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# Addressing the Challenges for TCP over Multihop Wireless Networks

Ruy de Oliveira
Universität Bern

# Outline

> Motivation
> Multihop networks
> Transmission Control Protocol (TCP)
> TCP challenges and proposed solutions
> ***Packet loss discrimination using Fuzzy Logic***
> ***Smart acknowledgment strategy***
> Conclusions and outlook

# Motivation

> More and more Internet traffic are foreseen in future wireless communications based on IEEE 802.11 standard

> Wireless communications are quite different from the wired world
  - Wireless medium are inherently noisy
  - Bandwidth in wireless channels is a scarce resource

> The widespread use of TCP in the Internet motivates its extension to wireless

# Multihop Wireless Networks

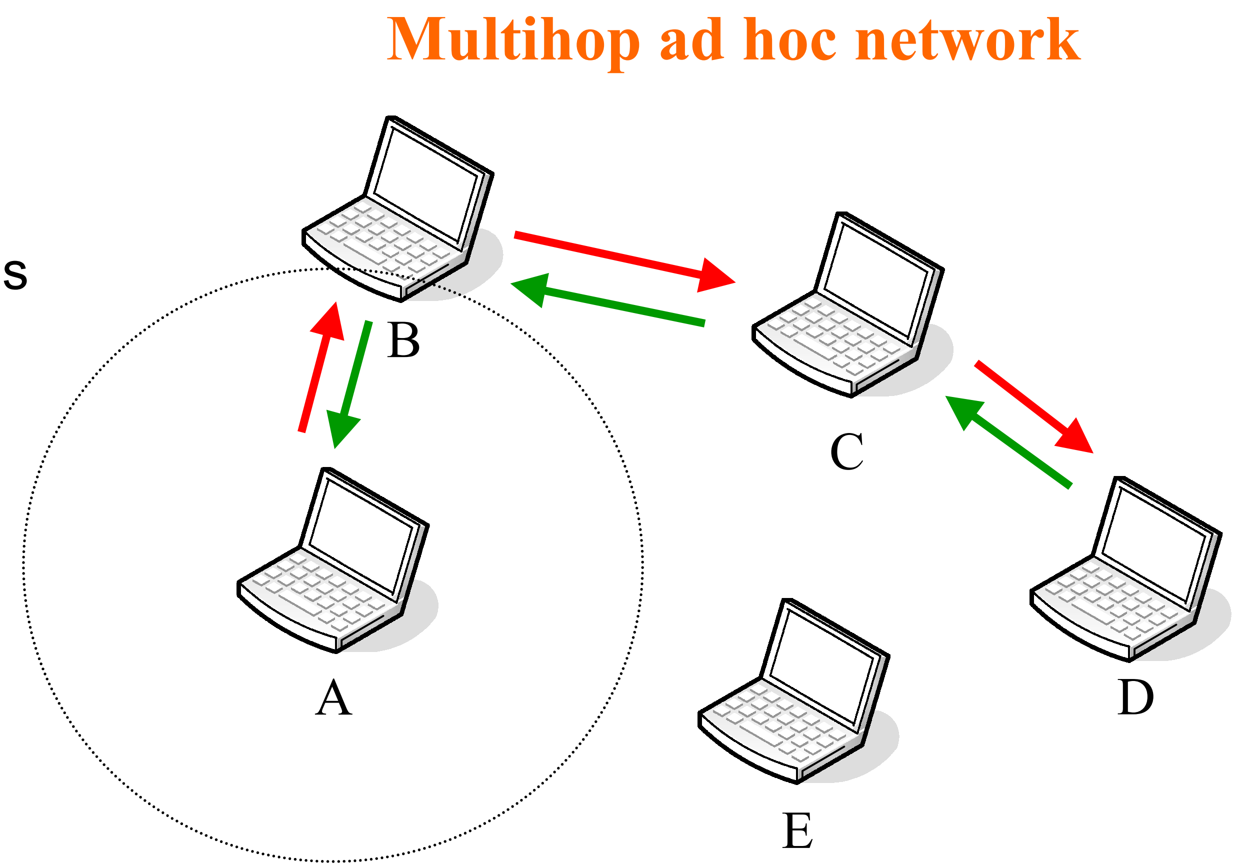
> No fixed infrastructure

> Communication range is increased by multiple links

> Nodes forward data to each other

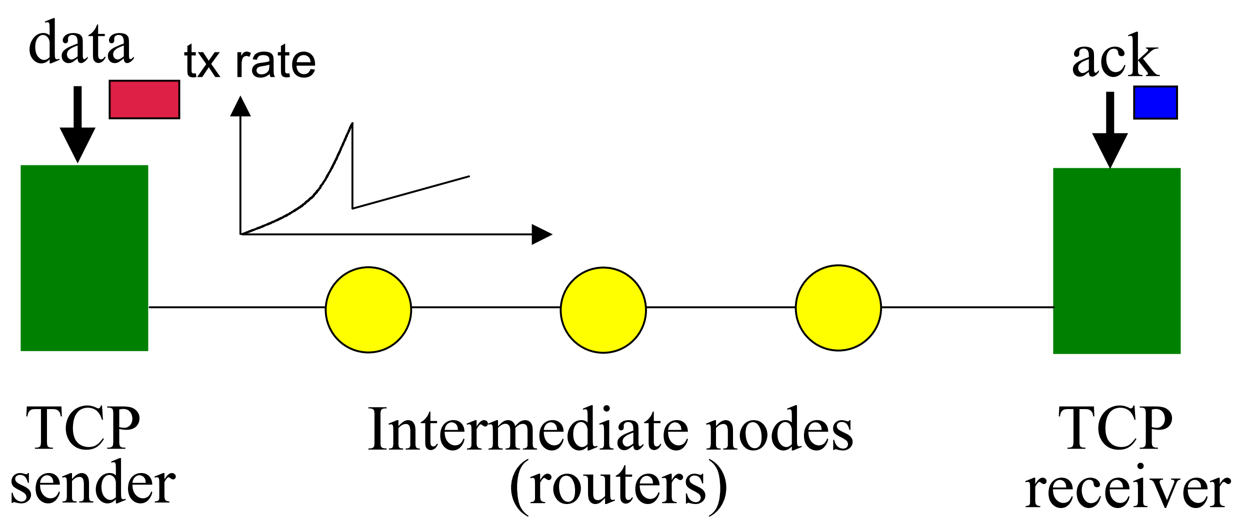
> Nodes may move

> Low energy resources



