Analysis of the Distribution of the Backoff Delay in 802.11 DCF: A Step Towards End-to-end Delay Guarantees in WLANs

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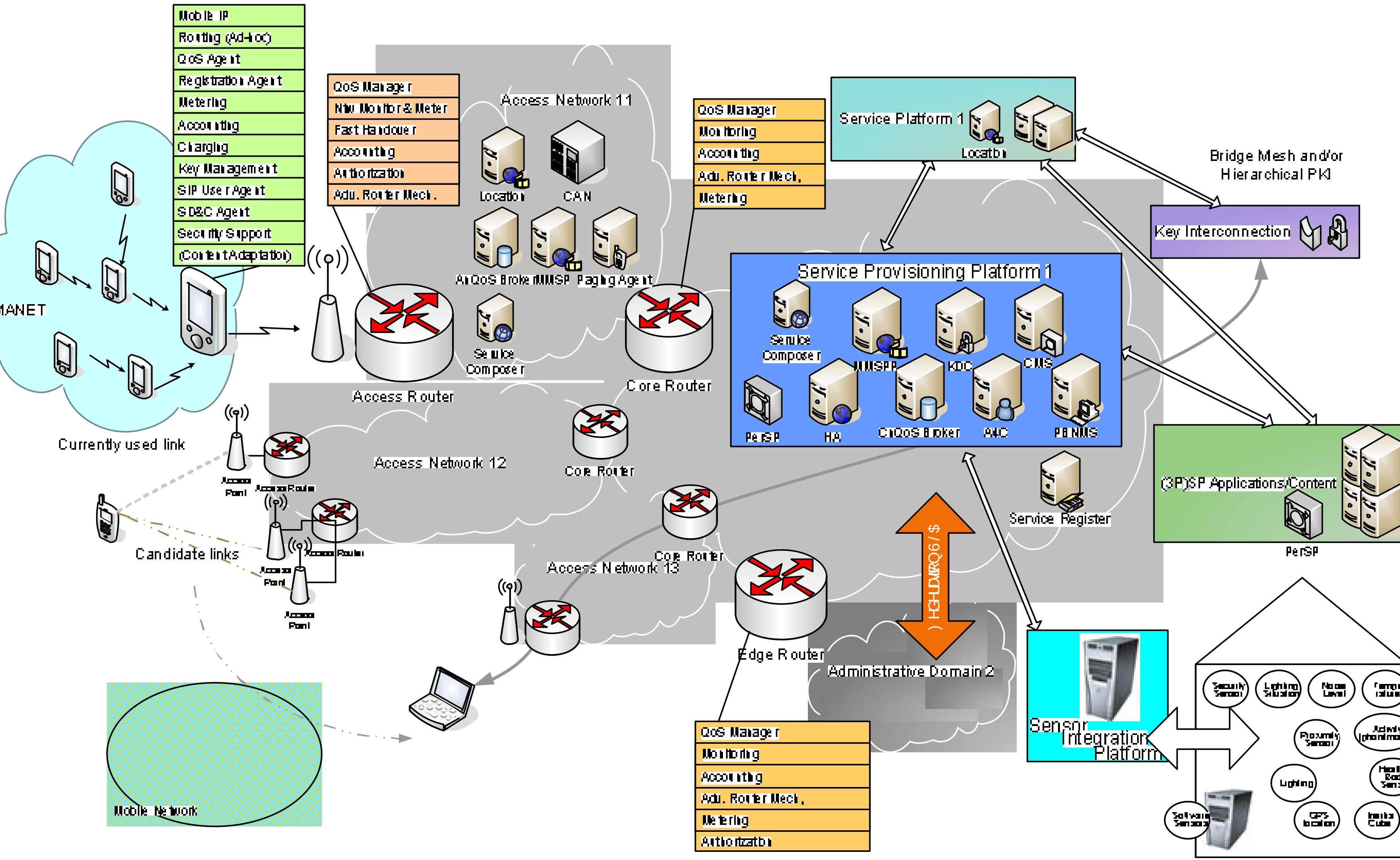
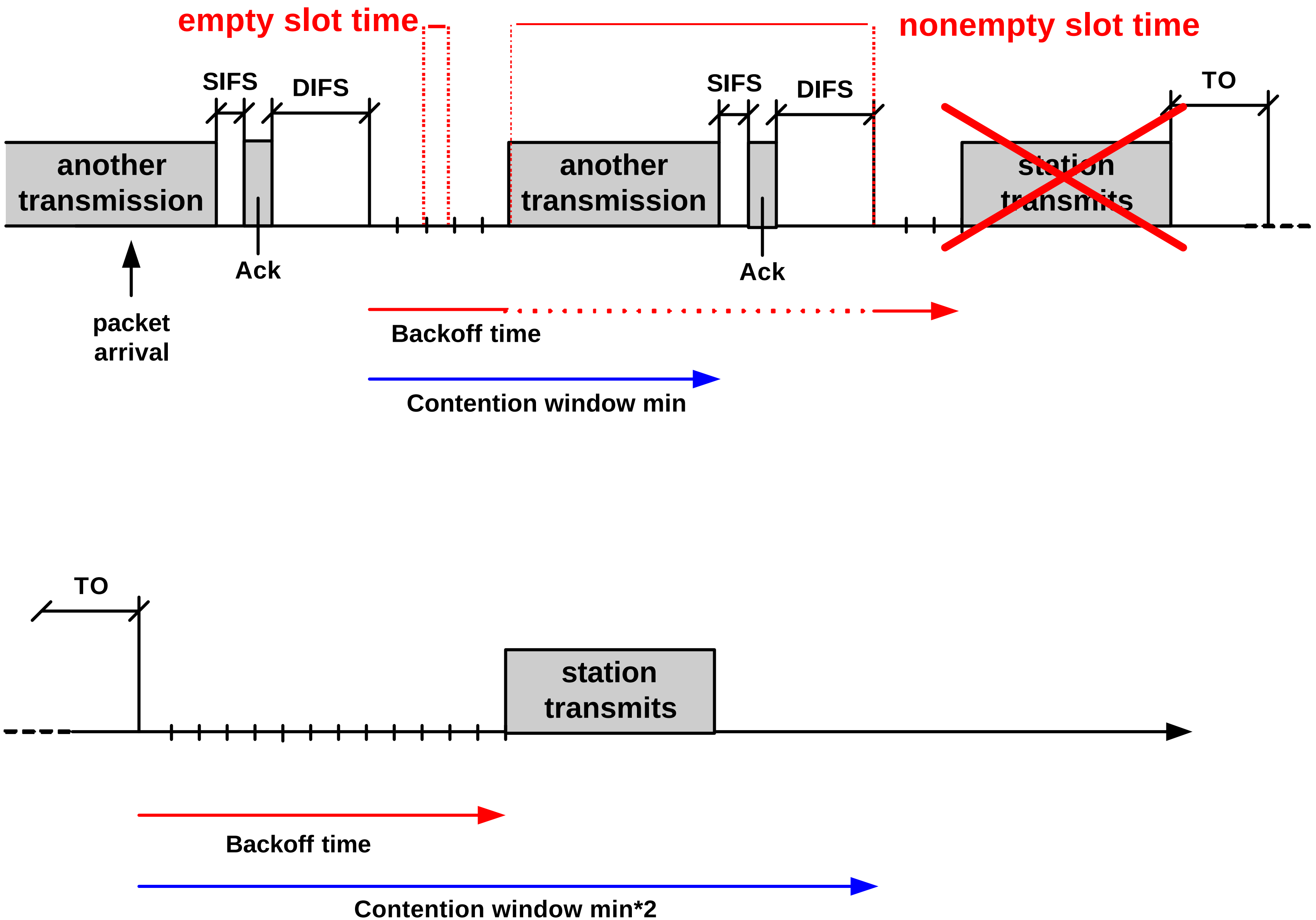
The Daidalos Project



