Modeling TCP flow control over IEEE 802.11 WLANs

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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

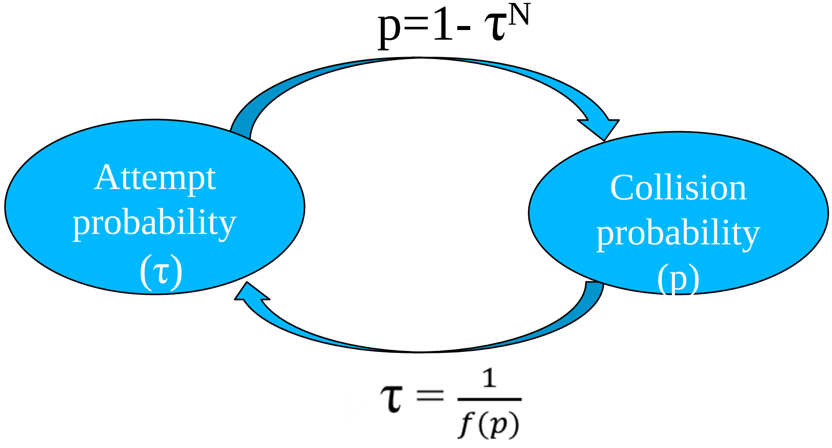
➡ How do they interact?

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



$p=1-\tau^N$

Attempt probability (τ)

Collision probability (p)

$$\tau = \frac{1}{f(p)}$$

$f(p)$: *Average contention window per backoff stage*

- From τ 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,

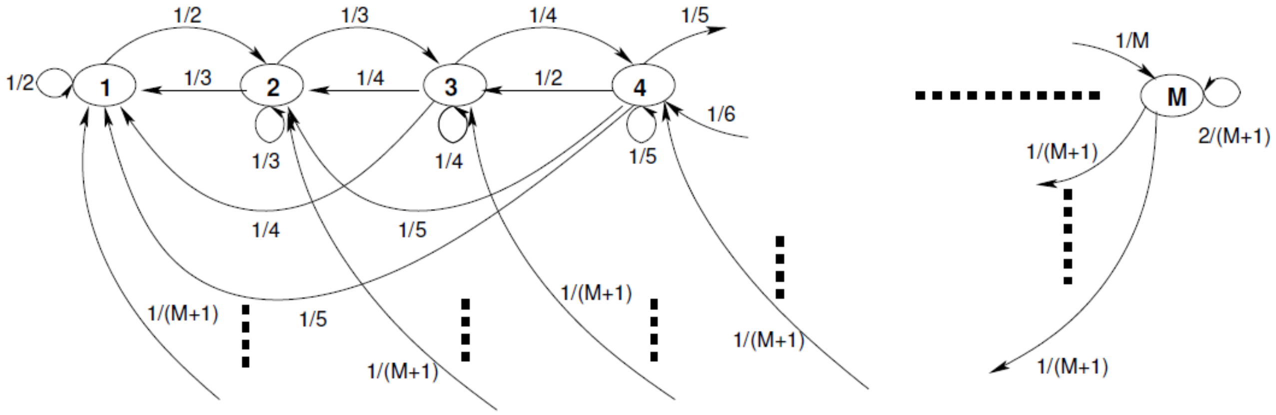
Markov chain models

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.

Bruno’04 model

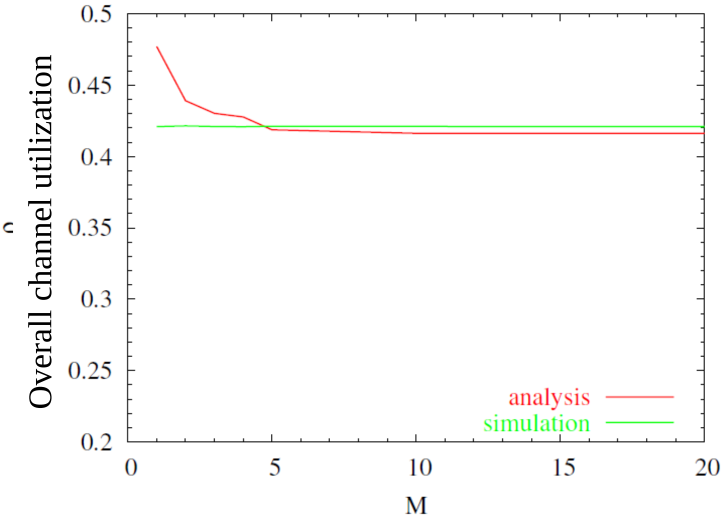
- Markov chain
  - M: number of stations



- Total channel utilization = Channel utilization of AP + Channel utilization of STAs
  - Channel utilization of AP = E[Time occupied by payload of a successful transmission of AP] / E[Duration between two consecutive successful transmission of AP]

Bruno’04 model

- Results
  - M<5: less accurate.

