Analysis of IEEE 802.11 Distributed Coordination Function with Service Differentiation Support in Non-Saturation Conditions

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Outline

- Introduction
- Performance analysis
- Idea of an adaptive scheme
- Results
- Conclusions

Introduction

- Challenge: Providing Quality of Service (QoS) guarantees over IP-based wireless access networks, such as, IEEE 802.11 MAC. CSMA/CA
- Basic DCF method is not appropriate for handling multimedia traffic which requires guarantees about throughput and delay.

Performance Analysis

802.11 access mechanism

basic access

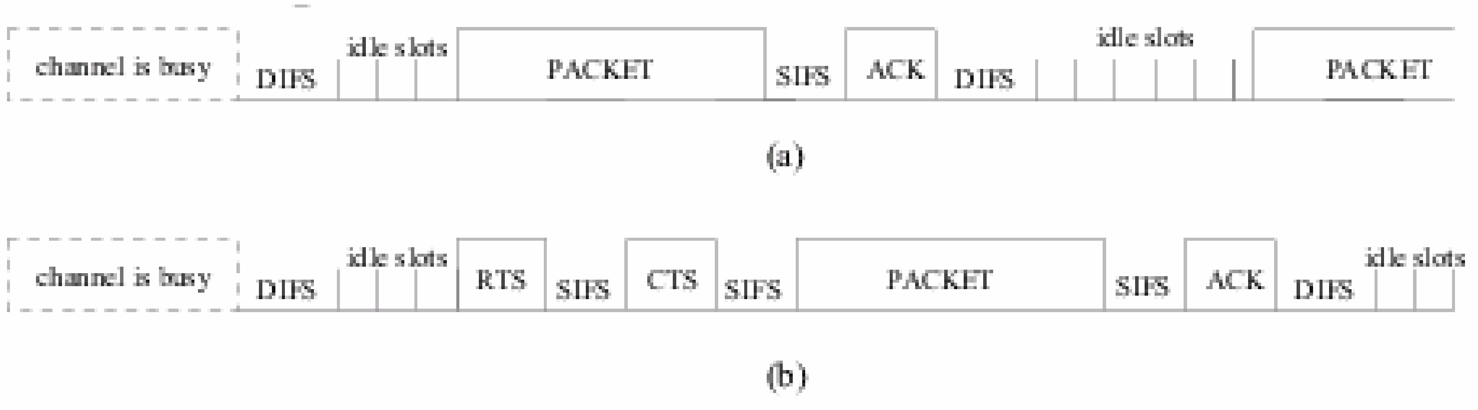


Figure from Winands et al. 2004

Introduction

- Contribution 1: Analysis of system performance in non-saturation state.
- Contribution 2: A simple model-based adaptive scheme is proposed. (ongoing work)

Performance Analysis

let us define $W_i = CW_{min,i}$ = as the minimum contention window

m_i "maximum backoff stage", the value

such that $CW_{max,i} = 2^{m_i} \cdot W_i$

One building blocks used to achieve service differentiation: differentiating the minimum contention window sizes of different traffic flows.

Performance Analysis

System Structure

1. A single-hop system is considered.
2. Channel conditions are ideal.
3. Each traffic flow has it own traffic characteristics.
4. Each traffic flow has it own performance requirements.