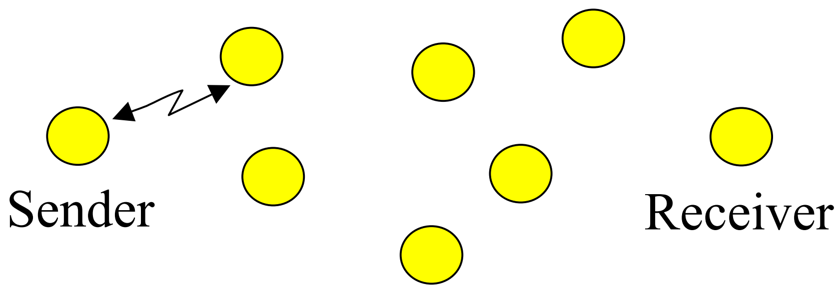
# Transmission Control Protocol (TCP)

- Provides reliable data delivery (bidirectional flow)
- Works on an end-to-end basis
- Continuously probes the network for resources
- Retransmission: - *retransmit timeout (timer expiration)*
  - *fast retransmit (3 duplicate ACKs)*



# Challenges and Solutions for TCP

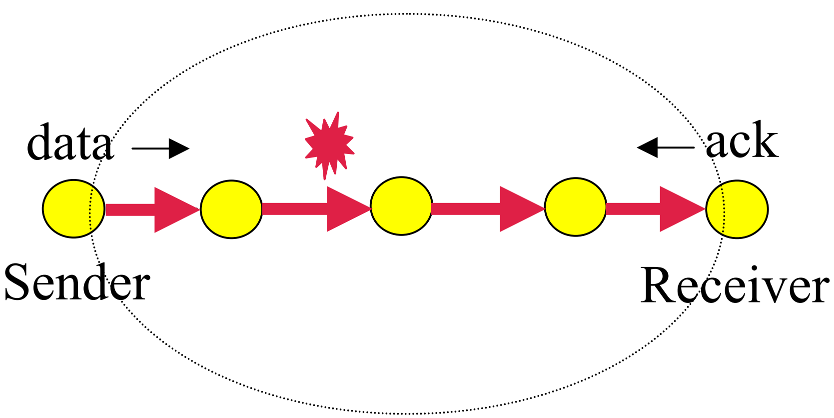
Wireless network




Lossy channel

↓

> Packet loss discrimination




Traffic redundancy

↓

> Smart ACK managment

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# First Main Contribution: Packet Loss Discrimination

- Purpose:
  - To distinguish between congestion and medium induced errors
- How:
  - Evaluating packet delay variations (Round-Trip Time) inside the network
- Advantages:
  - Very lightweight (only a few logic operations)
  - Independent of explicit signaling from the network (end-to-end)
- Assumptions:
  - Fixed packet size
  - Conventional lower layer protocols
  - Known RTT distributions as a function of the # of hops