QoS in 802.11

- Daidalos aims at providing QoS guarantees over 802.11 among other wireless technologies
- QoS over 802.11 is being implemented using the EDCA access mechanism of the upcoming 802.11e standard
- We need algorithms that can efficiently compute the delay performance in order to guarantee QoS by means of admission control executed at run-time
- Delay analyses of EDCA are not available in the literature
- Delay analysis of DCF are restricted to
  - average delay (not sufficient for real-time applications)
  - pgf (very costly computationally)
- In this work we study as a first step towards QoS in 802.11 the distribution of the backoff component of the delay in DCF under saturation conditions

802.11 DCF



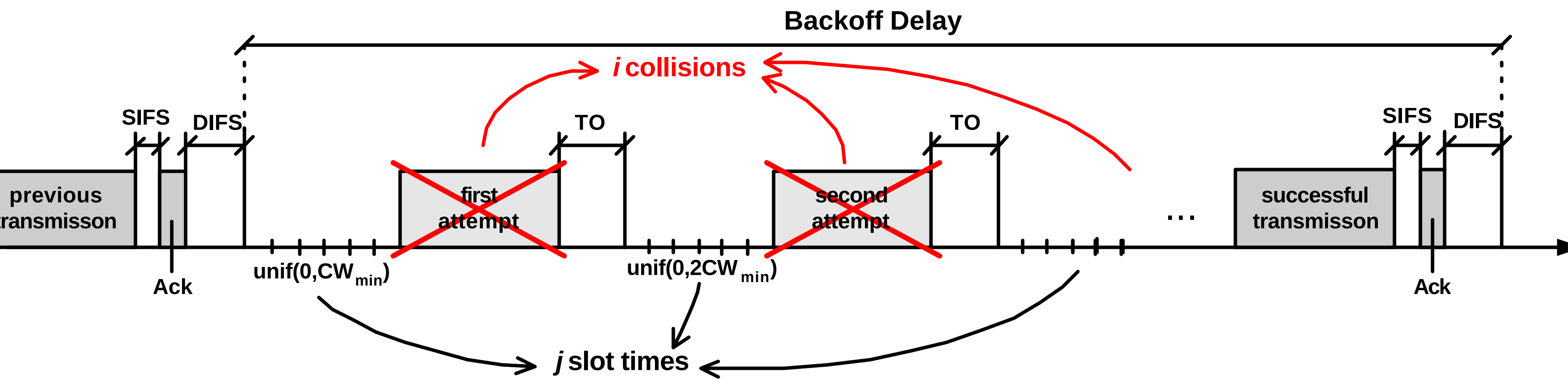
empty slot time
nonempty slot time
SIFS
DIFS
SIFS
DIFS
TO
another transmission
another transmission
station transmits
Ack
Ack
packet arrival
Backoff time
Contention window min
TO
station transmits
Backoff time
Contention window min*2

Analysis: Assumptions and Goal

- **Backoff delay**: time elapsed since a frame starts its backoff process until it is successfully transmitted
  - one of the main components of the delay
  - another important component: queuing delay
- **Saturation conditions**: we assume that all stations have always packets to transmit
  - worst case
  - can be used to provide delay guarantees
- **Goal**: distribution of the backoff delay under saturation conditions
  - number of stations: N

$$P(d < D)$$

Analysis (I)



- **i**: number of collisions suffered by the packet

$$P(d < D) = \sum_{i=0}^{R} P(d < D / i \text{ col}) P(i \text{ col})$$

- **j**: total number of slot times until successful transmission

$$P(d < D) = \sum_{i=0}^{R} \sum_{j=0}^{M} P(d < D / i \text{ col}, j \text{ slots}) P(j \text{ slots} / i \text{ col}) P(i \text{ col})$$

Analysis (II)

- The total number of slots given **i** collisions is the sum of i uniform random variables
  - can be computed efficiently using FFT

$$P(j\ \text{slots} / i\ \text{col}) = \left(f_1 * f_2 * \ldots * f_i \right)_j$$