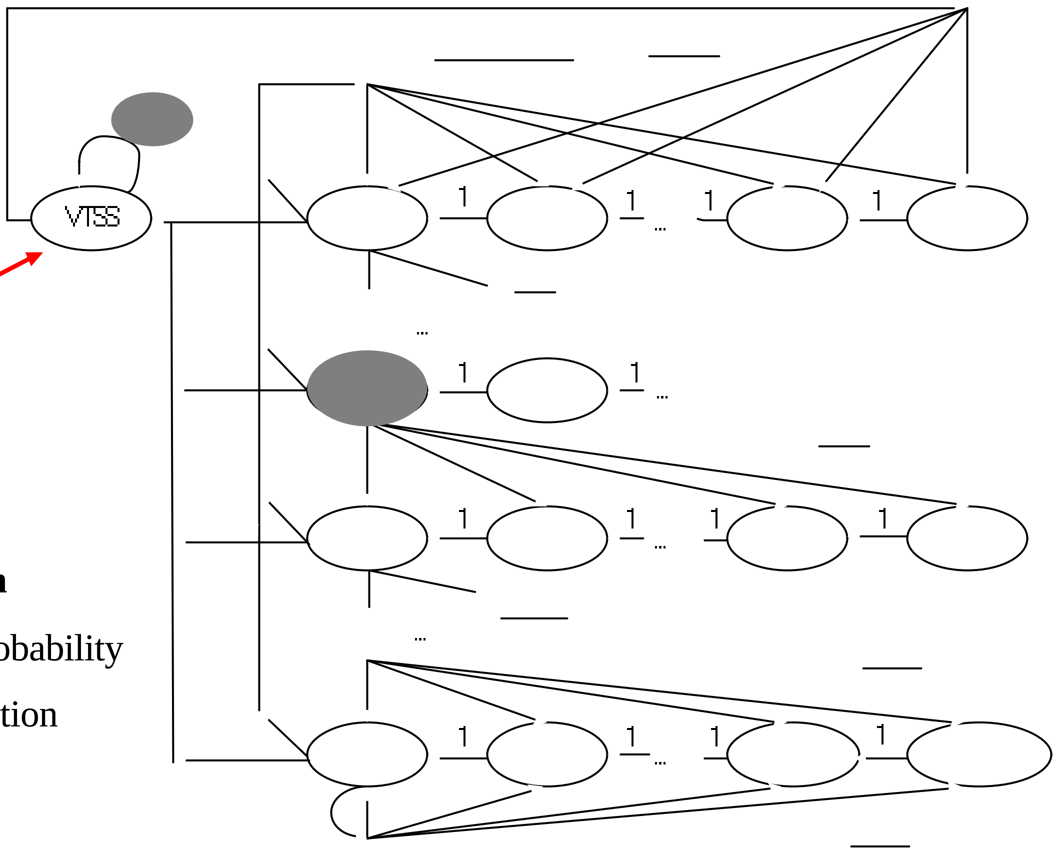
Performance Analysis

A two-dimensional discrete-time Markov chain is used to model the behavior of a traffic flow. The states are defined as the combinations of two integers $\{s_i(t), b_i(t)\}$ $(i=1,\ldots,M)$

Backoff stage

Backoff time counter

Performance Analysis



waiting for

next packet

DCF: "slotted" version

conditional collision probability

related to packet generation

i.d. traffic flows)

Markov model of backoff process for *i*-th traffic flows

Performance Analysis

P_L: The time duration for a packet payload.

P_s: The average time of a slot when successful transmission of a packet.

P_c: The average time of a slot when a collision occurs.

$T_{p,i}$: The average packet inter-arrival duration for *i*-th traffic flow.

$T_{d,i}$: The average packet delay for *i*-th traffic flow.

$P_{VTSS,i}$: The probability for the traffic flow being at VTSS (Virtual Time Slot State).

Performance Analysis

Important relationships:

$$\frac{\left\{(1-2p_i)(W_i+1)+p_iW_i[1-(2p_i)^{m_i}]\right\}\cdot t_i}{2(1-2p_i)}+P_{VTSS,i}=1$$

τ_i probability that type *i* traffic flow transmits in a time slot

$$p_i=\alpha_i\cdot[1-(1-\tau_i)^{n_i-1}\prod_{j=1,j\neq i}^{M}(1-\tau_j)^{n_j}]$$

Compensation factors to account for correlations

onditional collision probability

Performance Analysis

Important relationships:

Total throughput

$$S = \sum_{i=1}^{M} s_i = \sum_{i=1}^{M} \frac{P_L}{T_{p,i}}$$

$$= \frac{P_L \cdot \sum_{i=1}^{M} t_i \cdot (1 - p_i)}{h \cdot s \cdot \prod_{i=1}^{M} (1 - t_i) + P_s \cdot \sum_{i=1}^{M} t_i \cdot (1 - p_i) + [1 - h \cdot \prod_{i=1}^{M} (1 - t_i) - \sum_{i=1}^{M} t_i \cdot (1 - p_i)] \cdot P_c}$$