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# Design Rationale

## Why RTT measurements?

> TCP relies naturally on round-trip time measurements for taking decisions

> It is intuitive that such measurements may be useful in inferring the internal network state

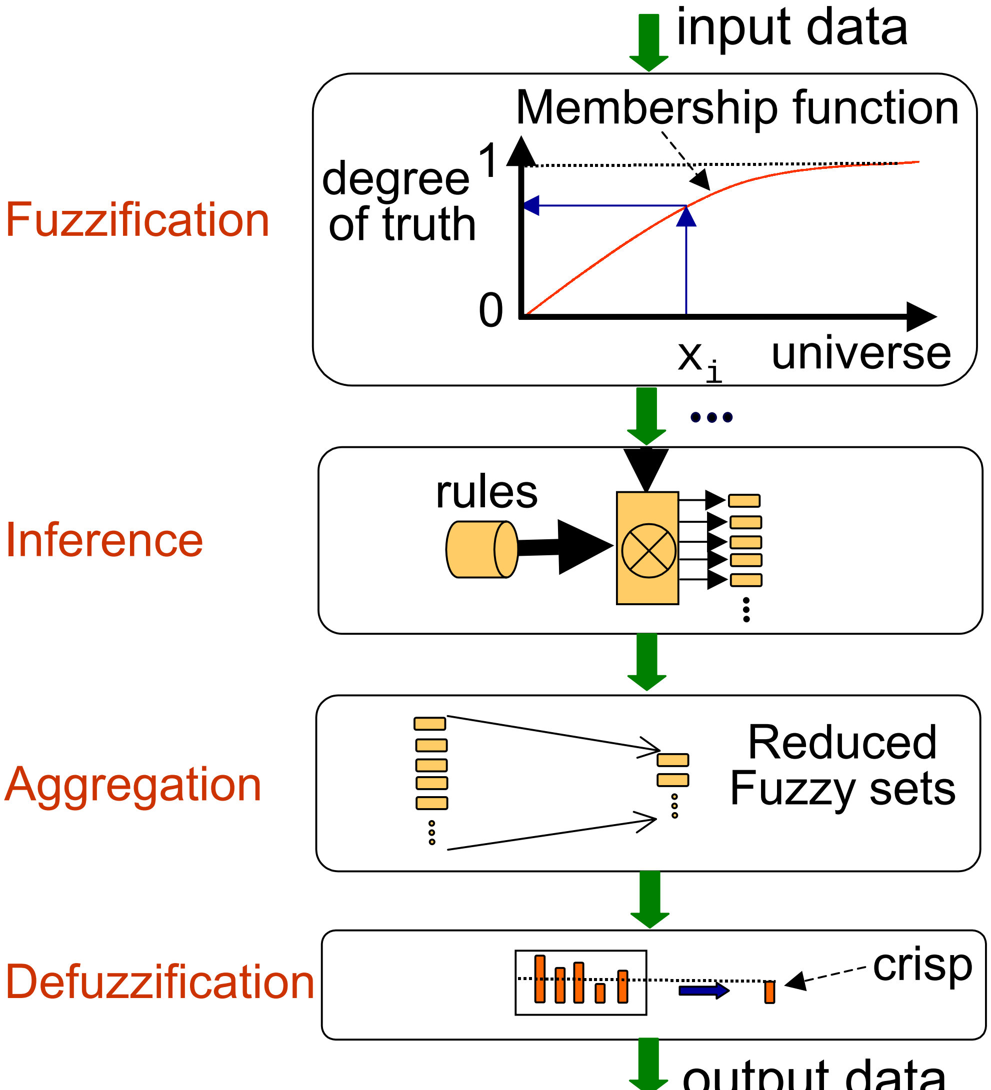
## Difficulties

> RTT measurements may contain overlapping values under certain conditions

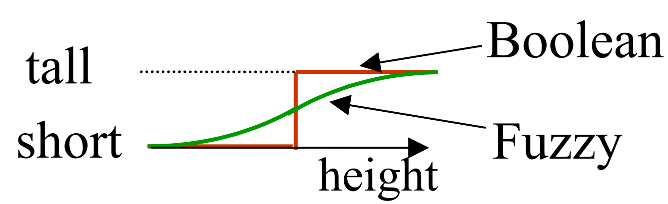