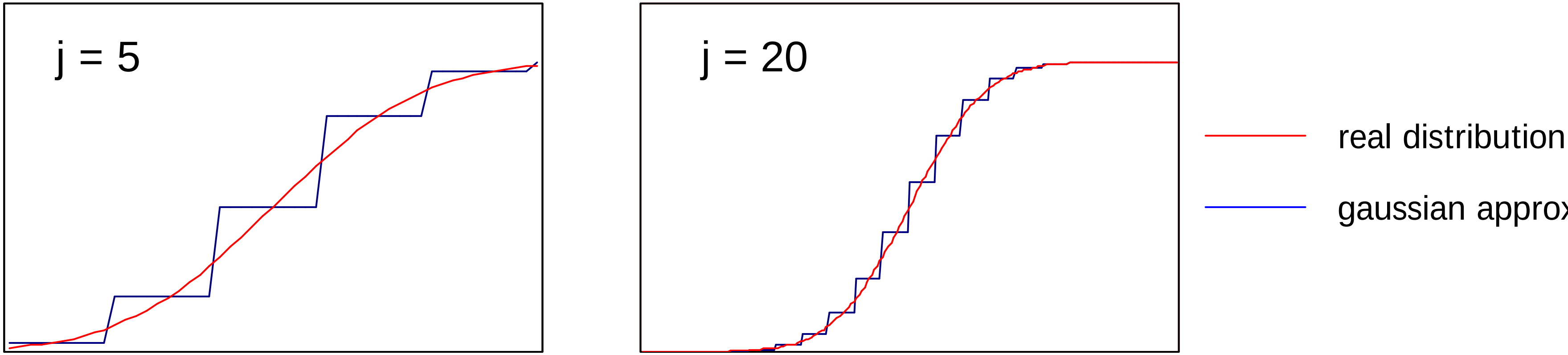
- t : probability that a station transmits at a randomly chosen slot time
  - computed by Wu et al., INFOCOM 2002

$$P(i\ \text{col}) = P_c^i P_s = (1-(1-t)^{N-1})^i (1-t)^{N-1}$$

Analysis (III)

$$P(d < D) = \sum_{i=0}^{R} \sum_{j=0}^{M} \underbrace{P(d < D / i\ \mathrm{col},\ j\ \mathrm{slots})}_{\text{missing: } P(d_{ij}<D)} \underbrace{P(j\ \mathrm{slots} / i\ \mathrm{col})}_{\text{done}} \underbrace{P(i\ \mathrm{col})}_{\text{done}}$$

- **Key approximation**: **d_{ij}** follows a gaussian distribution
  - ➢ CLT ensures that this approximation is accurate for j large
  - ➢ j small is not relevant (delay guarantees are surely met)



Analysis (IV)

- With the gaussian assumption, it is enough to obtain the average and typical deviation of $\mathbf{d_{ij}}$ to compute $P(d_{ij}<D)$