Compensation factor to account for correlations

Performance Analysis

Important relationships:

$$T_{d,i} \approx \frac{P_L}{s_i}(1 - P_{VTSS,i}) + \frac{P_s}{1 - p_i} \cdot P_{VTSS,i}$$

Average packet delay

Performance Analysis

Important relationships:

Assuming $\tau_i^* \ll 1$

Target packet delay requirements

$$W_i < \left(\hat{T}_{d,i} - \frac{P_s}{1 - p_i^{'}} \right) \Big/ g^{'}$$

System operation point

where

$$g^{'} = \left(\frac{P_L}{s_i} - \frac{P_s}{1 - p_i^{'}} \right) \cdot \frac{(1 - 2p_i^{'}) + p_i^{'} \cdot [1 - (2p_i^{'})^{m_i}]}{2(1 - 2p_i^{'})} \cdot t_i^{'}$$

Adaptive Scheme

Approximation:

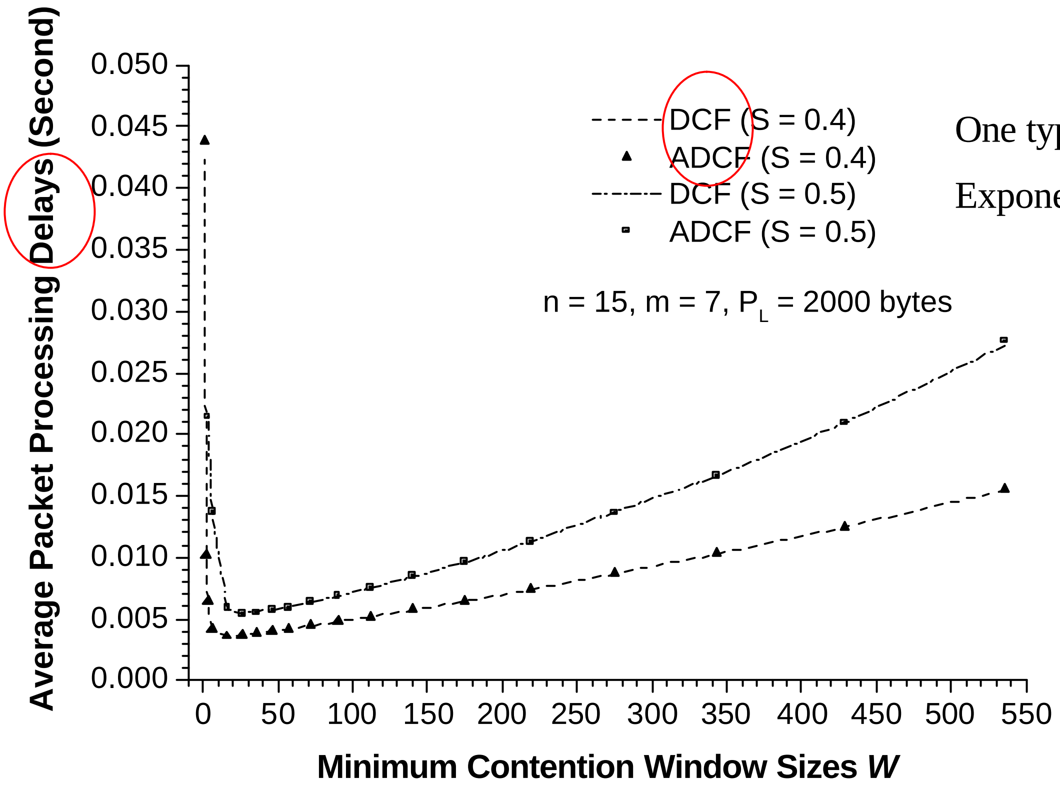
$$S=\sum_{i=1}^{M} s_i=\sum_{i=1}^{M}\frac{P_L}{T_{p,i}}\approx\frac{t_i\cdot\sum_{j=1}^{M}\frac{s_j}{s_i}}{\left(s+P_s\cdot t_i\cdot\sum_{j=1}^{M}\frac{s_j}{s_i}+P_c\cdot t_i^{\,2}\cdot\sum_{\substack{j\neq k\\1\leq j,k\leq M}}\frac{s_j s_k}{s_i^{\,2}}\right)}$$