## Then

> Appropriate tool may perform good reasoning on the measured data → Fuzzy logic

# Fuzzy Logic (FL)

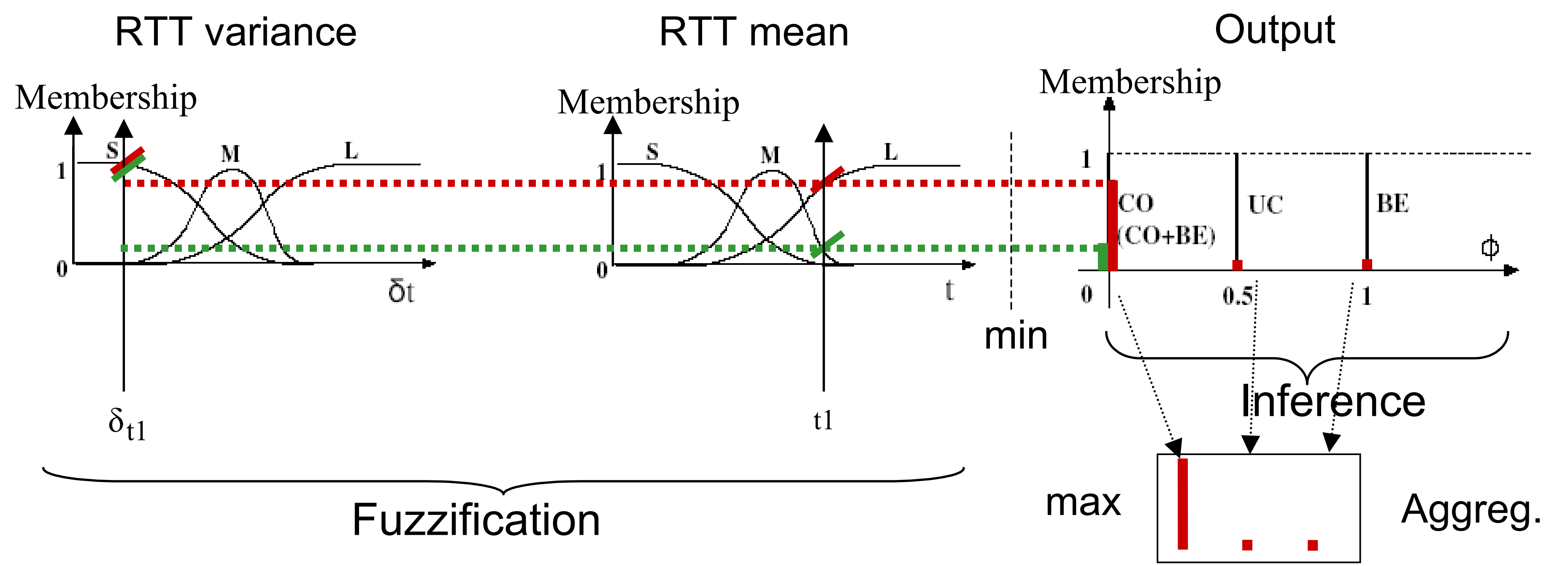



- It uses membership functions and rules to reason about the data
- FL avoids rigid boundaries
  ex. “people height”:
  is 1.79m short and 1.80m tall?




- FL is proper for pattern recognition tasks

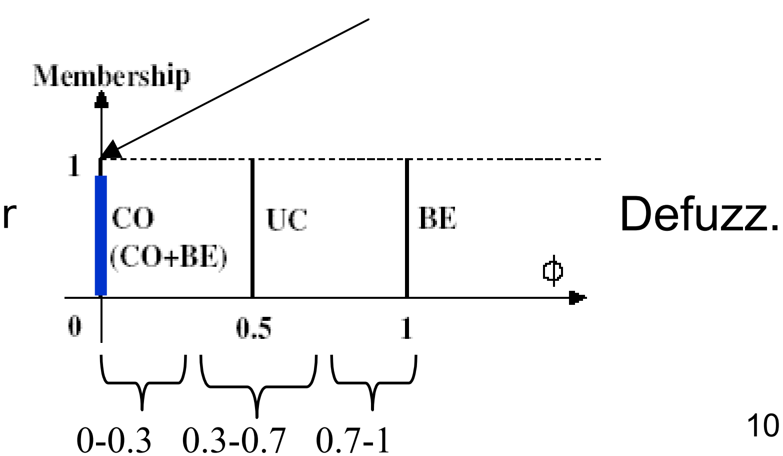
# The Inference Procedure of the Fuzzy Engine



