X-TCP: a Cross Layer Approach for TCP Uplink Flows in mmWave Networks

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Outline

- Introduction
- TCP and TCP for mmWave
- Proposal: cross layer approach
- Performance evaluation
  - Random scenario
  - Outage scenario
- Conclusions
TCP is one of the most used transport protocols

mmWave links will be probably used in next generation cellular networks

The end-to-end performance depends on the interaction between different layers
TCP issues in mmWave

- mmWave links
  - blockage and link disruption
  - bandwidth fluctuation in LOS/NLOS transitions
- TCP suffers: suboptimal performance and waste of resources
  - Long time to recover full throughput after an outage
  - Very high RTT in NLOS + bufferbloat

[3] Zhang et al., *Transport Layer Performance in 5G mmWave Cellular*
[4] Zhang et al., *The Bufferbloat Problem over Intermittent Multi-Gbps mmWave Links*
Traditional approach

TCP can only infer the state of the mmWave link from “information” in ACKs.
Cross layer approach

TCP directly knows the state of the mmWave link

- Direct knowledge is feasible only for local links
- Uplink approach
Information needed

- Assumption
  - 3GPP-like protocol stack (PHY, MAC, RLC, PDCP)
  - TDD physical layer
- Transport block size at MAC layer + slot duration
  - Scaled to account for higher layer headers

Estimation of available data rate $\hat{e}_{\text{datarate}}$

- Round trip time (with ACK timestamps) $\hat{e}_{\text{rtt}}$
  - Consider minimum RTT in an interval $rtt_{\text{min}}$
  - Avoid adding buffering delays
to the sudden collapse of the congestion window after an RTO that these improvements do not avoid the performance loss due that can be sent. This dynamic receive window approach is mechanism actually imposes a limit on the number of packets the congestion window, and if the latter is too large, then this sender selects the minimum between the receive window and in order to optimally tune the receive window. Then, according Control Information (DCI) to estimate the allocated bandwidth, and [16], each UE uses information contained in the Downlink links has been proposed in [7]. Following the approach of [15] in [4], where it is shown that retransmissions increase the layer retransmissions for TCP on mmWave links is investigated RTO events. On the other hand, reducing the size of the RLC buffer and the queueing delay increase, eventually leading to decrease the congestion window. Therefore, the size of the RLC immediately detect the capacity reduction and, hence, does not and the datarate suddenly drops, the TCP sender does not fill the very large capacity provided by mmWave links in LOS congestion window at the sender keeps increasing in order to outages of the mmWave link in LOS conditions. Therefore, the the RLC to recover packet losses due to temporary short-term explained in the introduction, large buffers make it possible for buffers at the Radio Link Control (RLC) layer. In fact, as briefly parameters

\[ cwnd = \frac{cwnd}{\text{factor}} \]

\[ cwnd = \text{factor} \times cwnd \]

A first solution for downlink TCP streams over mmWave Despite the improvements brought about by these algorithms, studies. Paper [6] presents the first performance analysis of the performance of TCP connections over mmWave wireless

The core of the algorithm is the estimation of the data rate, thus mimicking the behavior of the Additive Increase Multiplicative Decrease (AIMD) paradigm, according to which the congestion window is divided by a factor \( cwnd = \frac{cwnd}{\text{factor}} \) for each packet loss, and then increased by summing the Maximum Segment Size (MSS)

\[ cwnd = cwnd \times \frac{1}{2} \]

\[ cwnd = cwnd + cwnd \]

The RTT can be estimated after the reception of every ACK for

\[ \text{rtt} = \text{rtt} + \frac{\text{rtt}}{\text{factor}} \]

\[ \text{rtt} = \text{rtt} + \text{factor} \times \text{rtt} \]

\[ \text{rtt} = \text{factor} \times \text{rtt} \]

Algorithm 1 Cross layer congestion window update

\[ \text{rtt}_{\text{min}} \leftarrow \infty \]

\[ \text{cwnd} \leftarrow \text{MSS} \]

\[ \text{rtt}_{\text{min}} \leftarrow \text{rtt}_{\text{min}} + \epsilon \]

\[ \text{cwnd} \leftarrow \lambda \times \text{rtt}_{\text{min}} \]

\[ \text{rtt}_{\text{min}} \leftarrow \text{rtt}_{\text{min}} + \epsilon \]

\[ \text{cwnd} \leftarrow \lambda \times \text{rtt}_{\text{min}} \]

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\[ \text{rtt}_{\text{min}} \leftarrow \text{rtt}_{\text{min}} + \epsilon \]

\[ \text{cwnd} \leftarrow \lambda \times \text{rtt}_{\text{min}} \]
Considerations

- Retransmissions at MAC and RLC layers may occupy the transport block.
- There may be congestion in other links.

Apply scaling factor $\lambda$ if

- SINR below threshold
- Estimated RTT $>> rtt_{\text{min}}$

- Empirical value
  - Scenario-based optimization left for future work.
Random scenario

- ns-3-based simulation
- End-to-end detailed protocol stack
- NYU statistical channel model
- Randomly generated obstacles
Example in NLOS

(a) Window

(b) RTT

(c) Throughput
Average results

(a) Average RTT

(b) RLC buffer occupancy

(c) Average throughput
Outage scenario

- Random channel realizations
- Fixed obstacles
- Forced outage
Example

NLOS  Forced outage  LOS  NLOS
Average results

<table>
<thead>
<tr>
<th>TCP flavor</th>
<th>Average throughput [Mbit/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-TCP</td>
<td>1225.21 ± 15.81</td>
</tr>
<tr>
<td>TCP BIC</td>
<td>1051.32 ± 10.42</td>
</tr>
<tr>
<td>TCP Illinois</td>
<td>949.87 ± 10.78</td>
</tr>
<tr>
<td>TCP CUBIC</td>
<td>342.79 ± 8.46</td>
</tr>
<tr>
<td>TCP NewReno</td>
<td>342.46 ± 10.33</td>
</tr>
</tbody>
</table>
Proposed a cross layer approach for uplink TCP
Performance evaluation over different scenarios
  - Randomly generated
  - Forced outage

Future works
  - Optimization of scaling factor $\lambda$
  - TCP split approach
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