University of Würzburg
Distributed Systems
Prof. Dr. P. Tran-Gia

Analytic Performance Evaluation of the RED Algorithm

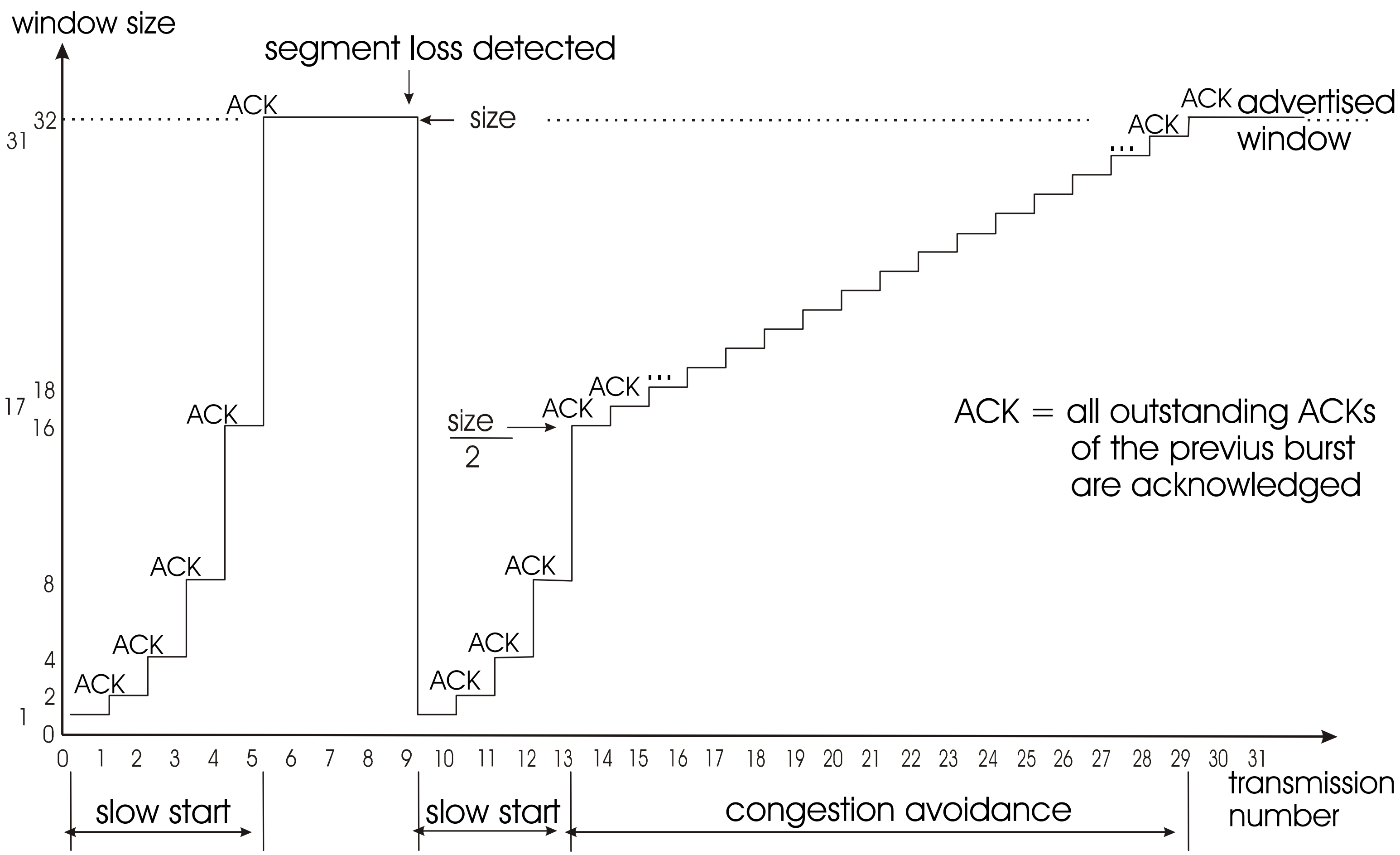
Stefan Köhler, Michael Menth, Norbert Vicari

