Understanding TCP Fairness over Wireless LAN

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Goals

- Identify Unfairness of TCP in 802.11 Networks through Data Measurements;
- Model the TCP scheme and simulate this Unfairness;
- Understand the Reasons of this Problem;
- Propose a Solution.
Tools

- **Communication Networks**: TCP scheme and other concepts;

- **Wireless Networks**: 802.11 standard;

- **Simulation Software**: NS2.
TCP in 802.11 Networks

- Network Setting: Base Station (BS, AP), mobile Senders and Receivers.

- Analysis of the interaction between 802.11 MAC Protocol and TCP.

- Relative Bandwidth for Uploads (Senders) and Downloads (Receivers).
The Problem of TCP Fairness

- Performance Tests results:

<table>
<thead>
<tr>
<th>MTU</th>
<th># of up flows</th>
<th># of down flows</th>
<th>UDP flow</th>
<th>$R_u/R_d$</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td>1</td>
<td>1</td>
<td>–</td>
<td>1.44</td>
<td>0.22</td>
</tr>
<tr>
<td>1500</td>
<td>2</td>
<td>2</td>
<td>–</td>
<td>1.58</td>
<td>0.23</td>
</tr>
<tr>
<td>1500</td>
<td>3</td>
<td>3</td>
<td>–</td>
<td>1.76</td>
<td>0.34</td>
</tr>
<tr>
<td>1500</td>
<td>4</td>
<td>4</td>
<td>–</td>
<td>1.80</td>
<td>0.27</td>
</tr>
<tr>
<td>1500</td>
<td>2</td>
<td>2</td>
<td>500/2ms</td>
<td>1.79</td>
<td>0.35</td>
</tr>
<tr>
<td>1500</td>
<td>2</td>
<td>2</td>
<td>1000/2ms</td>
<td>2.15</td>
<td>0.55</td>
</tr>
<tr>
<td>500</td>
<td>1</td>
<td>1</td>
<td>–</td>
<td>1.77</td>
<td>0.39</td>
</tr>
<tr>
<td>500</td>
<td>2</td>
<td>2</td>
<td>–</td>
<td>1.83</td>
<td>0.38</td>
</tr>
<tr>
<td>500</td>
<td>3</td>
<td>3</td>
<td>–</td>
<td>1.87</td>
<td>0.41</td>
</tr>
<tr>
<td>500</td>
<td>1</td>
<td>1</td>
<td>450/1ms</td>
<td>3.05</td>
<td>0.83</td>
</tr>
<tr>
<td>500</td>
<td>2</td>
<td>2</td>
<td>450/1ms</td>
<td>7.9</td>
<td>4.57</td>
</tr>
</tbody>
</table>

**TABLE I**

The ratio between the up and down flow in using commercial 802.11b

( MTU = Maximum Transmission Unit [Bytes] )
Simulation Study (NS2)

1. One Upstream and one Downstream Flow

MTU=1500 B; TCP Rec. Win.= 42 pck; data pck = 1024 B.

BS Buffer Size=6:85; \( \alpha = \text{Ack pck} / \text{data pck} = 1 \).
OBSERVATIONS:
Overall TP is constant;
BS Buffer Size plays a crucial role: Define 4 regions to separately analyze.
More Plots...

RTT Values for Upstream And Downstream Flows

Data and ACK loss rate
Amount of Packets sent through the MAC layer for different Buffer Sizes.
Simulation Study (NS2)

2. *Multiple flows*

Fixed BS Buffer Size = 100.

One Upstream Flow, Multiple Downstream Flows.

Downstream flows share the same resource.
Equal number of Up/Downstream Flows.
Up ACKs clutter BS buffer => Downstream flows experience timeouts due to packet drops.
Modeling TCP Access

• *Assumption*: all losses are due to buffer overflow at BS.

• 1up,1down; \( B = \) BS buffer size; \( w = \) receiver window size.

• *Observation*: loss of ACK at BS has no influence on sender window size (*cumulative acknowledgment* nature of TCP). Not true for downstream TCP window size.

• Then if \( B > (\alpha + 1)w \), no problems (as simulated).

• Else, in steady state, BS has \( \alpha w \) ACK pcks; then, for downstream, \( win = 3(B - \alpha w)/4 \).

• Therefore, \( R^* = 4w/3(B - \alpha w) \).
Partial results
Further Steps

- BS isn’t full with ACKs all the times.
- Think BS as an (M/M/1/K) queue;
- $R_d$, $R_u$ rate of TCP down/up flow;
- $\rho = (R_d + \alpha R_u) / R_u = 1 + R^*$ (arrival/service rate);
- Prob. that the queue in steady state has $k$ pcks

$$p_k = \frac{1 - \rho}{1 - \rho^{k+1}} \rho^k$$

=> For the BS, we obtain:

$$p = \frac{1 + BR^*}{1 + B}$$
Further Steps, cont’d

- Problem: $p$ and $R^*$ are unknown.
- Assuming no timeouts occur:

\[
R_d = \frac{1}{RTT_d} \sqrt{\frac{3\alpha}{2p}}
\]

Therefore:

\[
R^* = \frac{RTT^u}{RTT_d} \sqrt{\frac{3\alpha}{2\omega^2 p}}
\]

Assuming equal RTT’s:

\[
p = \frac{3}{2\omega^2 R^{*^2}}
\]

And it’s possible to relate $R^*$ to $B$. The results match the simulations in the second region.
Partial results
Further Steps, cont’d

It’s possible to blend the first two models into a general one:

\[
R^* = \frac{RTT_u}{\omega \cdot RTT_d} \left( \sqrt{\frac{3\alpha}{2p}} + \frac{3(B - \alpha \omega)}{4} \right)
\]

Now, how to justify the noise in Region 2?
We wrongly assume for the M/M/1/K “nice” arrivals.

If the BS buffer is small, how can we evaluate the upstream flow?
Further Steps, cont’d

- In the case of *multiple downstream flows* the results can be extended:

\[ \rho = \frac{nR_d + R_u}{R_u} = 1 + nR^*, \]

where \( n \) is the number of downstream flows.
The Solution

- First Idea: separate queues for TCP-data and TCP-ACK in BS buffer (*ineffective*).

- *Task*: don’t affect the MAC layer, operate above it.

- Use advertised Receiver window in the ACK pcks towards the Sender. This throttles the Sender in case the Receiver is congestioned.

- Ex.: n=flows, BS buffer size=B; In ACK pcks toward sender, set rec.-win.=min {advert. Rec.-win. , B/n}. 
Results from Simulations
Conclusions

• Evaluation of the interaction btw MAC and TCP for Wireless LANs.

• BS buffer size plays a key role in the unfairness in TCP throughput ratio btw upstream and downstream flows.

• Open Questions:
  – Account for Channel Losses;
  – Different RTT for up and downstream;
  – Is steady state analysis satisfactory?