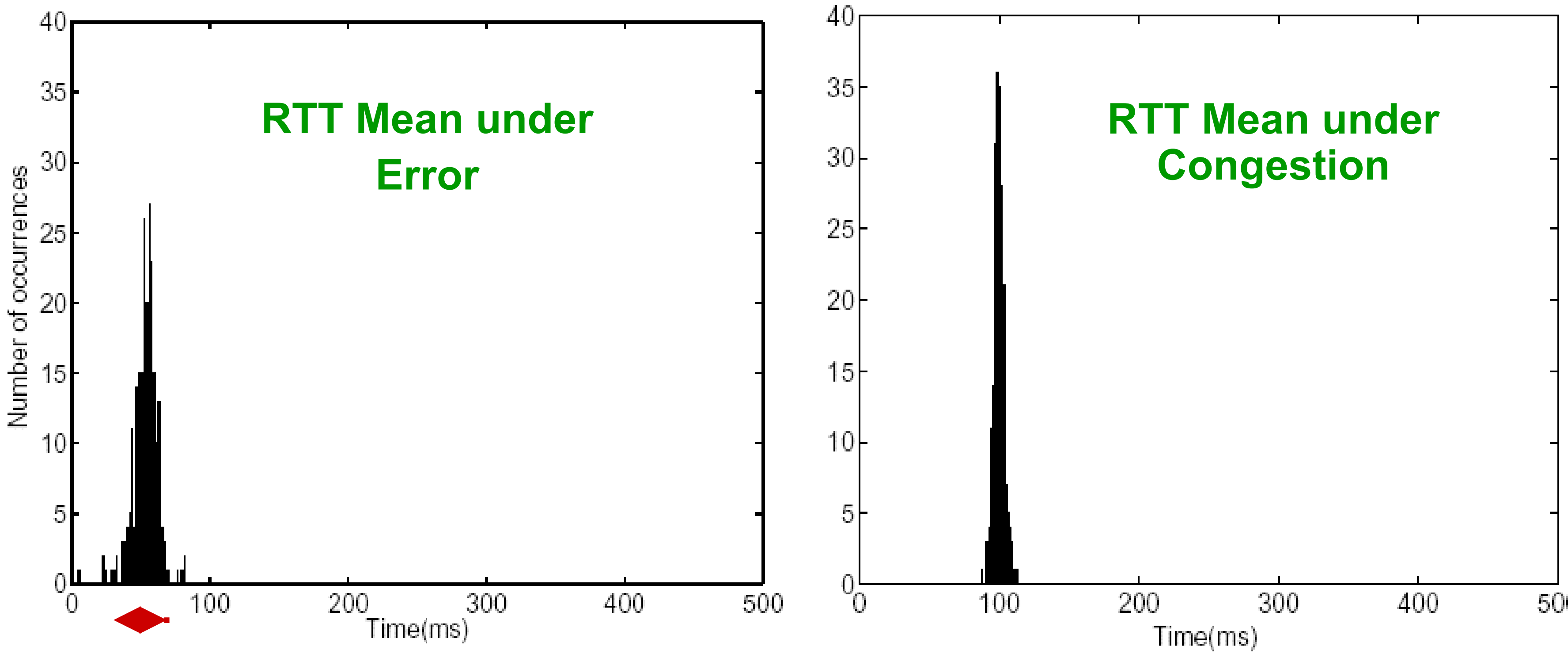

Fuzzy rules output Φ

| Var(δ) \mean (t) | S | M | L |
|---|---|---|---|
| **S** | BE | CO | CO |
| **M** | BE | UC | CO |
| **L** | BE | BE | CO |