- TCP Model
- RED Model
- TCP over RED
- Results

TCP

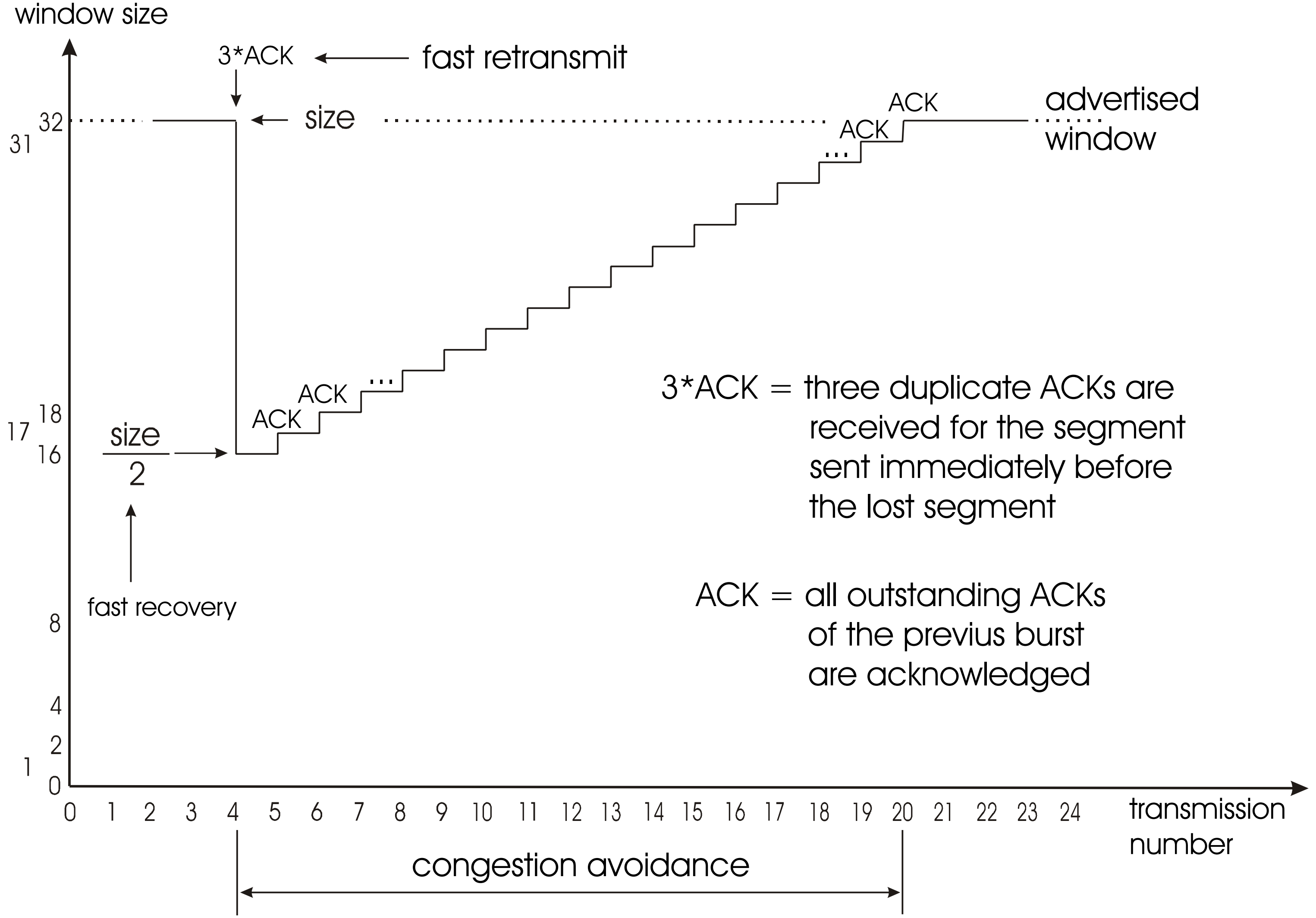
- Reliable transmission
- Closed loop flow control
- Elastic traffic without real-time requirements
- Major part of Internet traffic
- Interactive Applications

TCP‘s slow start and congestion avoidance



ACK = all outstanding ACKs of the previus burst are acknowledged

TCP‘s fast retransmit algorithm

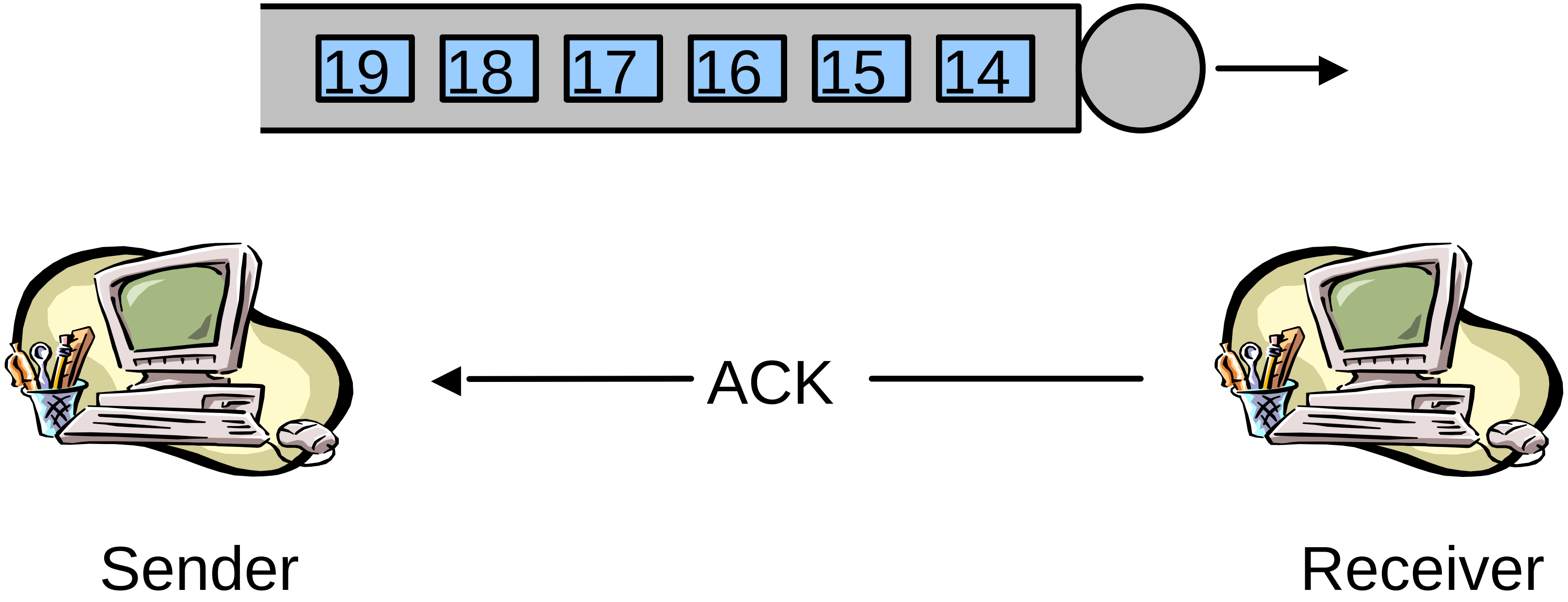


3*ACK = three duplicate ACKs are
received for the segment
sent immediately before
the lost segment

