TCP over WLANs

- WLANs: a means to provide Internet access.
  - IEEE 802.11: collision avoidance mechanism
- TCP: transport protocol used by many Internet applications (i.e. file transfer, web browsing).
  - Closed-loop behaviour: Flow control and congestion control

How do they interact?
Modeling IEEE 802.11 WLANs

- Many models of IEEE 802.11 MAC consider
  - saturated sources or
  - finite-load sources with certain packet arrival rate and synthetic traffic pattern (i.e. Poisson).

- Effects of closed-loop nature of TCP to modeling.
  - Sources may not be saturated, even though TCP senders have infinite data amount to send.
  - Finite-load source models do not capture properly.

- This requires models which explicitly capture the interaction between TCP and MAC.

Review of IEEE 802.11 MAC models for saturated sources

- Central to the model:
  - Fixed point system

\[
p = 1 - \tau^N
\]

\[
\tau = \frac{1}{f(p)}
\]

\[ f(p) : \text{Average contention window per backoff stage} \]

- From \( \tau \) and \( p \), throughput of each station can be determined.
Existing IEEE 802.11 MAC models with TCP

- Common assumptions:
  - No loss due to buffer overflow and TCP timeout.
  - Channel is ideal
  - TCP senders have infinite amount of data
  - TCP advertised window < maximum TCP congestion window
  - Applications read data at the rate it is received from network.
  - Wireless link is the only bottleneck.

  Only flow control is considered.

Existing IEEE 802.11 MAC models with TCP flow control

- General method
  - Based on the saturated model of IEEE 802.11 MAC
  - Calculate the number of backlogged stations in the network

- Difference among models
  - Approach to calculate the number of backlogged stations.
    - Non-Markov chain: [4], [5], [6]
    - Markov chain: [1], [2], [3], [7], [8]
Non-Markov chain

- Daniele’s model:
  - Main features:
    - Infrastructure mode
    - Only TCP downstream flows
  - Model
    - Assume that AP is saturated
    - When number of STAs = 1,
Bruno’04 model [1]

- Main features:
  - Infrastructure mode
  - Only TCP downstream flows
  - No more than one TCP packet is enqueued in the buffer of an active station.

- Model
  - Markov chain
    - Each state of Markov chain: number of active stations after a successful transmission of the AP.
    - State transition: after a successful transmission of the AP.
    - Steady-state probabilities allow the calculation of total channel utilization.

Total channel utilization = Channel utilization of AP + Channel utilization of STAs

- Channel utilization of AP = \( \frac{E[\text{Time occupied by payload of a successful transmission of AP}]}{E[\text{Duration between two consecutive successful transmission of AP}]} \)
Bruno’04 model

- Results
  - M<5: less accurate.

![Graph showing overall channel utilization](attachment://overall_channel_utilization.png)

Yu’s model [2]

- Main features:
  - Infrastructure mode
  - Stations either download or upload data
  - Arbitrary advertised window W.

- Model:
  - Markov chain.
    - State of Markov chain: a vector of the number of active stations with 0, 1, 2, ..., W packets in the queue.
    - State transition: when a successful transmission occurs (either from AP or STA).
Yu’s model

- Markov chain
  - M: total number of states, N_{STA}: number of stations.

- Throughput = Average over the throughput at all states.
  - Throughput at each state =
    \[ E[\text{Length of a data frame}] / E[\text{Duration between 2 successful transmissions}] \]

- Results

- Cons
  - Number of state exploded when W is large
Yu’s model

- Results

- Cons
  - Number of state exploded when $W$ is large

Bruno’08 model [3]

- Main features:
  - Infrastructure mode: $N_u$ upload stations and $N_d$ download stations.
  - A station either download or upload TCP data.
  - Arbitrary advertised window $W$.

- Model:
  - Markov chain.
    - State $(i, j)$: $i$ TCP data packets in the transmission queues of all upload stations and $j$ TCP ACK packets in the transmission queues of all download stations.
    - State transition: when a successful transmission occurs (either from AP or STA).
Bruno’08 model

- Markov chain

\[
\begin{align*}
\alpha_{0,0} & \quad \rho_{0,0}^u \\
\alpha_{1,0} & \quad \rho_{1,0}^u \\
\vdots & \quad \vdots \\
\alpha_{i,0} & \quad \rho_{i,0}^u \\
\alpha_{n_u,0} & \quad \rho_{n_u,0}^u \\
\beta_{0,0} & \quad \alpha_{0,0}^u \\
\beta_{1,0} & \quad \alpha_{1,0}^u \\
\vdots & \quad \vdots \\
\beta_{i,0} & \quad \alpha_{i,0}^u \\
\beta_{n_u,0} & \quad \alpha_{n_u,0}^u
\end{align*}
\]

\[
\begin{align*}
\alpha_{0,1} & \quad \rho_{0,1}^d \\
\alpha_{1,1} & \quad \rho_{1,1}^d \\
\vdots & \quad \vdots \\
\alpha_{j,1} & \quad \rho_{j,1}^d \\
\alpha_{n_d,1} & \quad \rho_{n_d,1}^d \\
\beta_{0,1} & \quad \alpha_{0,1}^d \\
\beta_{1,1} & \quad \alpha_{1,1}^d \\
\vdots & \quad \vdots \\
\beta_{j,1} & \quad \alpha_{j,1}^d \\
\beta_{n_d,1} & \quad \alpha_{n_d,1}^d
\end{align*}
\]

- Throughput calculation

First, determine for each state \((i,j)\)

- number of active upload stations = \(\min(i, N_u)\)
- number of active download stations = \(\min(j, N_d)\)

Then, calculate for each state

- the average TCP payload bits, and
- average duration between two consecutive successful frame transmission when the network.

Throughput = \(\frac{\text{Average TCP payload bits}}{\text{Average duration between two consecutive successful frame transmissions}}\)
Bruno’08 model

- Results

Non-Markov chain models
Kumar’s model [4]

- Main features:
  - Allow one station with multiple TCP connections of arbitrary types.
  - Assume TCP senders are saturated
    - Considerably limit scenarios where the analysis applies.

Sakurai’s model [5]

- Main features:
  - Infrastructure mode, n stations
  - All stations are either TCP upstream or downstream flows.
  - Arbitrary advertised window W

- Model
  - AP: assumed to be saturated
  - Fixed point system
    - $\tau_{AP} = \frac{1}{\text{Average backoff window per backoff stage}}$
    - $\tau_{STA} = \frac{\tau_{AP}}{n}$
    - $p_{AP} = 1 - (1 - \tau_{STA})^n$
    - $p_{STA} = 1 - (1 - \tau_{AP})(1 - \tau_{STA})^{n-1}$
Sakurai’s model

Results

TCP throughputs for persistent uplink flows.

TCP throughputs for persistent downlink flows.

Conclusion

- Infrastructure mode, with TCP flow control:
  - AP is the bottleneck
  - Total TCP throughput: constant regardless of number of TCP connections.
  - Average number of backlogged station: bounded by 2.
  - TCP upstream and downstream equally share channel bandwidth.

- Modelling TCP flow control
  - Based on saturated IEEE 802.11 MAC model.
  - Estimate the number of backlogged stations.
References


[7] B. Bellalta, M. Meo, and M. Oliver, “Comprehensive Analytical Models to Evaluate the TCP Performance in 802.11 WLANs,” 4th Wired/Wireless Internet Communications (LNCS), Bern, Switzerland, May 2006.