S = Small
M = Medium
L = Large
CO = Congestior
UC = Uncertain
BE = Bit Error



# Settings of the Membership Functions for RTT mean by Simulations (3-hop)




Being conservative: RTT > 60 → congestion

RTT < 40 → medium error

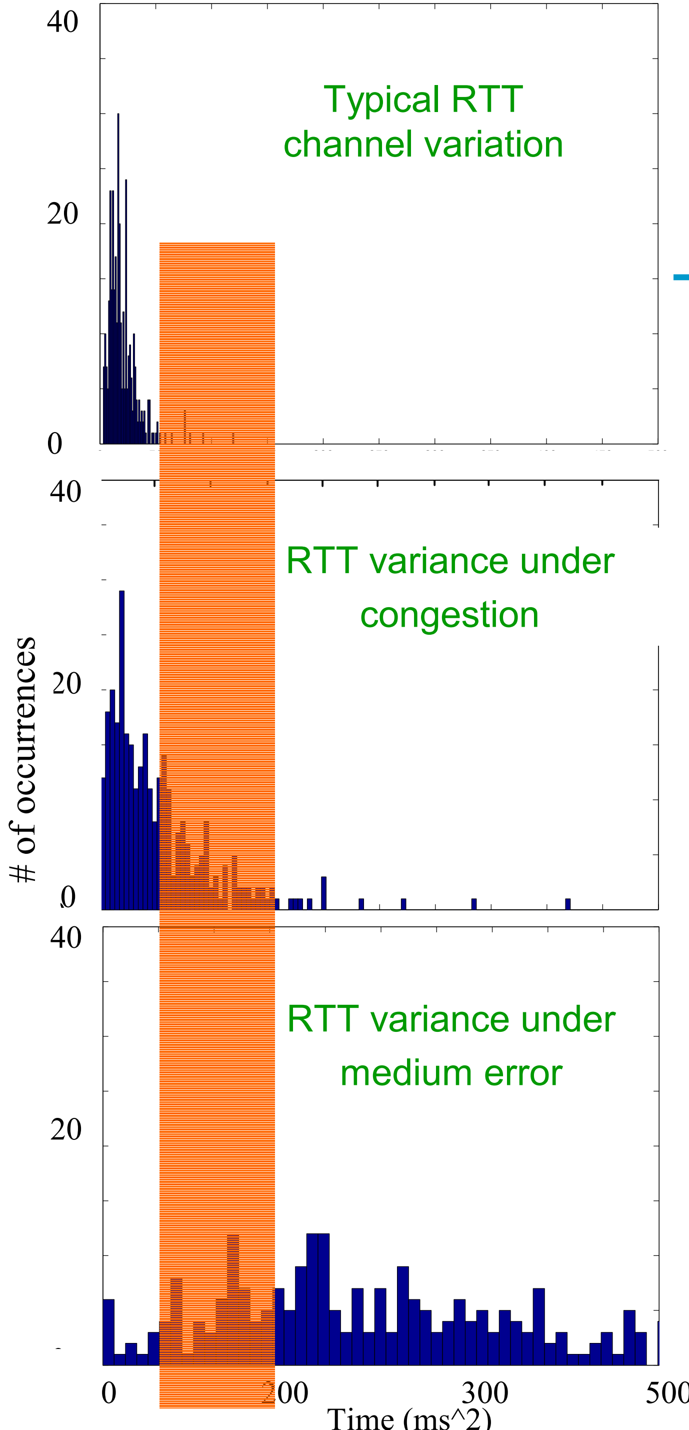
Fuzzy settings: Gaussian curve center is 50 and width is 20

# Settings of the Membership Functions for RTT var. (3-hop)

- Congestion and medium error have distinct distributions for RTT variance
- There is an overlapping area between 50-150 (ms^2)
- Below 50 the values are clearly low and above 150 clearly high

Fuzzy settings:

- Gaussian curve: center is 100 and width is 50.
- Universe of discourse is 500



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# Fuzzy Engine Features

> **Fuzzy Input**
  - RTT mean (t) and variance (ᵭ )

> **Fuzzy Rules**

Fuzzy rules output Φ

| $\delta_t$\t | S | M | L |
|---|---|---|---|
| **S** | BE | CO | CO |
| **M** | BE | UC | CO |
| **L** | BE | BE | CO |

> **Settings of the membership functions**
- ✓ mean (t): 50 +/- 20 ms
- ✓ Variance (ᵭ ): 100 +/- 50 ms^2
- ✓ Universe of discourse is 500 ms^2
- ✓ Output ranges: - CO: 0.0-0.3
  - UC: 0.3-0.7
  - BE: 0.7-1.0

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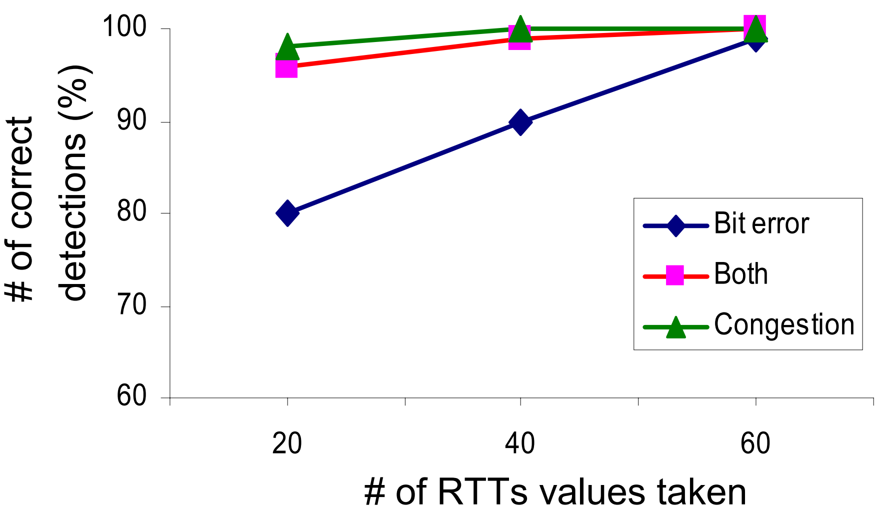
# Fuzzy engine output correctness