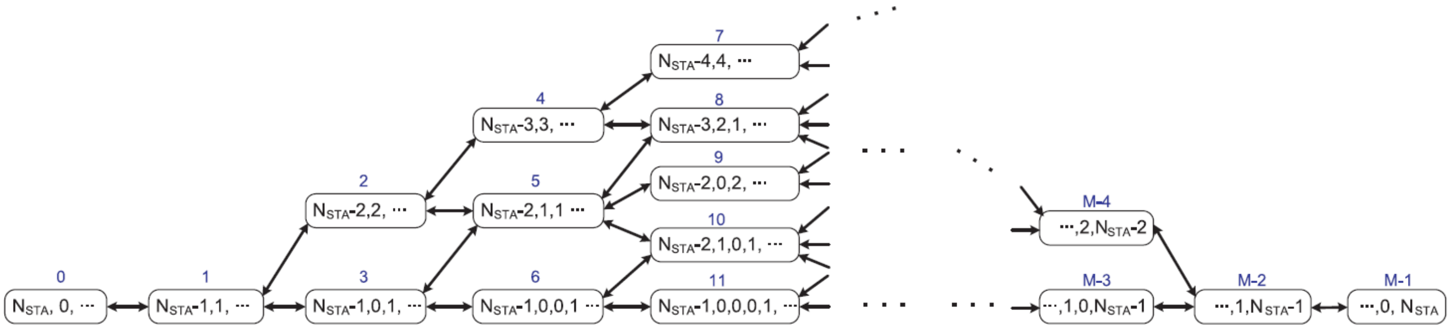


Yu’s model [2]

- 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.

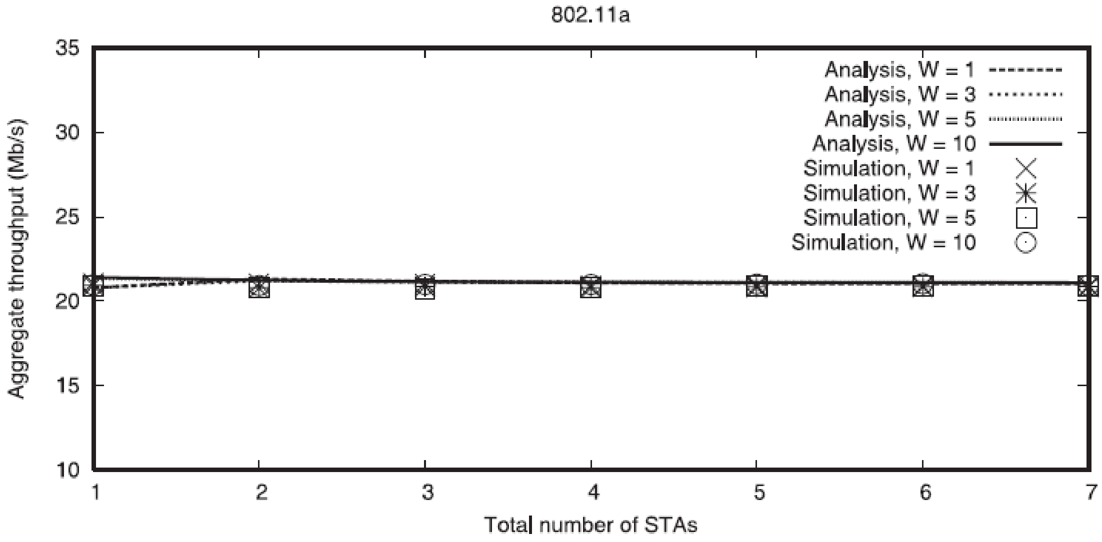


- Throughput = Average over the throughput at all states.
  - Throughput at each state =

    E[Length of a data frame] / E[Duration between 2 successful transmissions]