ACK = all outstanding ACKs
of the previus burst
are acknowledged

Analytical Approach

- ▷ Semi-Markov process (SMP)
- ▷ Renewal points: Time instant when last packet that has seen the last renewal point has left the queue.
- ▷ „TCP rounds“



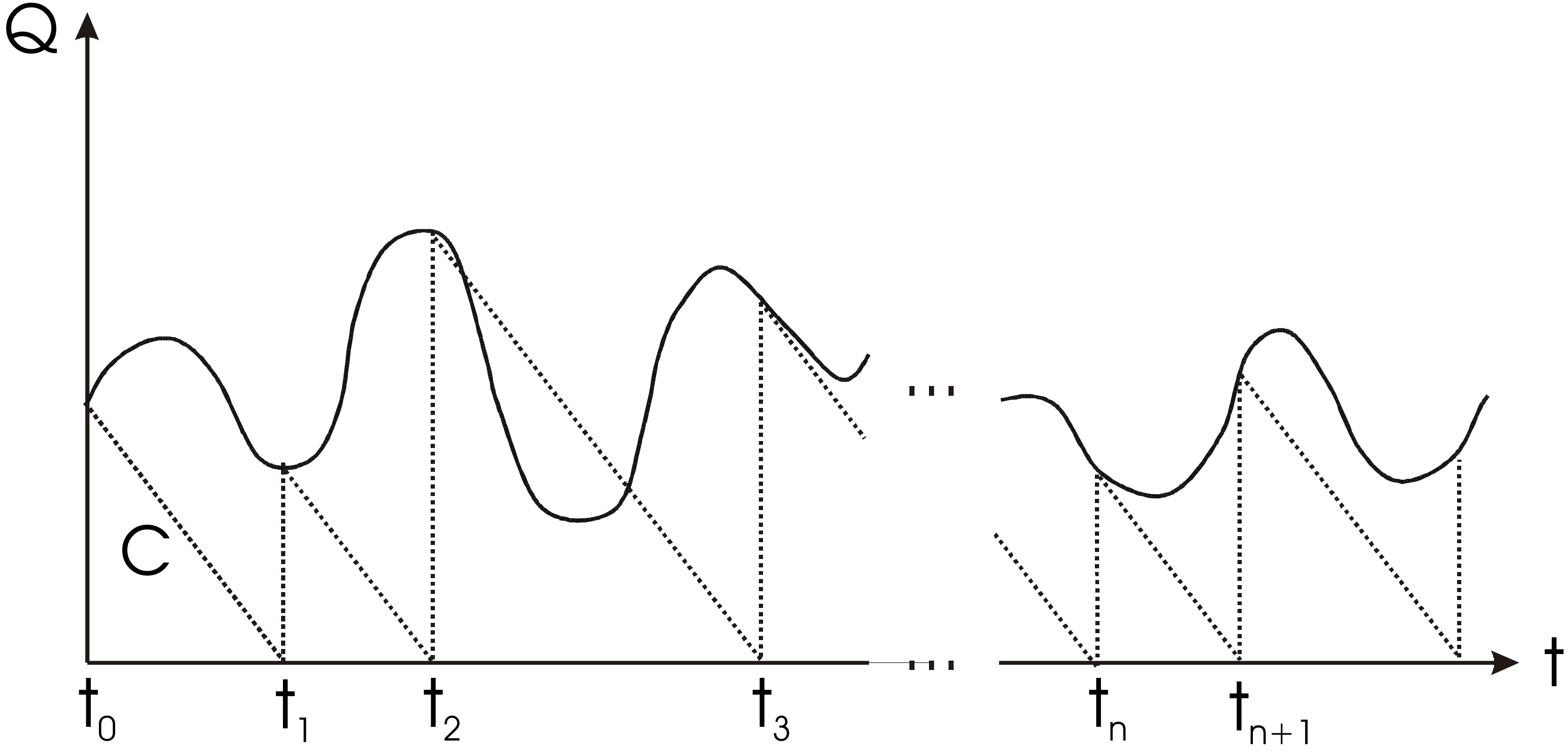
19 18 17 16 15 14

ACK

Sender

Receiver

Renewal Points



Discrete-Time Model for a Single TCP Connection

▷ Assumptions

- TCP Reno
- FTP-source
- Independent packet losses (later based on RED)
- State variables:

  (W_n, S_n, M_n) := (CWND(t), SSTRESH(t), Loss(t))
- Observation: TCP-Round

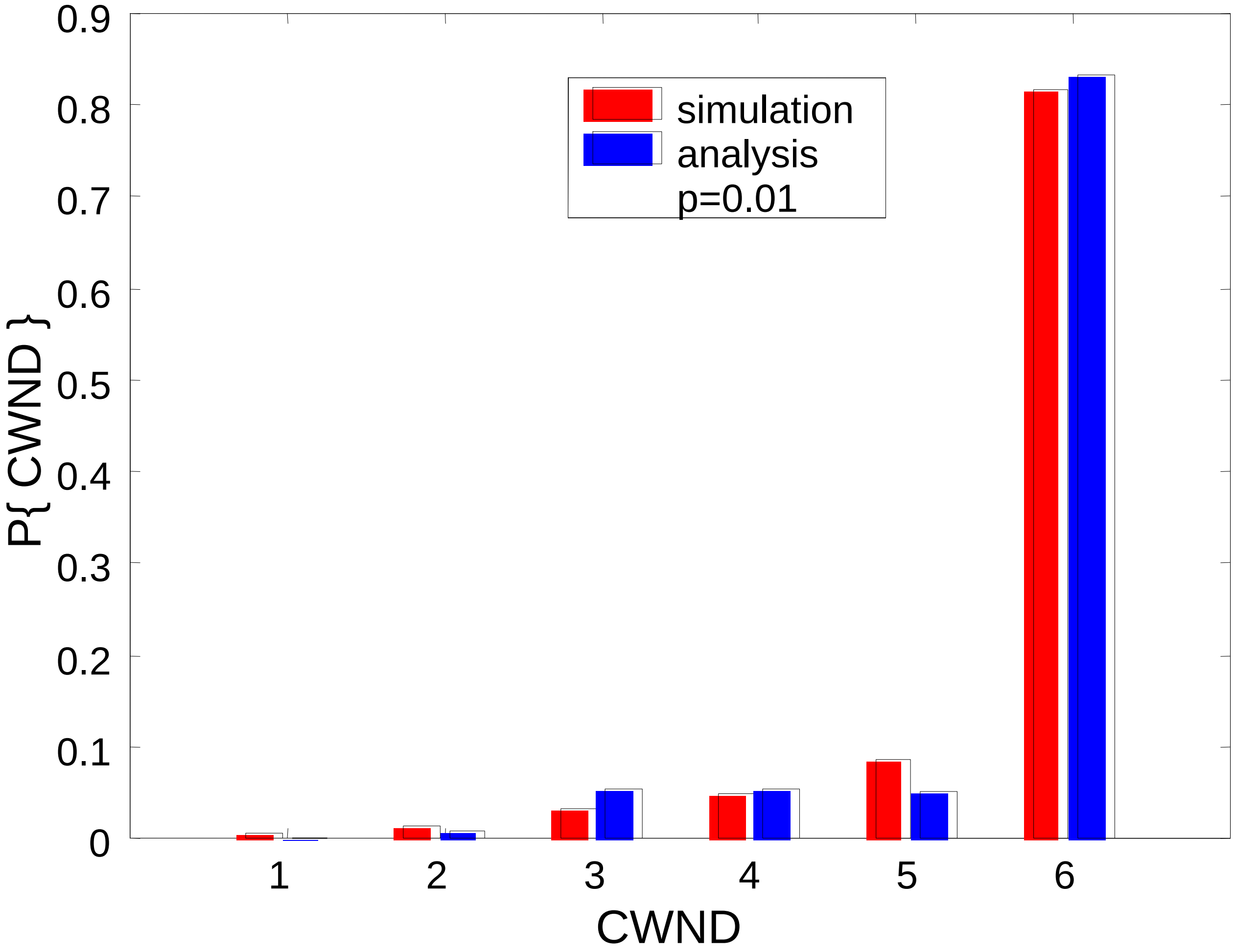
A Single TCP Connection

```
Input:  model state ($W_n$, $S_n$, $M_n$), model factor ($L(W_n)$)

  if ($M_n = 0$) then              {no loss last round}
   $S_{n+1} := S_n$
   if ($W_n = W_{max}$) then       {full window possible}
        $W_{n+1} := W_n$
   else
        if ($W_n < S_n$) then      {slow start}
        $W_{n+1} := 2*W_n$
        else                       {congestion avoidance}
        $W_{n+1} := W_n + 1$
        endif
   endif
  else
```