Adaptive Scheme

Implementation Considerations:

1. the implementation is based on an fully distributed scheme
2. throughputs s_i (i=1,…,M) are to be estimated by each station in the network. It can be implemented by counting ACK packets for each traffic flow over the wireless channel.
3. After obtaining the estimated packet transmission rates, packet collision rate can be obtained. Then, the target minimum contention window size can be obtained.

Some Results

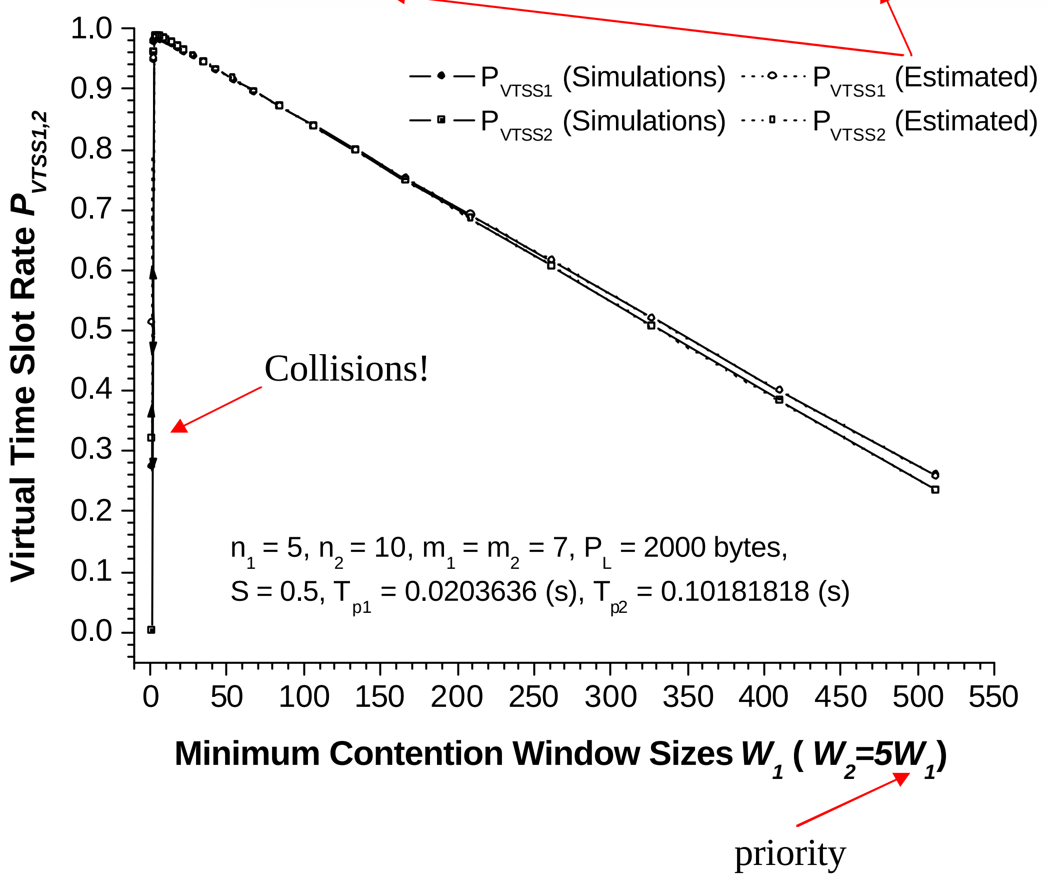


One type of traffic

Exponential distribution for i.arrival

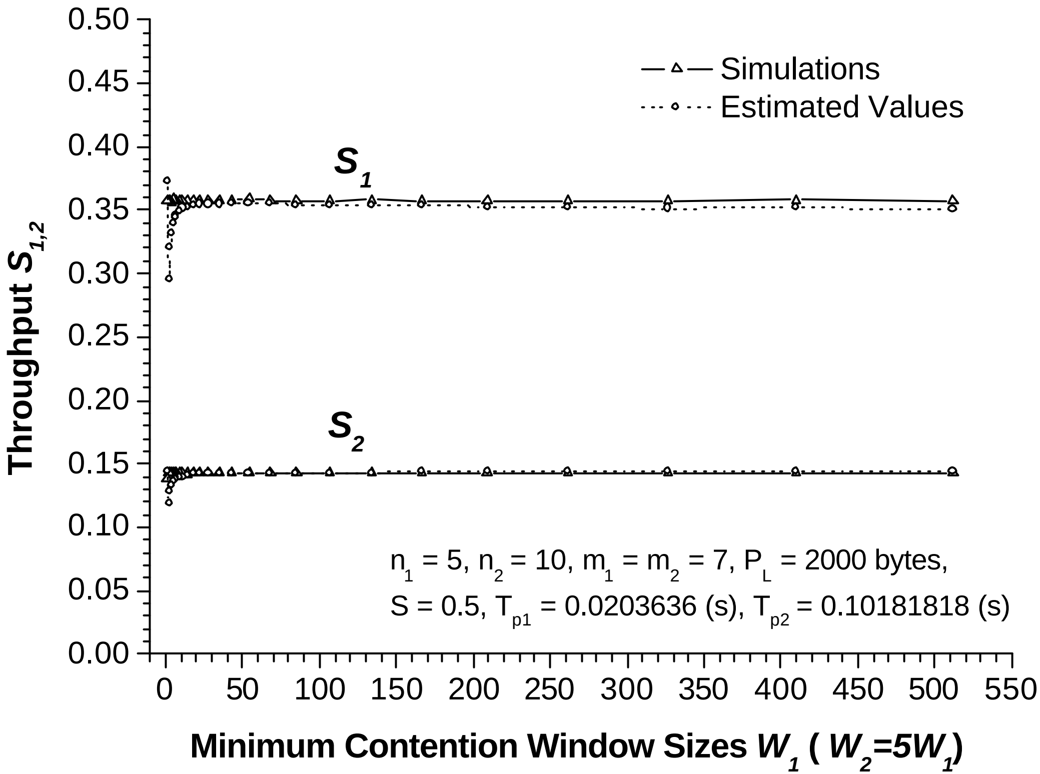
Some Results

$$\left\{(1-2p_i)(W_i+1)+p_iW_i[1-(2p_i)^{m_i}]\right\}\cdot\tau_i\Big/[2(1-2p_i)]+P_{VTSS,i}=1 \qquad (3)$$