Yu’s model

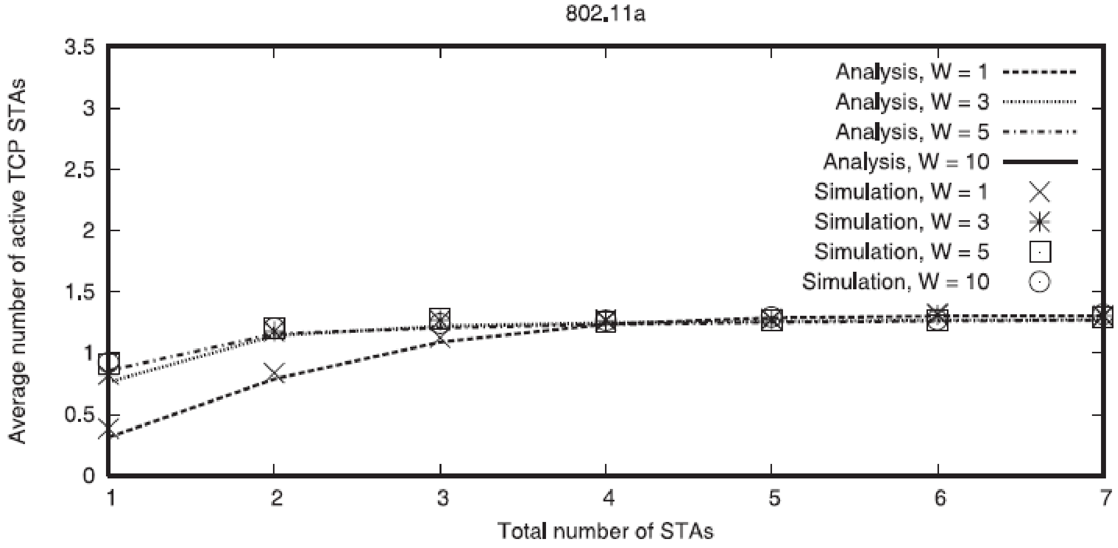
- Results



- Cons
  - Number of state exploded when W is large

Yu's model

- Results



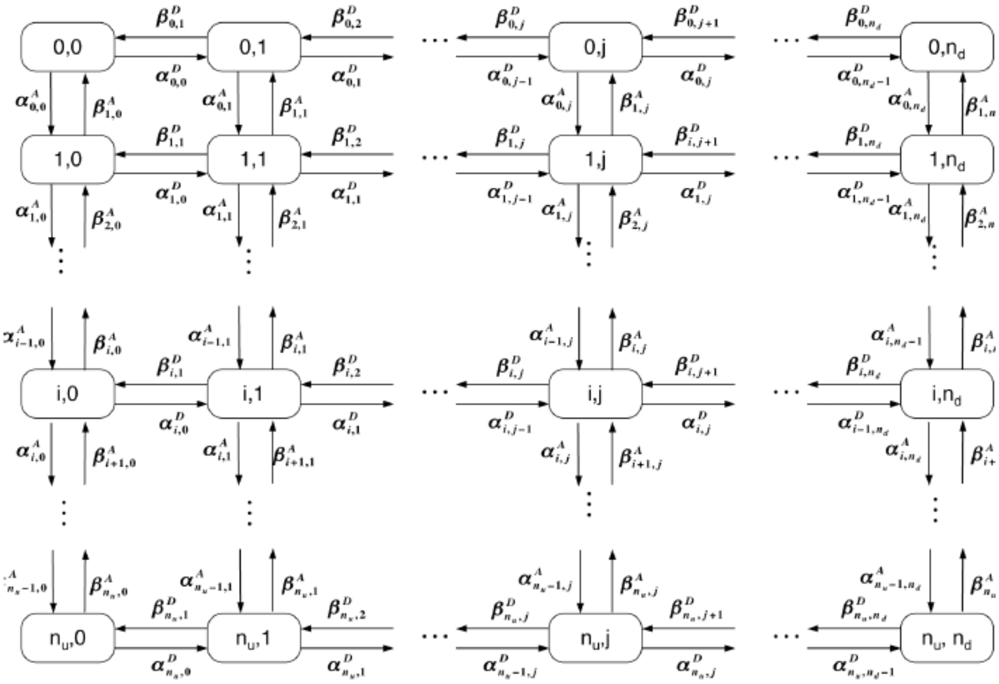
- Cons
  - Number of state exploded when W is large