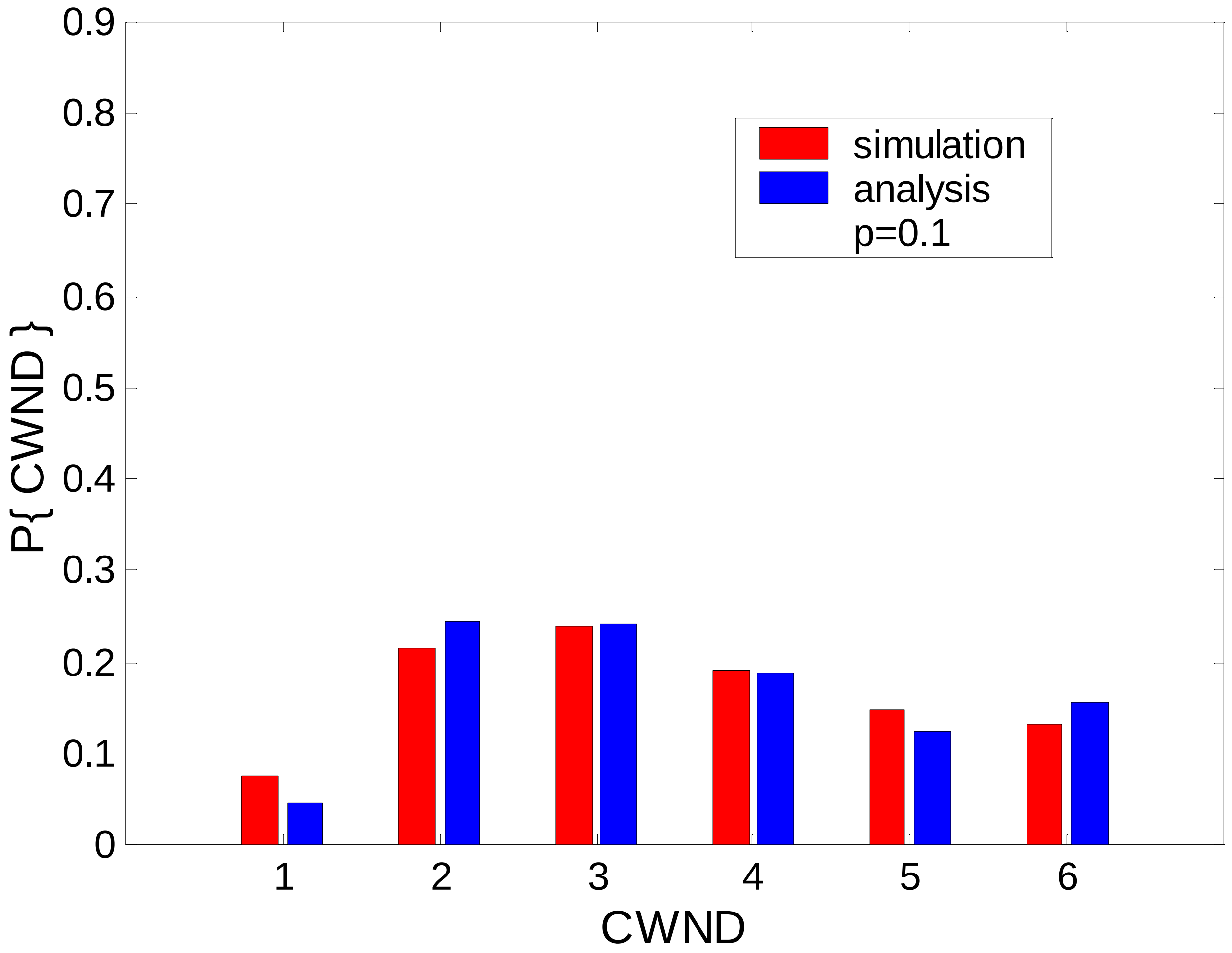
A Single TCP Connection

```
else
 if ($M_n$ = 1) then          {one loss last round}
     $S_{n+1}$ := max($W_n$/2,2)
     $W_{n+1}$ := $S_{n+1}$
 else                         {more than one loss last round}
     $S_{n+1}$ := max($W_n$/2,2)
     $W_{n+1}$ := 1
 endif
endif
$M_{n+1}$ := min(L($W_n$),2)

Output: model state($W_{n+1}$, $S_{n+1}$, $M_{n+1}$)
```

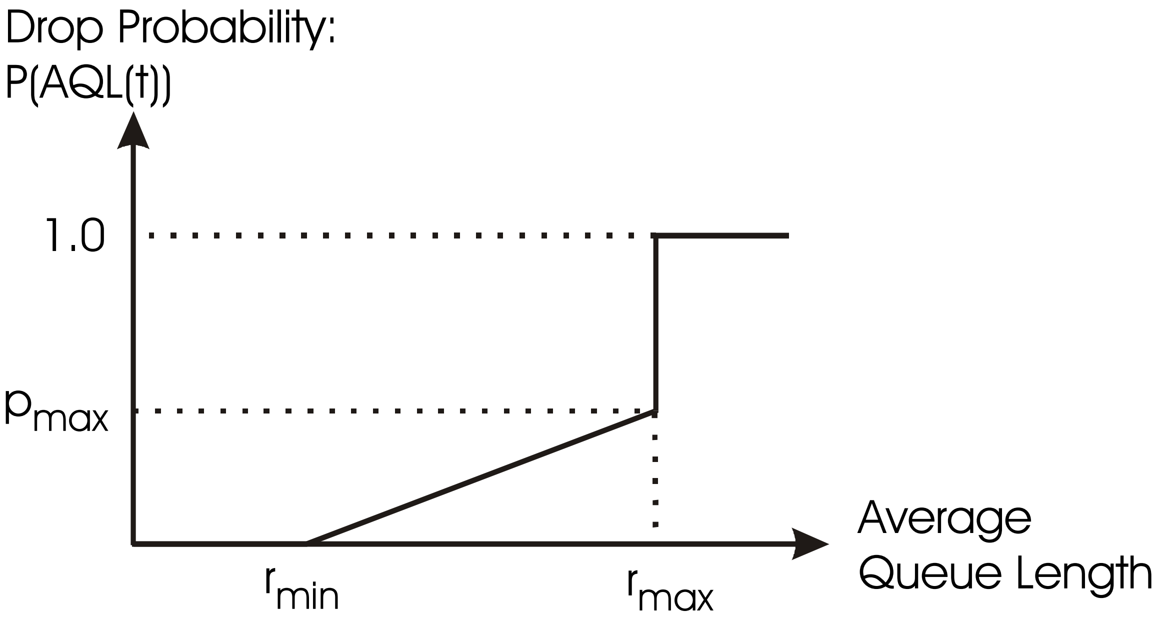
Simulation ⇔ Analysis (I)



Simulation ⇔ Analysis (II)