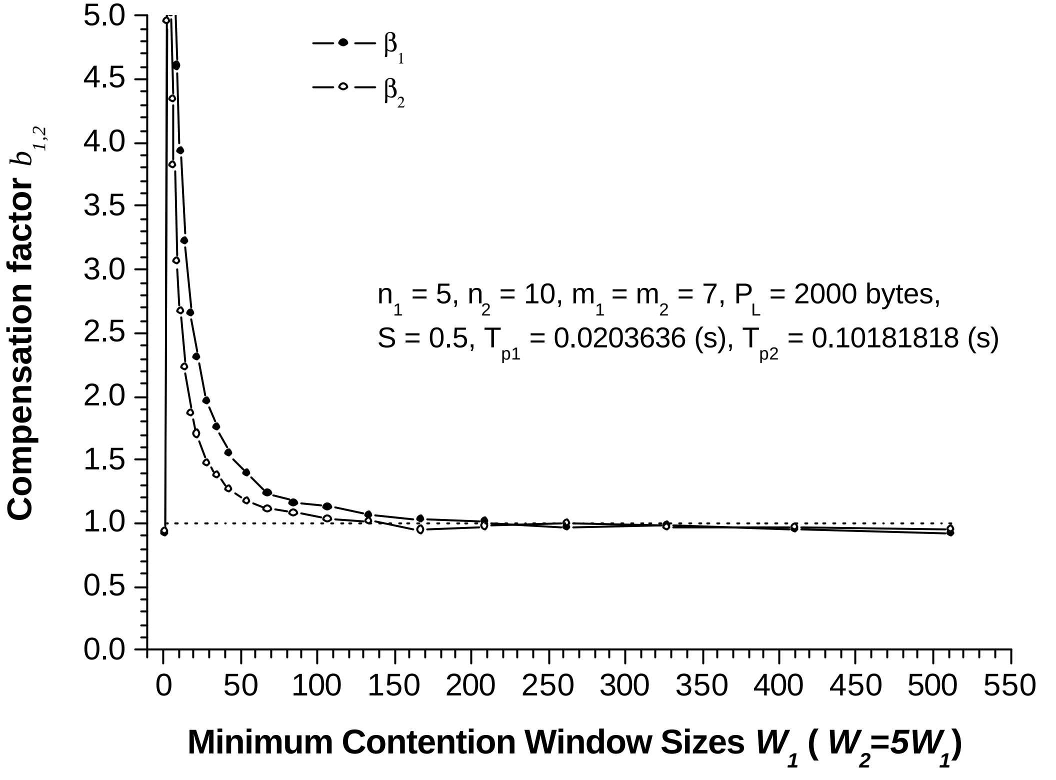
Some Results

$$S=\sum_{i=1}^{M}S_i=\sum_{i=1}^{M}\frac{n_i P_L}{T_{p,i}}=\frac{P_L\cdot\sum_{i=1}^{M}n_i\cdot\tau_i\cdot(1-p_i)}{\left(\begin{array}{l}\beta\cdot\sigma\cdot\prod_{i=1}^{M}(1-\tau_i)^{n_i}+P_s\cdot\sum_{i=1}^{M}n_i\cdot\tau_i\cdot(1-p_i)+\\ {[1-\beta\cdot\prod_{i=1}^{M}(1-\tau_i)^{n_i}-\sum_{i=1}^{M}n_i\cdot\tau_i\cdot(1-p_i)]\cdot P_c}\end{array}\right)} \quad (5$$