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

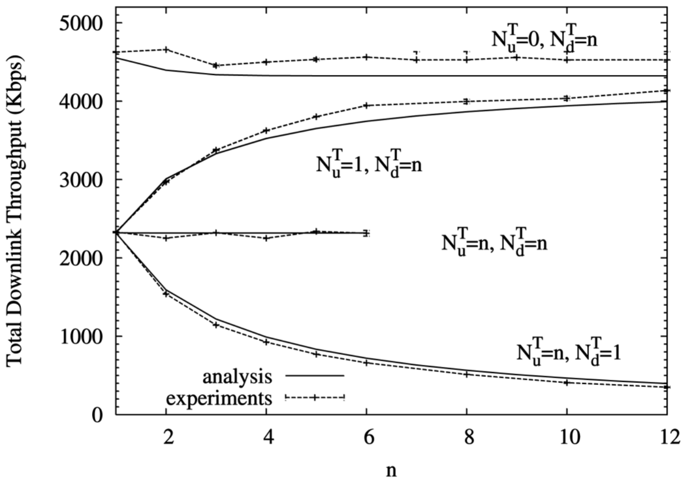


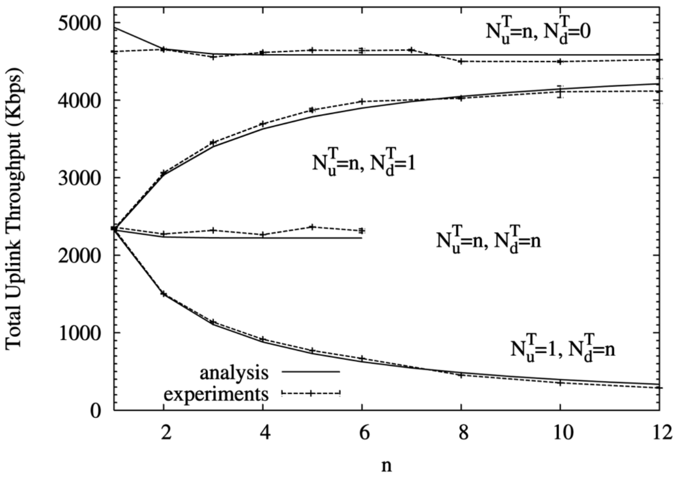
Bruno’08 model

- 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 = Average TCP payload bits / Average duration between two consecutive successful frame transmissions.

Bruno’08 model

- Results





Non-Markov chain models

Kumar's model [4]

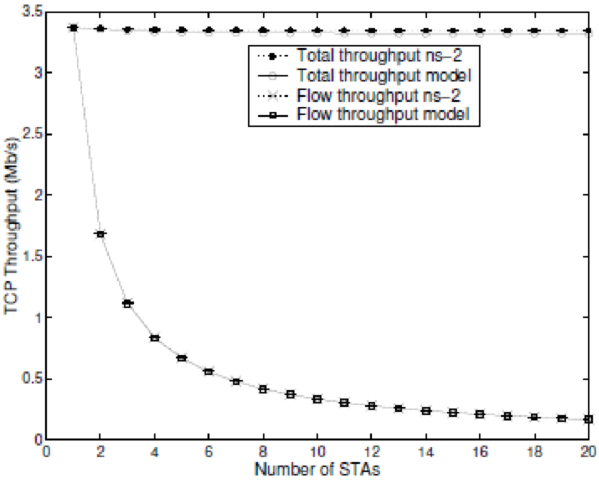
- Main features:
  - Allow one station with multiple TCP connections of arbitrary types.
  - Assume TCP senders are saturated
    - Considerably limit scenarios where the analysis applies.

Sakurai's model [5]

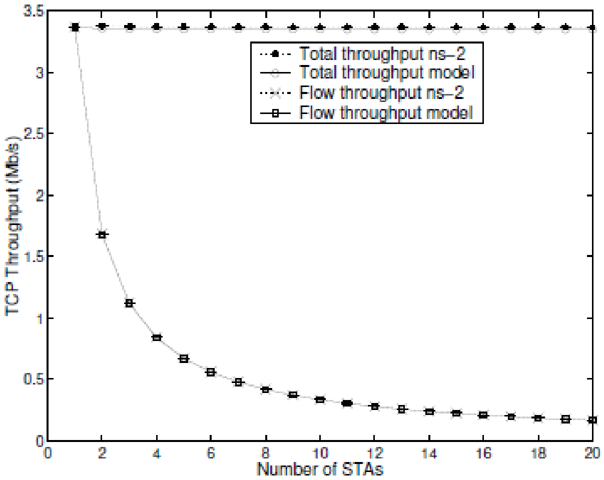
- Main features:
  - Infrastructure mode, n stations
  - All stations are either TCP upstream or downstream flows.
  - Arbitrary advertised window W
- Model
  - AP: assumed to be saturated
  - Fixed point system
    - τ_{AP} = 1 / Average backoff window per backoff stage
    - $\tau_{STA} = \frac{\tau_{AP}}{n}$
    - $p_{AP}=1-(1-\tau_{STA})^n$
    - $p_{STA}=1-(1-\tau_{AP})(1-\tau_{STA})^{n-1}$

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.

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[6] D. Miorandi, A. Kherani, and E. Altman, “A Queueing Model for HTTP Traffic over IEEE 802.11 WLANs,” Elsevier Computer Networks J., vol. 50, no. 1, pp. 63-79, Jan. 2006.

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