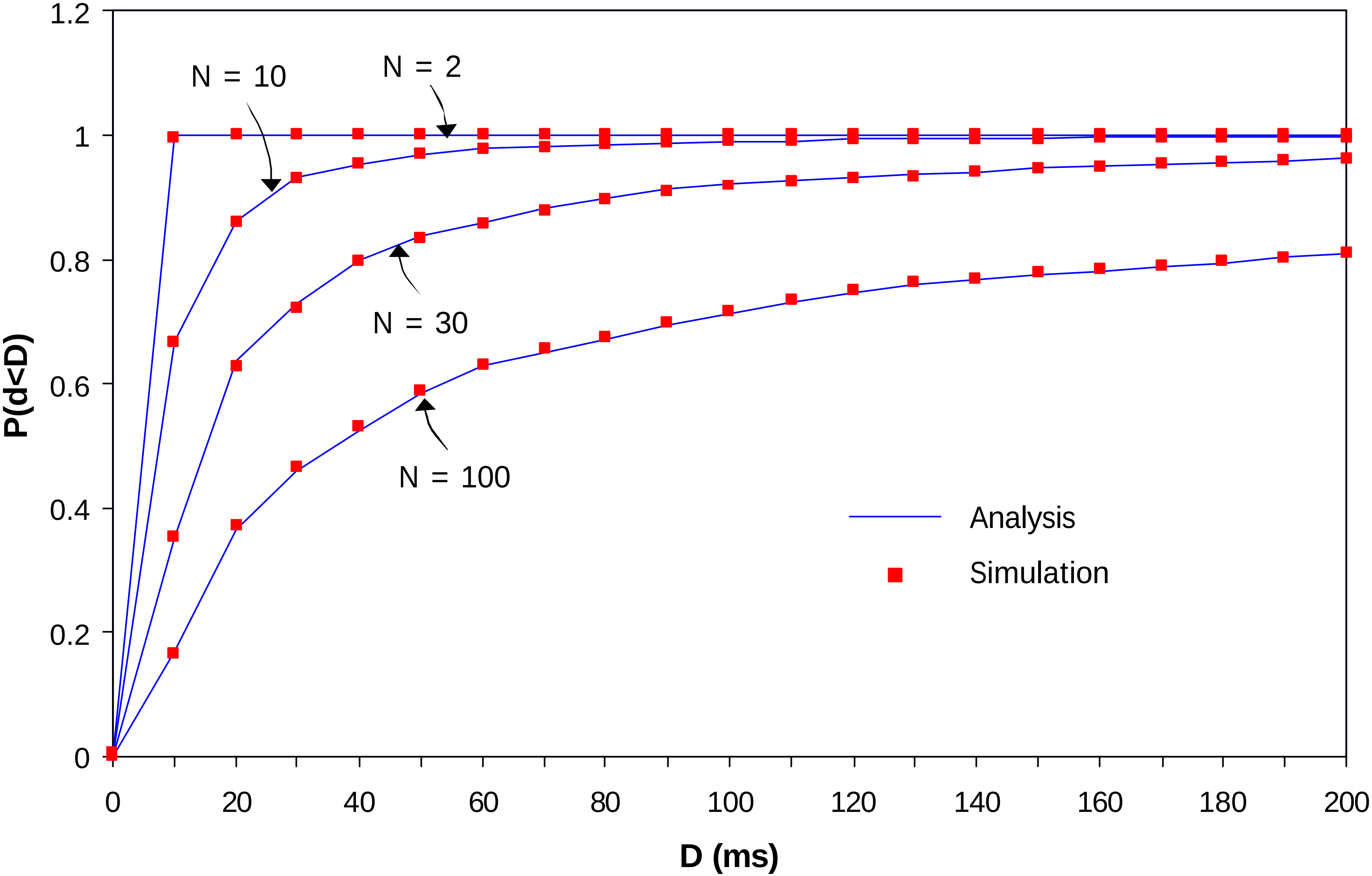
$$m_{ij} = j(P_s T_s + P_e T_e + P_c T_c) + iT_c + T_s$$