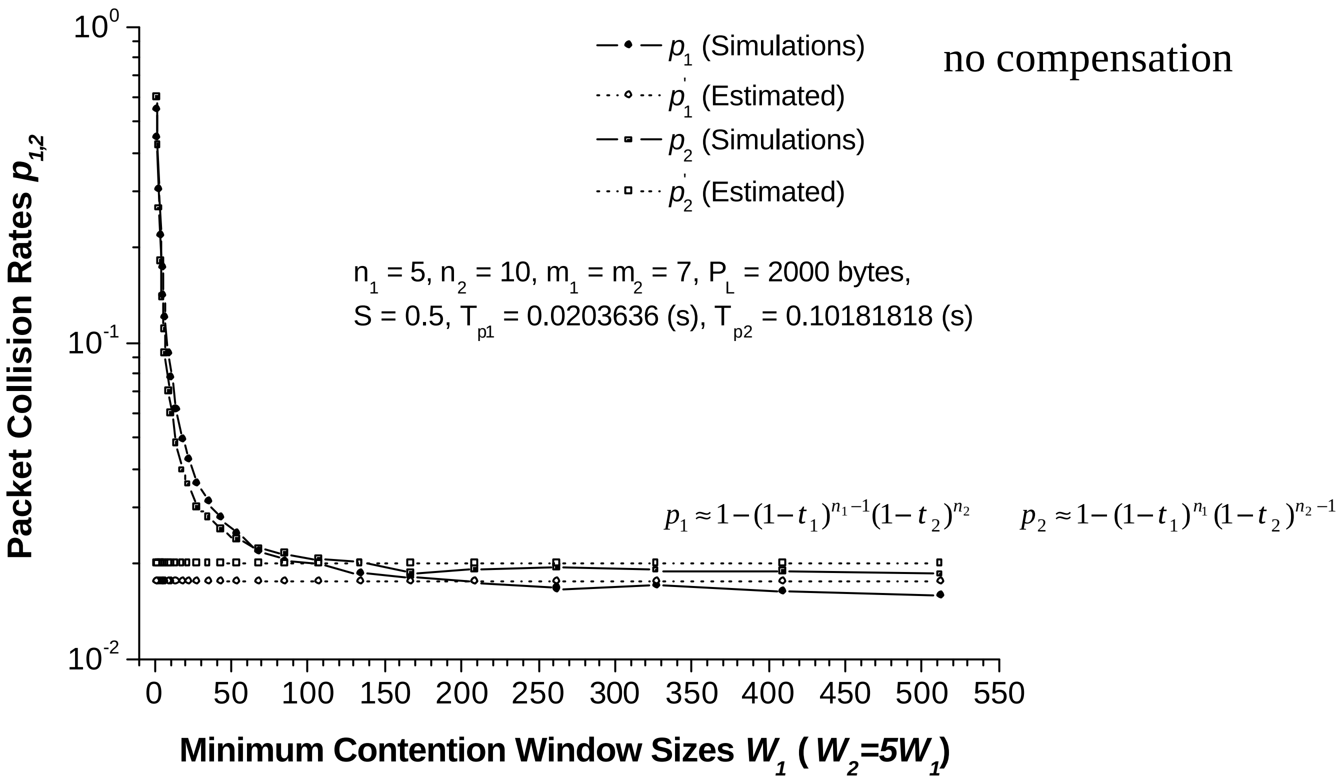


Some Results

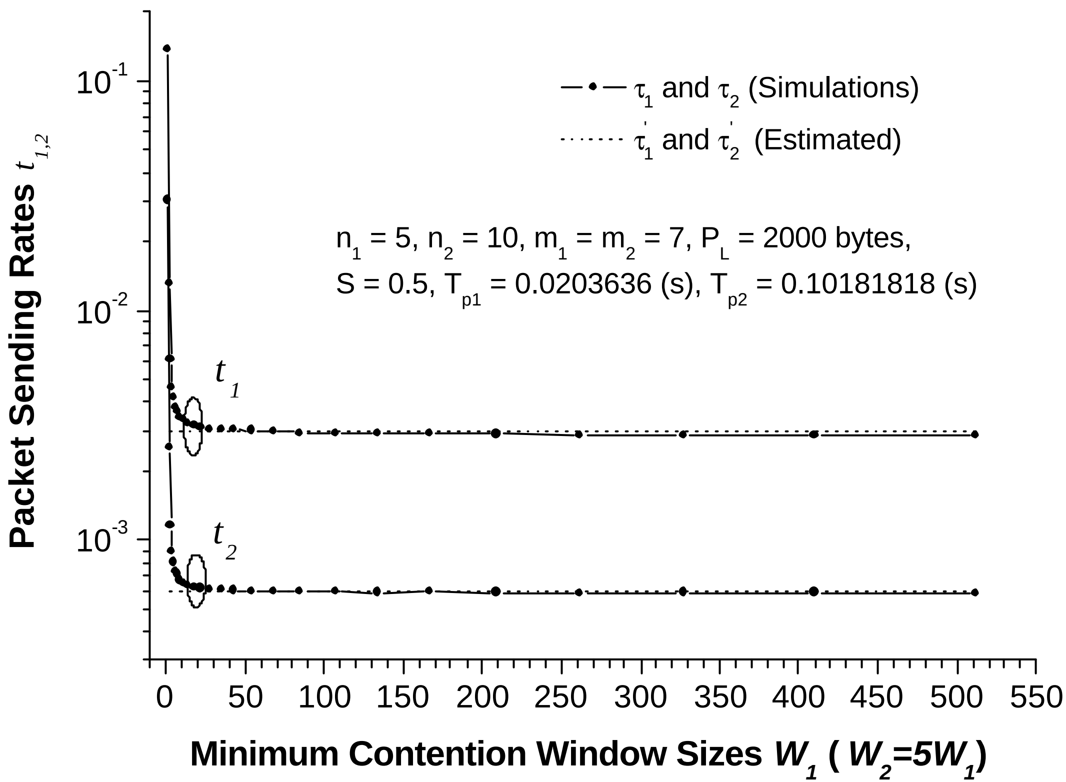
$$p_i = \alpha_i \cdot [1-(1-\tau_i)^{n_i-1} \prod_{j=1, j\neq i}^{M} (1-\tau_j)^{n_j}]$$