**Correct detection (%) vs. # of RTTs per sampling**
***Worst case***



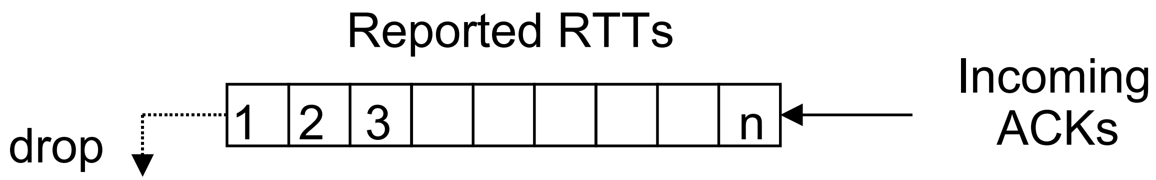

## Results

- Congestion was detected in over 98% of the cases
- Bit error requires more values

## scenario

- Chain topology with 3 hops
- 3 distinct runs of 100 seconds
  - Packet error rate of 10%
  - 1 competing flow for cong.
  - Both (PER=5% + 1 c. flow)

- **History of RTTs**



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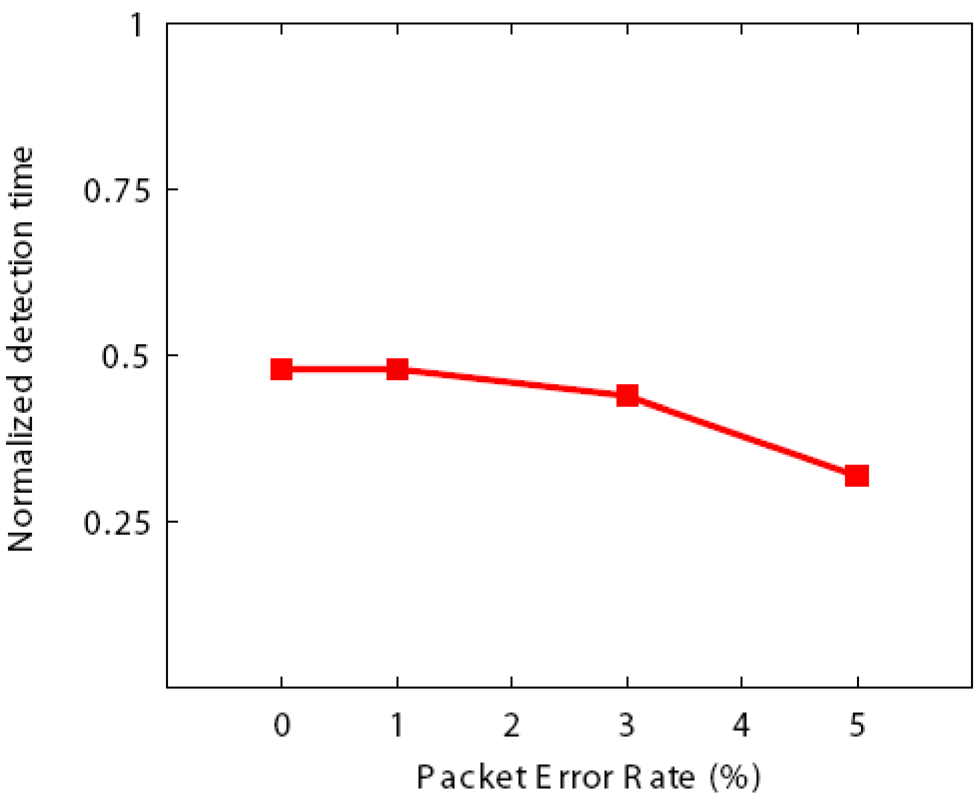
# Fuzzy engine reaction time to abrupt congestion

Detection time vs. error rate




> Scenario: an unconstrained channel is suddenly overloaded

> The fuzzy engine detects incipient congestion in time

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# Summary of the Fuzzy Engine based Approach

- If correctly adjusted it may provide accurate results
- Most effective in steady state conditions
- It is very computational inexpensive
- It cannot always obtain a conclusive result
- Tradeoff between speed and accuracy is always an issue
- RTT measurements tend to become unfeasible for large number of hops

**Future work**

- Different scenarios
- More elaborated fuzzy engines
- Adaptive algorithms for setting the fuzzy engine parameters
- Integration with the "error recovery" mechanism