Random Early Discard (RED) Queue



$$p(A=i)=\begin{cases} 0 & 0 \le i < r_{min} \\ \left(\frac{i-r_{min}}{r_{max}-r_{min}}\right)\cdot p_{max} & r_{min} \le i \le r_{max} \\ 1 & r_{max} < i \le \infty \end{cases}$$

RED Queue Mechanism

Input: model state (A_n), model factor $(B, L(B,A_n))$

$$Q := B - L(B, A_n)$$

$$A_{n+1} := w_q \bullet Q + (1-w_q) \bullet A_n$$

B: batch of packets
A: average queue size
L: loss
Q: actual queue size
w_q: weighting factor

Output: model state (A_{n+1})

The probability of k losses within a batch B of j packets follows a binomial distribution:

$$l(A=i, B=j)[k] = \binom{j}{k} p(A=i)^k \cdot (1-p(A=i))^{j-k}$$

Compound Analysis

- h TCP Connections under RED:

Input: model state $((Wi_n, Si_n, Mi_n),(A_n))$, model factor Li$(A_n,Wi_n)$

```
for $i$ Î $\{1, \ldots, h\}$ do
    $(Wi_{n+1}, Si_{n+1}, Mi_{n+1}) := TCP((Wi_n, Si_n, Mi_n), \mathrm{Li}(A_n, Wi_n))$
end for

$A_{n+1} := RED( (A_n), (S\ Wi_n, S\ Li(A_n,Wi)) )$
```