Some Results



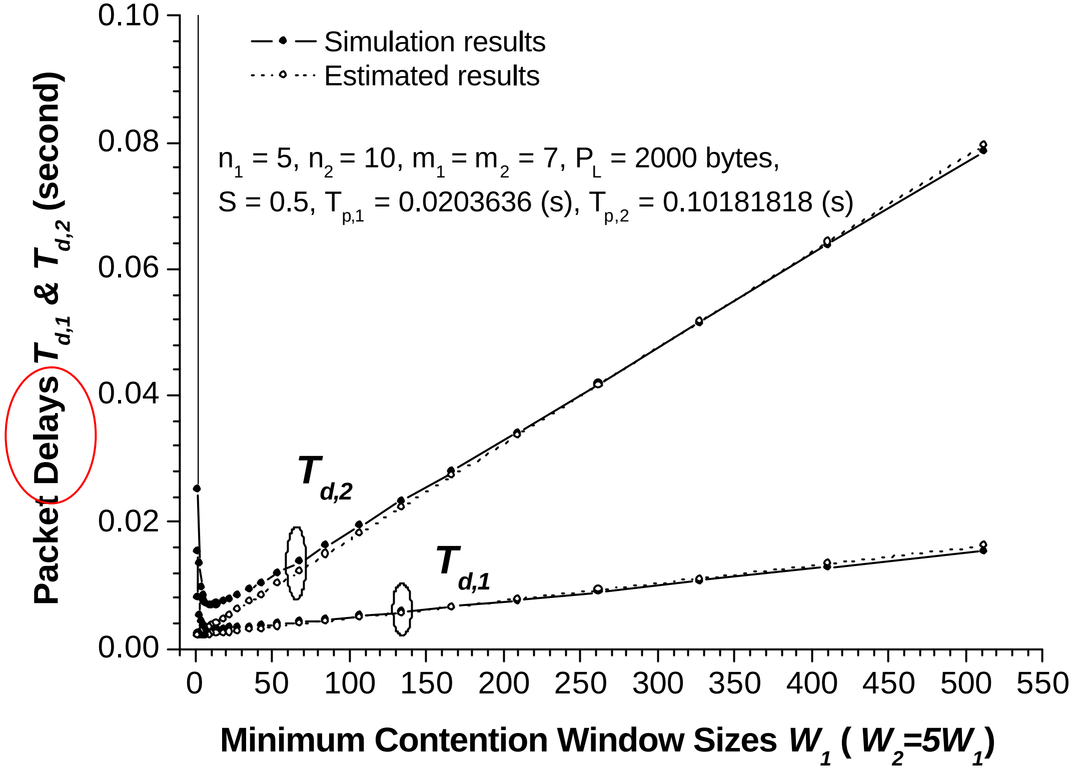
Some Results



Some Results

$$T_{d,i} = T_{p,i} - \overline{n}_{VTS,i} \cdot T_{VTS,i} \approx \frac{n_i P_L}{S_i}(1 - P_{VTSS,i}) + \frac{P_s}{1-p_i} \cdot P_{VTSS,i} \quad (11)$$

No compensation factors



Some Results

Node ID	Delay requirements	Average Delay
1	0.005	0.005137
2	0.005	0.005074
3	0.005	0.005258
4	0.010	0.010040
5	0.010	0.010291
6	0.010	0.095630
7	0.015	0.015363
8	0.015	0.015757
9	0.015	0.014321
10	0.020	0.019425
11	0.020	0.019446
12	0.020	0.018734
13	0.025	0.025403
14	0.025	0.024120
15	0.025	0.022622

set Wi

Conclusions

- Propose an analysis model for IEEE 802.11 DCF in non-saturation state.
- Propose a simple model-based adaptive scheme.
- Limitation 1: Based on single-hop assumption.
- Limitation 2: Ideal Channel assumptions.

Thank you!