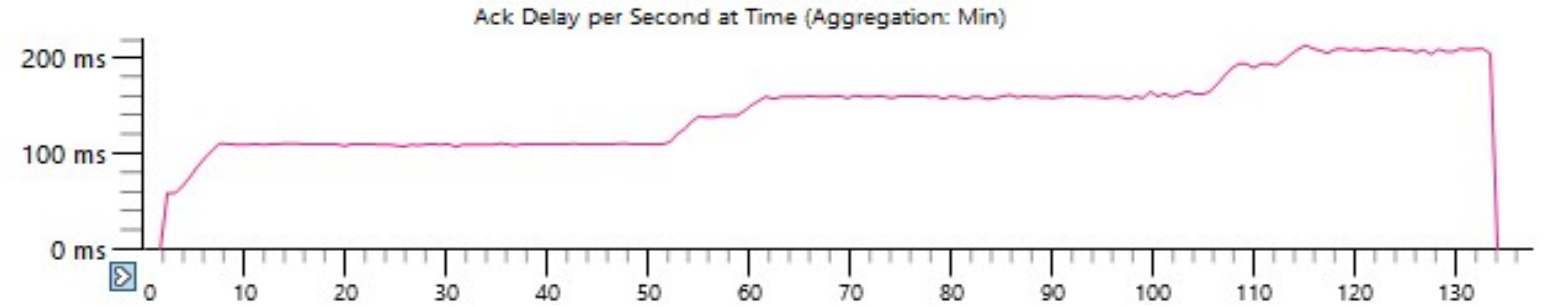


LEDBAT++

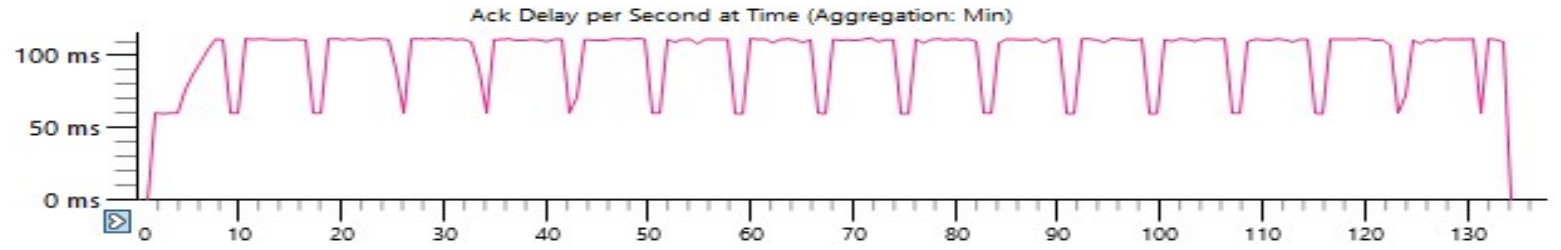
Handling latency drift



Standard LEDBAT

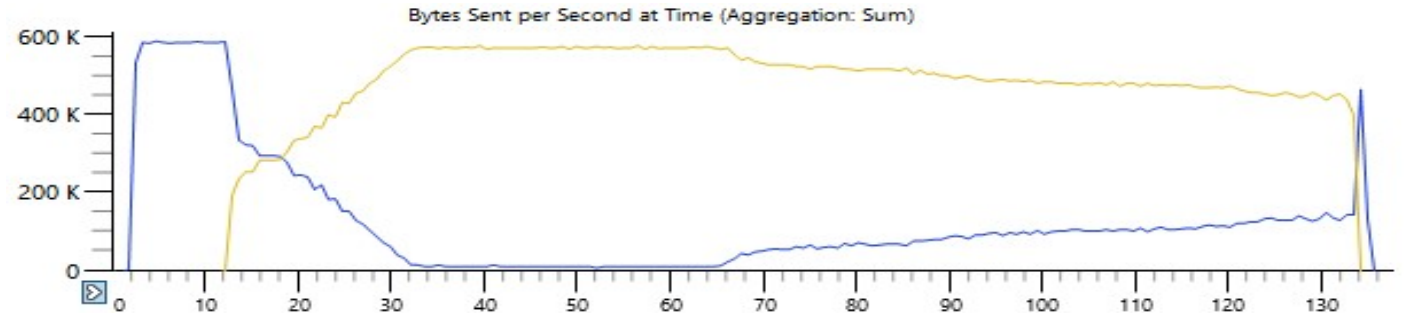