Output: model state $((Wi_{n+1}, Si_{n+1}, Mi_{n+1}),(Q_{n+1}, A_{n+1}))$

Results

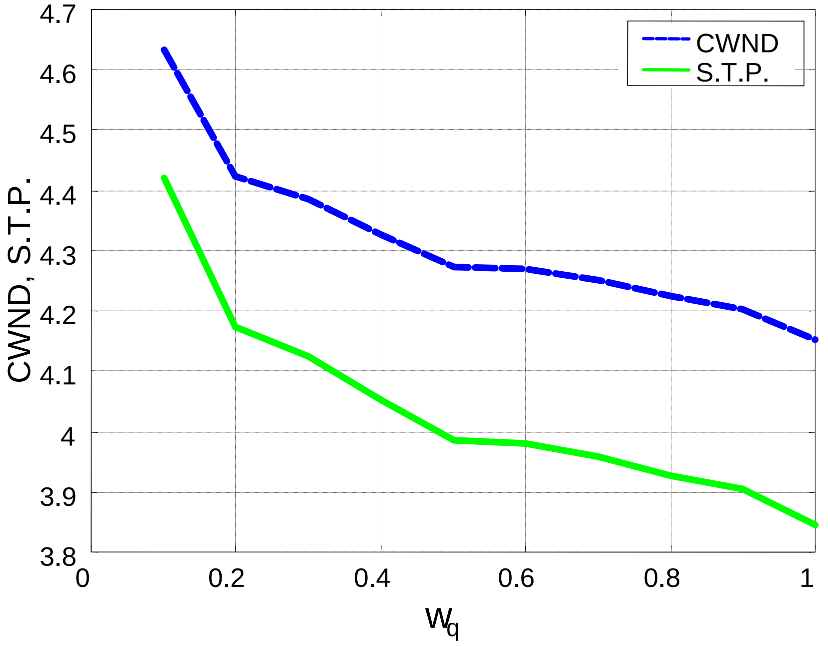
Parameters

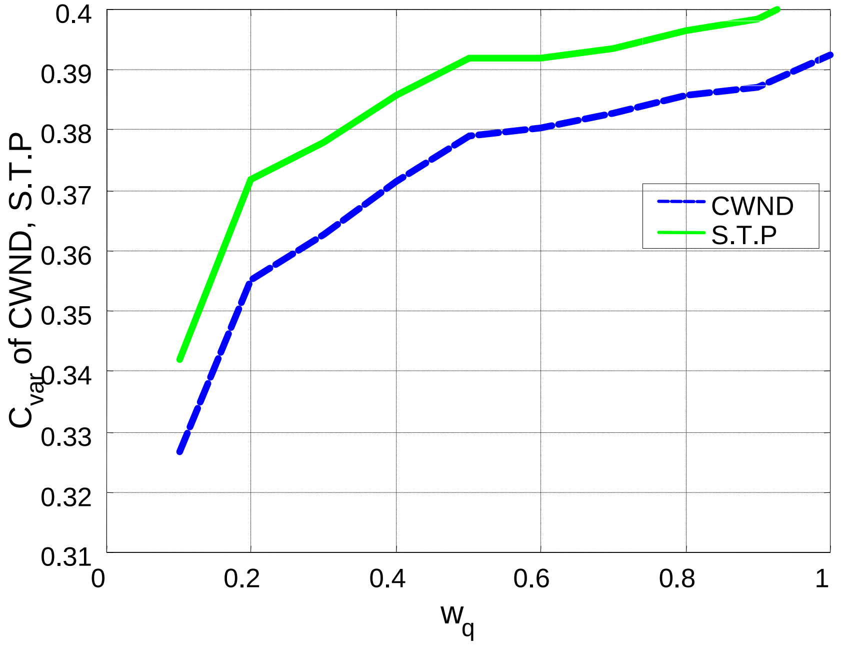
If not stated differently

- R_{min}=9
- R_{max}=18
- w_q=0.3
- 3 TCP sources
- CWND=6

Influence of the Weighting Factor

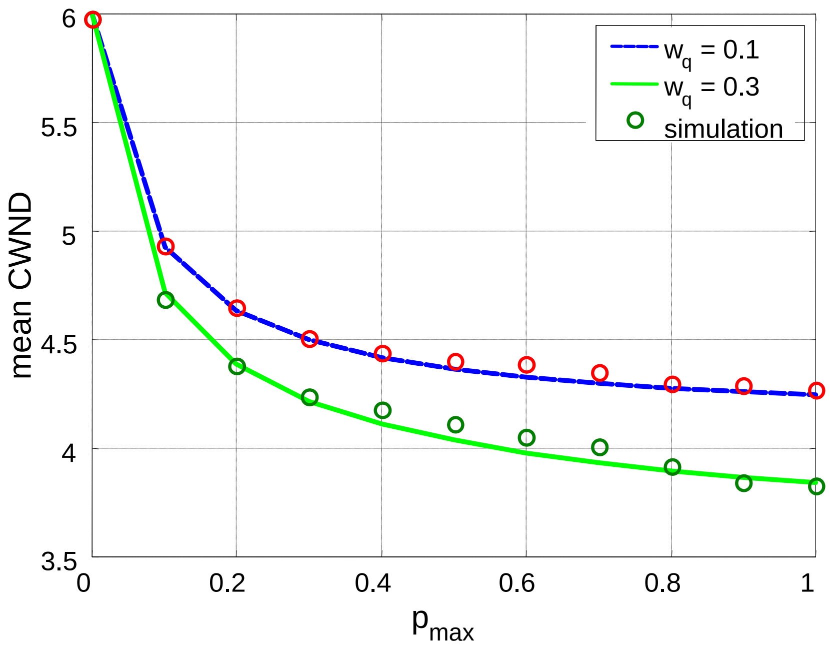
$p_{max} = 0.5$

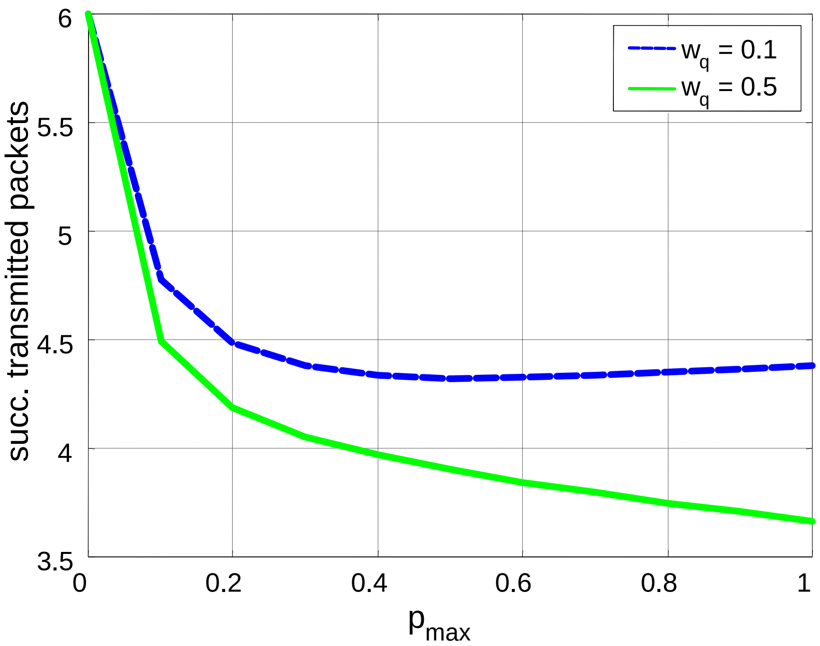




- ▷ Increased throughput, reduced variance

Influence of the Loss Function

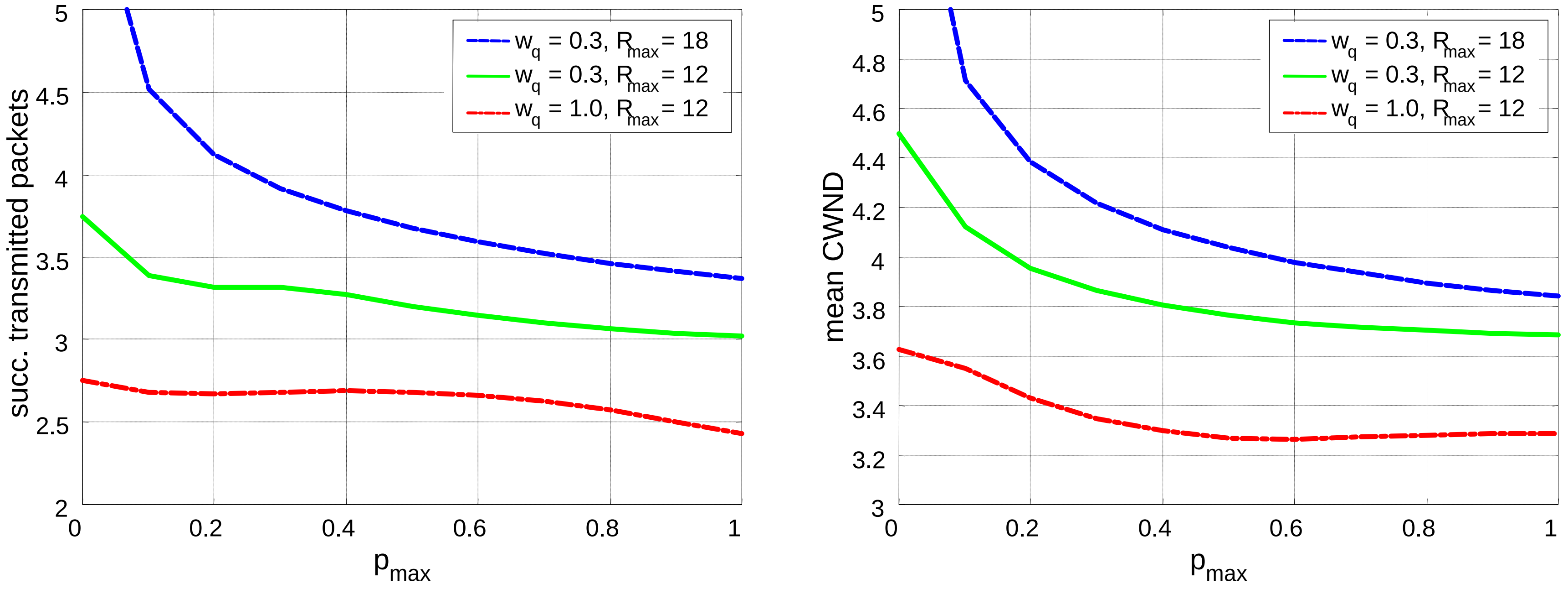




- ▷ High loss probability reduces throughput.
- ▷ “Long Memory” provides better results.

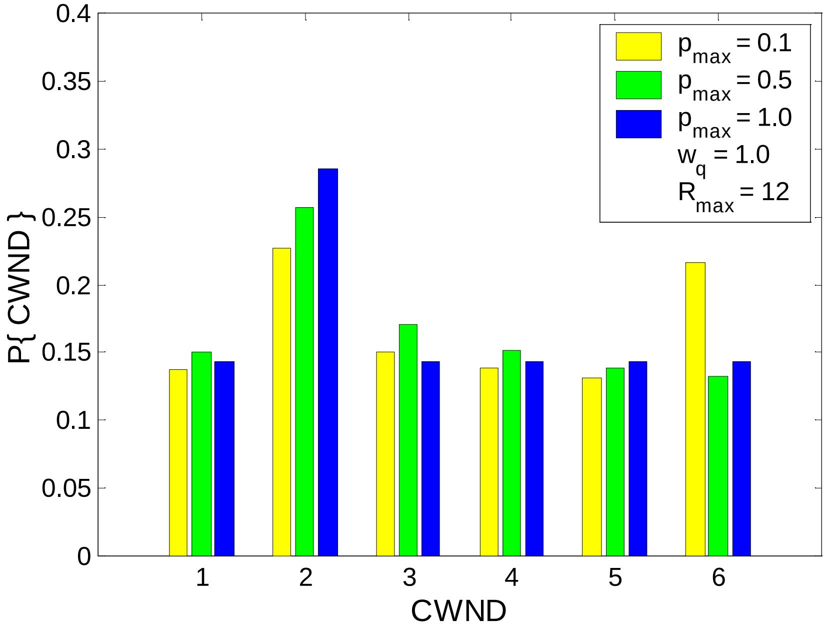
Influence of the Buffer Size