$$\boldsymbol{s}_{ij}^{2} = j(P_s T_s^2 + P_e T_e^2 + P_c T_c^2)$$

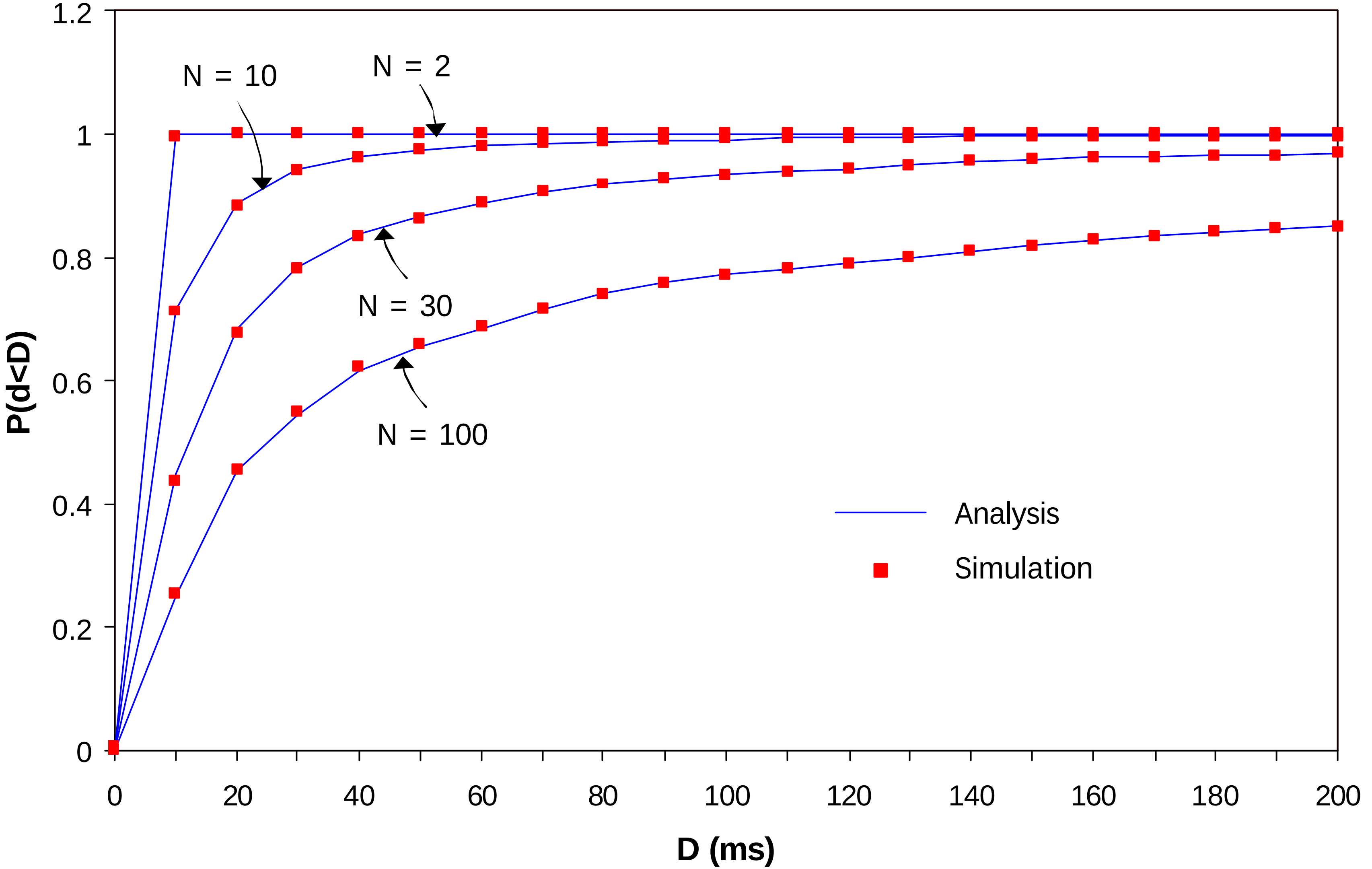
where P_s, P_c and P_e are the probabilities of success, collision and empty (which can be computed from t), and T_s, T_c and T_e are the respective time slot durations

- The basic analysis assumes no RTS/CTS and fixed packet lengths
    - ➢ extensions for RTS/CTS and non fixed lengths are provided in the paper