Mult. Decrease

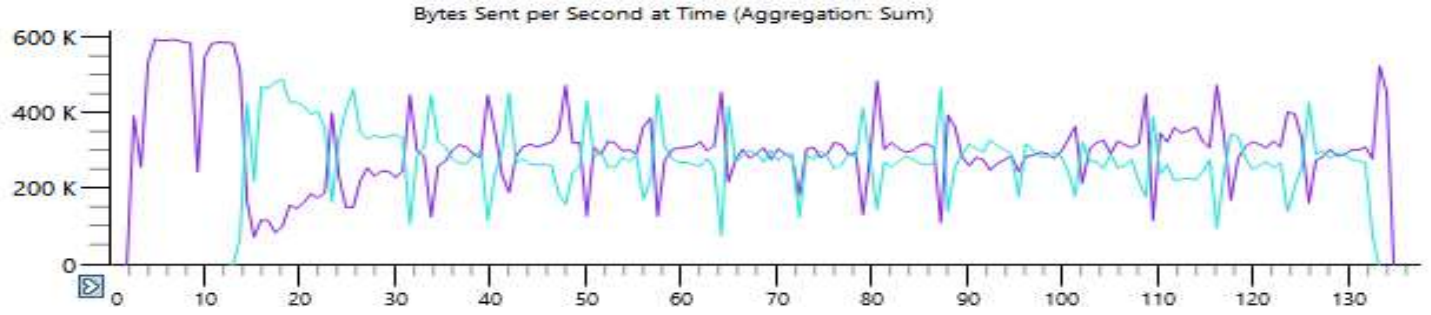


Mult. Decrease + slowdowns

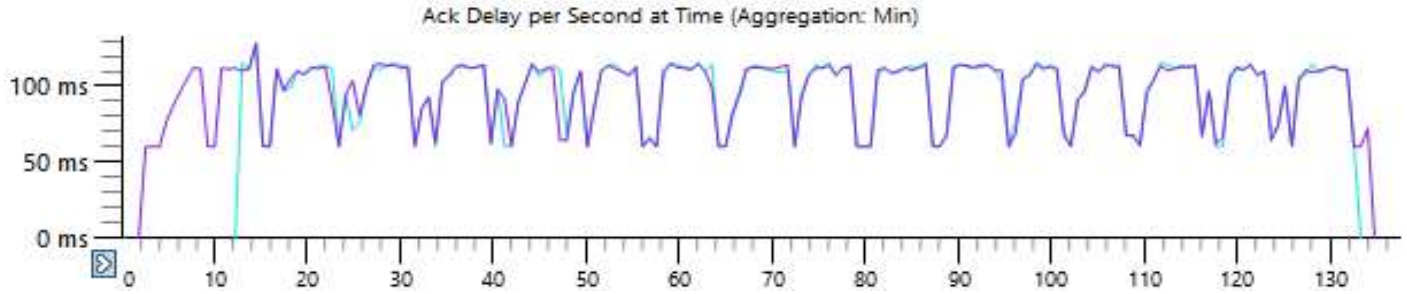
Latecomer advantage & Inter-LEDBAT fairness