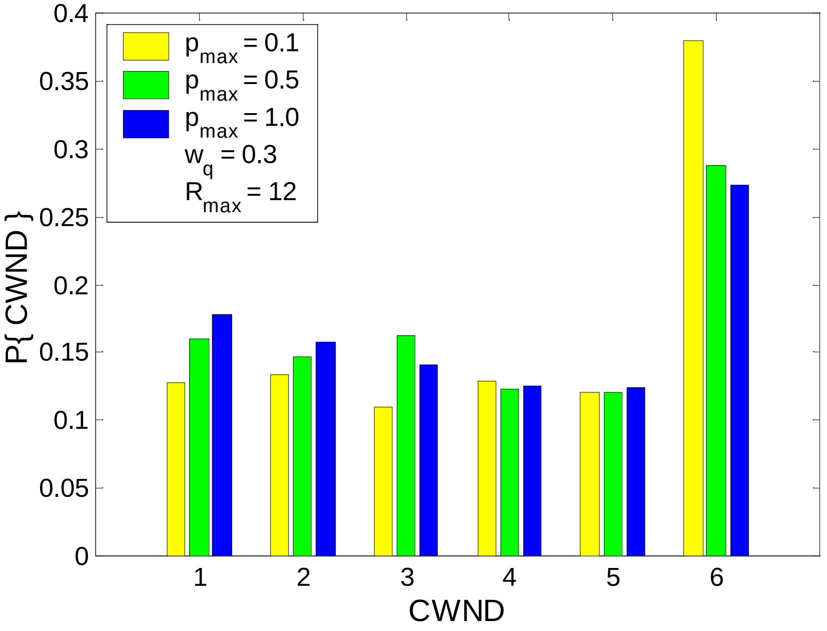
w_q=0.3



- ▷ Short (or congested) queues limit the congestion window size.
- ▷ FIFO ⇔ RED

Distribution of CWND





- “Long Memory” and small loss probabilities show larger congestion windows

Conclusion and Outlook

- Summary
  - Discrete-Time Model of TCP and RED
    - Correlation of TCP sources
  - Analytical Performance Evaluation
  - Distributions for all TCP state variables
- Results
  - Sensitivity of TCP to
    - Weighting factor
    - Loss function
    - Congestion or short queues
  - Good Performance: “Smoothed FIFO-Queues”
- Outlook
  - Comparison of different TCP implementations
  - Influence of non-linear loss functions
  - Fairness studies

THE END