The Bufferbloat Problem over Intermittent Multi-Gbps mmWave Links

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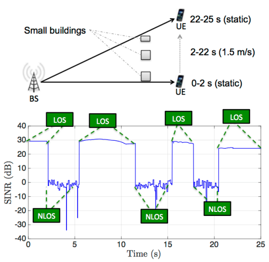
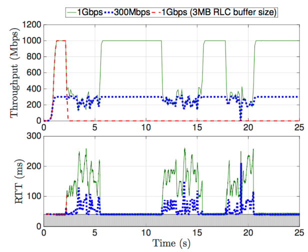
Problem

Bufferbloat is high latency due to excessive buffering.

In our previous work [1], we showed that intermittent multi-Gbps mmWave links will severely suffer from this phenomenon.





Existing Solutions

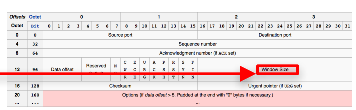
Active Queue Management (AQM)

Early dropping of packets before buffer overflow.
E.g., Random Early Detection (**RED**) and Controlled Delay (**CoDel**).

Tweaking the Advertised Receiver Window (ARW)

The sending rate is given by
min(congestion window,
advertised receiver window)

ARW = K RTT$_{min}$

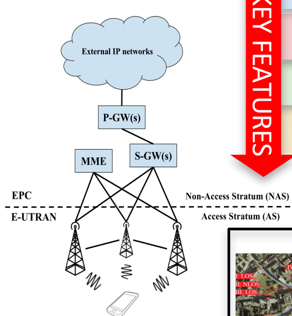


TCP HEADER

In [2], **K** is the actual throughput.

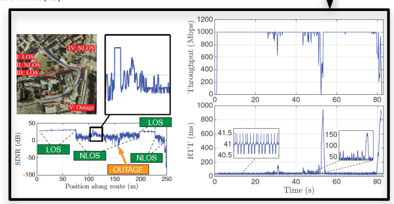
In [3], **K** is the channel capacity.

Simulation

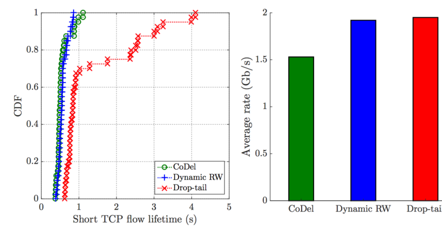


KEY FEATURES

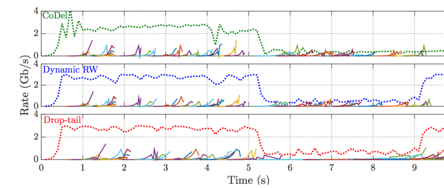
- EPC inherited from LTE
- RLC, PDCP, RRC inherited from LTE. Modified RRC for fast HO and cell tracking
- mmWave MAC/PHY with low-latency flexible TTI frame and modified HARQ
- mmWave channel: Statistical, semi-empirical, or real traces



(2) Single user with multiple flows

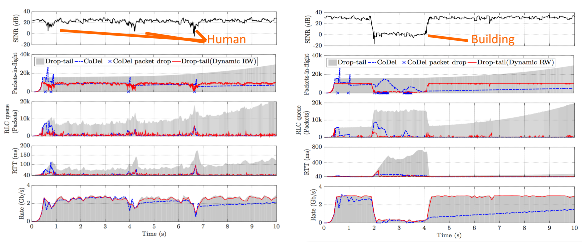


DRW exhibits
- *low latency* as CoDel
- *high throughput* as Drop-tail



The **long flow** (dashed line) represents the background traffic.
The **short flows** represent web browsing or texting.

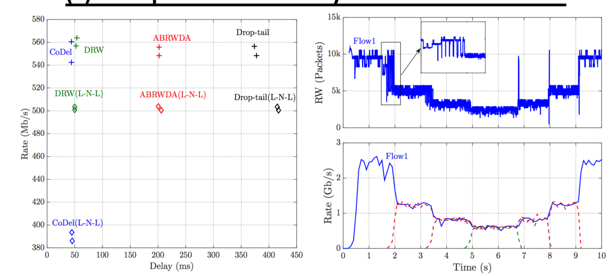
(1) Single user with a long TCP flow



Drop-tail: Large congestion window results in *high buffer occupancy* and *long delays*

CoDel: Low buffer occupancy results in *low delay* but *degraded throughput*

(3) Multiple users served by the same base station



DRW outperforms other methods in terms of both throughput and delay
DRW quickly adapt its window size when users arrive or leave

Our Contribution

Simulation based on ns-3

- Performance evaluation of existing solutions, leveraging our end-to-end 5G mmWave simulation framework [4];
- Introduction of our algorithm, Dynamic Receive Window (**DRW**), which dynamically operates in two regimes [5]:

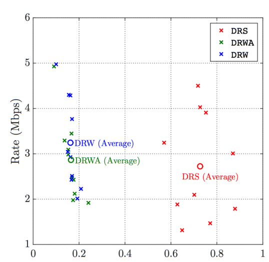
  LOW DELAY: **ARW$_{LD}$** = Capacity*RTT$_{avg}$

  HIGH DELAY: **ARW$_{HD}$** = Throughput*RTT$_{avg}$

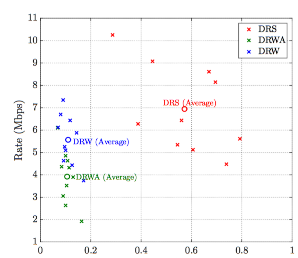
Implementation on real devices

The proposed algorithm has been implemented and validated on commercial 4G LTE devices by operating directly on the kernel.

Implementation



LTE weak signal



LTE strong signal

References

[1] M. Zhang, M. Mezzavilla, R. Ford, S. Rangan, S. Panwar, E. Mellios, D. Kong, A. Nix, and M. Zorzi, "Transport layer performance in 5G mmwave cellular," IEEE INFOCOM 2016 - Millimeter Wave Networking Workshop.

[2] H. Jiang, Y. Wang, K. Lee, and I. Rhee, "Tackling bufferbloat in 3G/4G networks," in Proceedings of the 2012 ACM Conference on Internet Measurements.

[3] X. Liu, F. Ren, R. Shu, T. Zhang, T. Dai, "Mitigating Bufferbloat with Receiver-based TCP Flow Control Mechanism in Cellular Networks", IEEE ICCCN 2015.

[4] R. Ford, M. Zhang, S. Dutta, M. Mezzavilla, S. Rangan, and M. Zorzi, "A framework for end-to-end evaluation of 5G mmwave cellular networks in ns-3," in Proceedings of the Workshop on Ns-3, WNS3 2016.

[5] M. Zhang, M. Mezzavilla, J. Zhu, S. Rangan, and S. Panwar, " The bufferbloat problem over intermittent multi-Gbps mmWave links", submitted to ICC 2017.