Standard LEDBAT

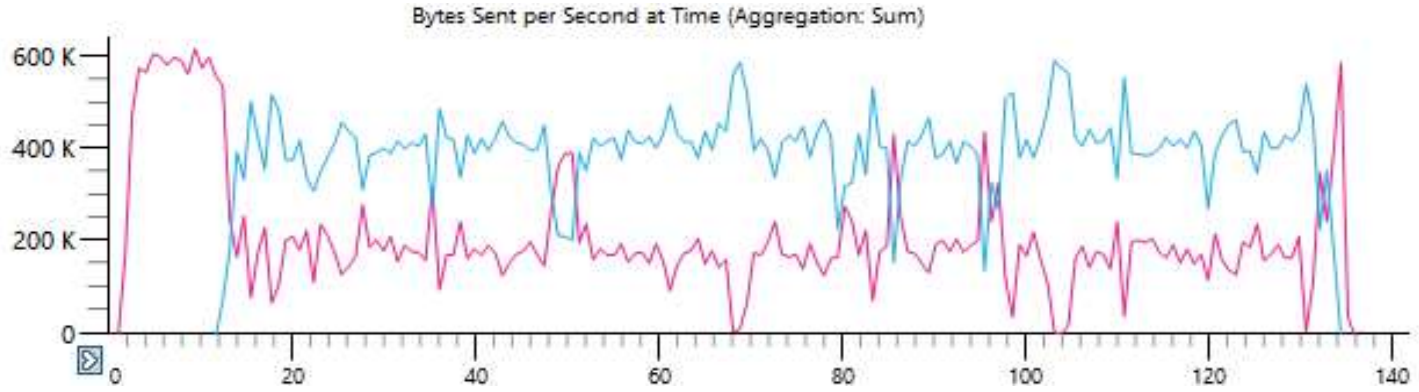


LEDBAT++

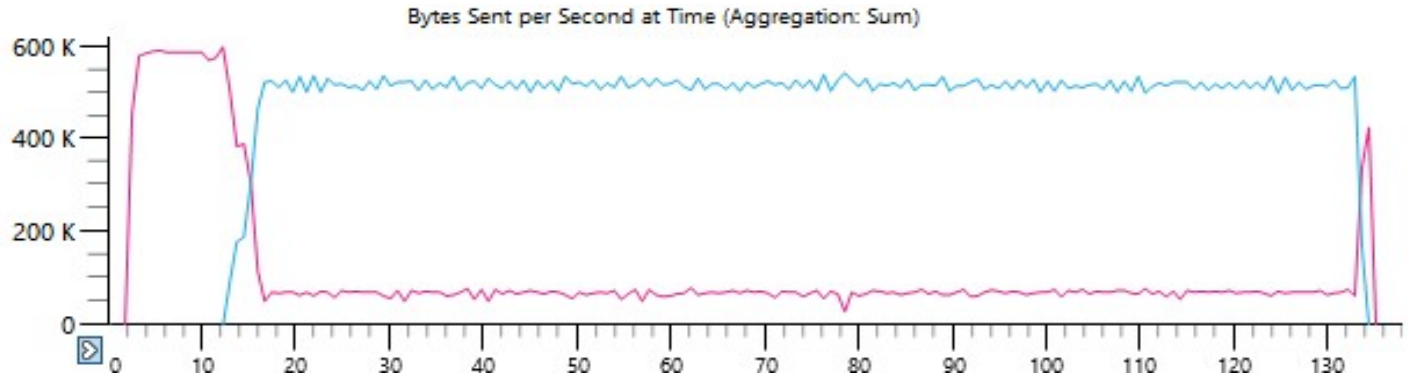


LEDBAT++

Handling low latency competition



Blue: Standard TCP
Red: LEDBAT++,
Fixed F=1



Blue: Standard TCP
Red: LEDBAT++,
adaptive F=16

Conclusion

- We found several shortcomings of LEDBAT as a solution for background connections
- LEDBAT++ is an attempt to overcome these problems
- Experiments show that LEDBAT++ addresses the shortcomings
- LEDBAT++ is already deployed and used on millions of systems
- Working on making API and knob public
- Working on a draft submission
  - Should it be to iccrg or tcpm?

References and Q&A

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Q&A