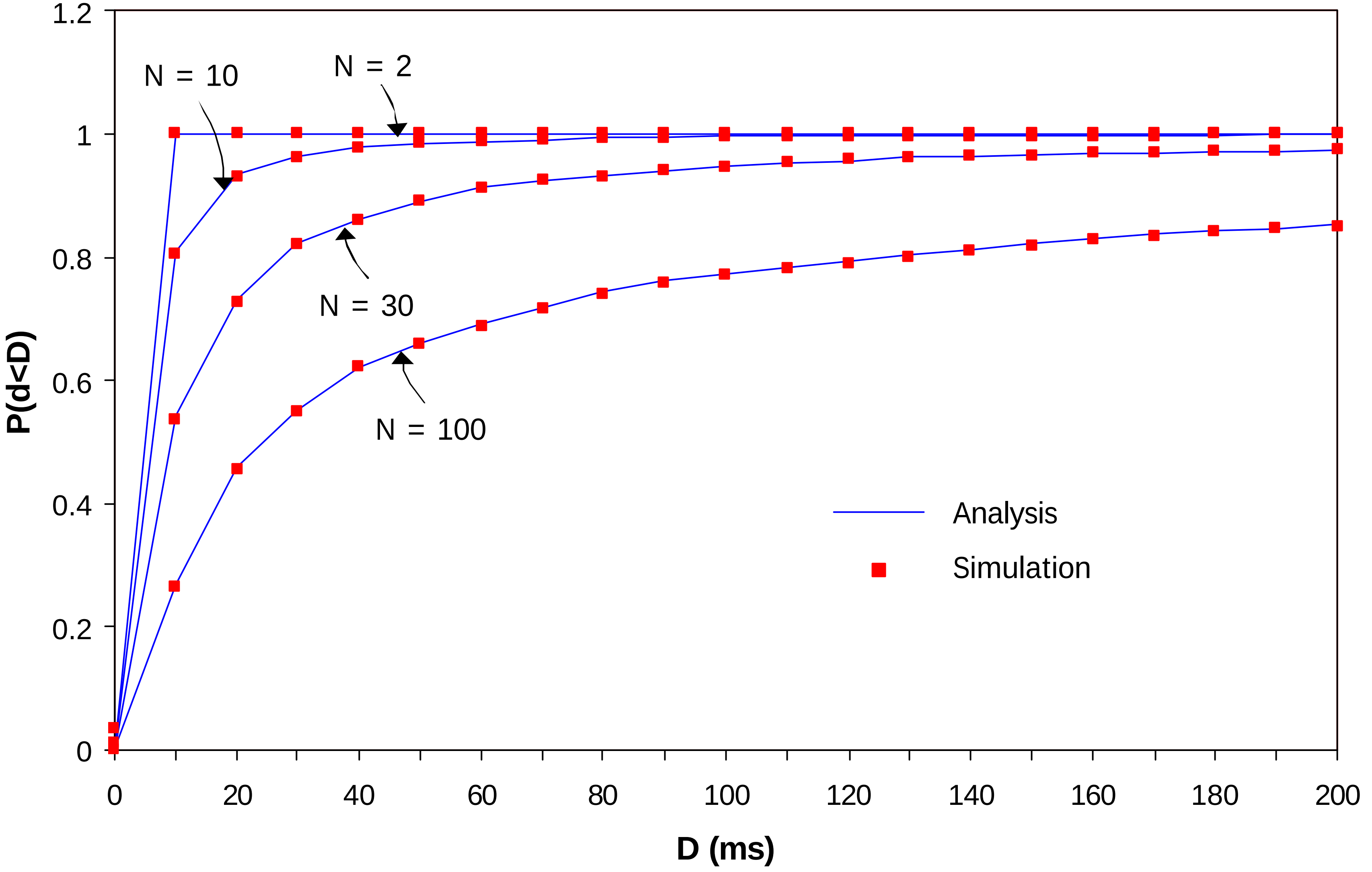
Performance Evaluation (I): Fixed Packet length, no RTS/CTS



Performance Evaluation (II): Fixed Packet length, RTS/CTS



Performance Evaluation (III): Variable Packet length, no RTS/CTS



Performance Evaluation (IV): Computational Efficiency

- Time required to compute the 20 points of the previous graphs with a Pentium IV PC (in seconds)

	N = 2	N = 10	N = 30	N = 100
Basic	0.38	0.45	0.43	0.40
RTS/CTS	0.39	0.45	0.44	0.42
Non fixed	0.37	0.45	0.45	0.44

- Computational times are small and almost constant
- Acceptable for taking an admission control decision

Discussion on end-to-end delay guarantees and Future Work

Real-time applications require that most of the packets to suffer a delay smaller than a certain threshold

- we are interested in the worst-case distribution of the e2e delay

Our model assumes saturation conditions

- worst-case delay for a given station

e2e delay consists of two main components: queuing delay and backoff delay

- the problem of deriving the queuing delay can be seen as analyzing a G/G/1 queue where the service time follows the distribution of the backoff delay
- 802.11 allows that once a station accesses the channel it sends all the packets waiting for transmission. In this case the backoff delay is the only component of the e2e delay

Summary and final Remarks

We have presented a model to efficiently and accurately compute the distribution of the backoff delay

The model is a first step towards an admission control algorithm that provides e2e delay guarantees

Our analysis assumes saturation conditions as this is the worst case for the delay

- if t for nonsaturation conditions is given, the model can also be applied to nonsaturation conditions

The analysis works accurately with/without RTS/CTS, for fixed/variable packet lengths

Many solutions have been proposed in the literature to provide real-time traffic support in WLAN (including PCF), but have not been deployed

Our analysis can be extended to the EDCA mechanism of the upcoming 802.11e standard