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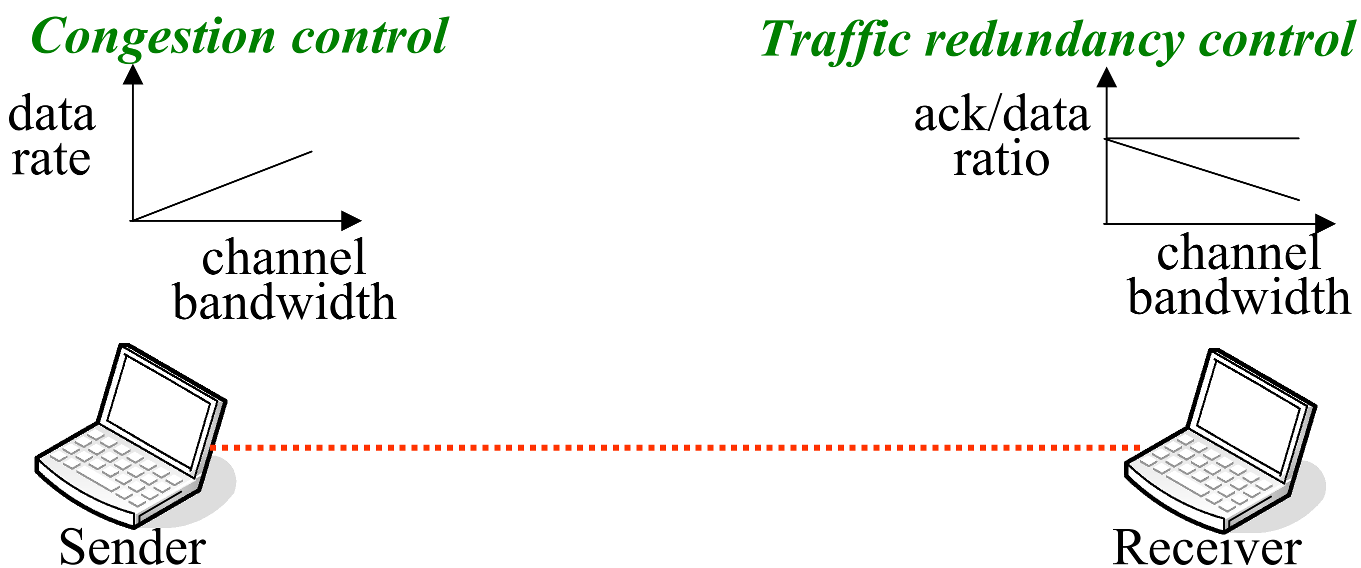
# Second Main Contribution: A Smart TCP Acknowledgment Approach

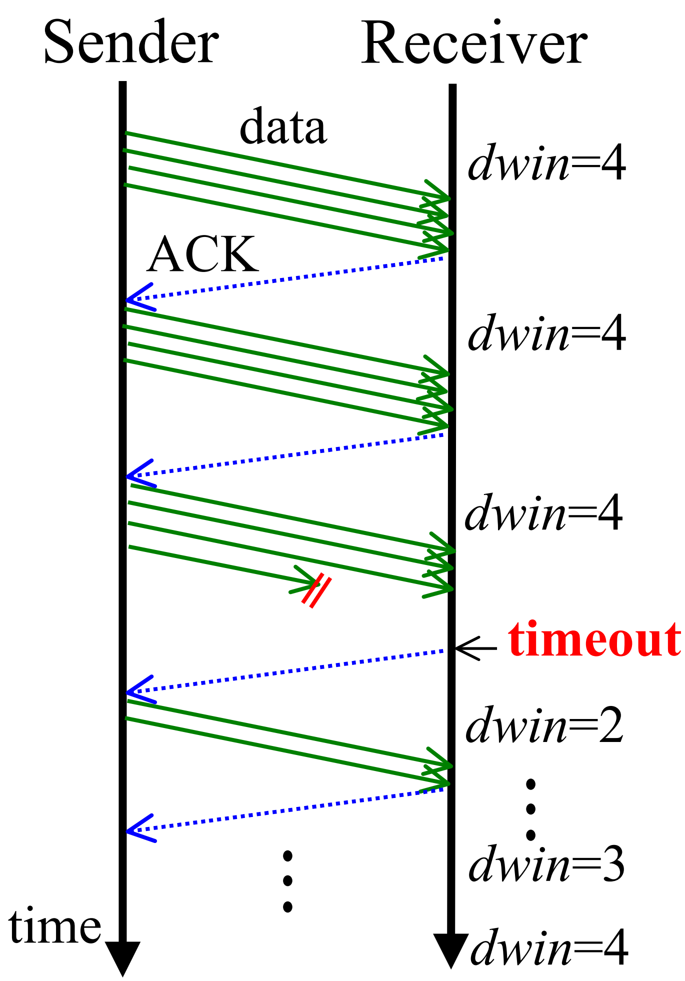
## Smart Acknowledgment




**Dynamic Adaptive Acknowledgements (DAA)**

– Less ACKs leave more bandwidth for data packets
– Avoid useless retransmissions ! save energy
– Self-adjustment depending on channel conditions

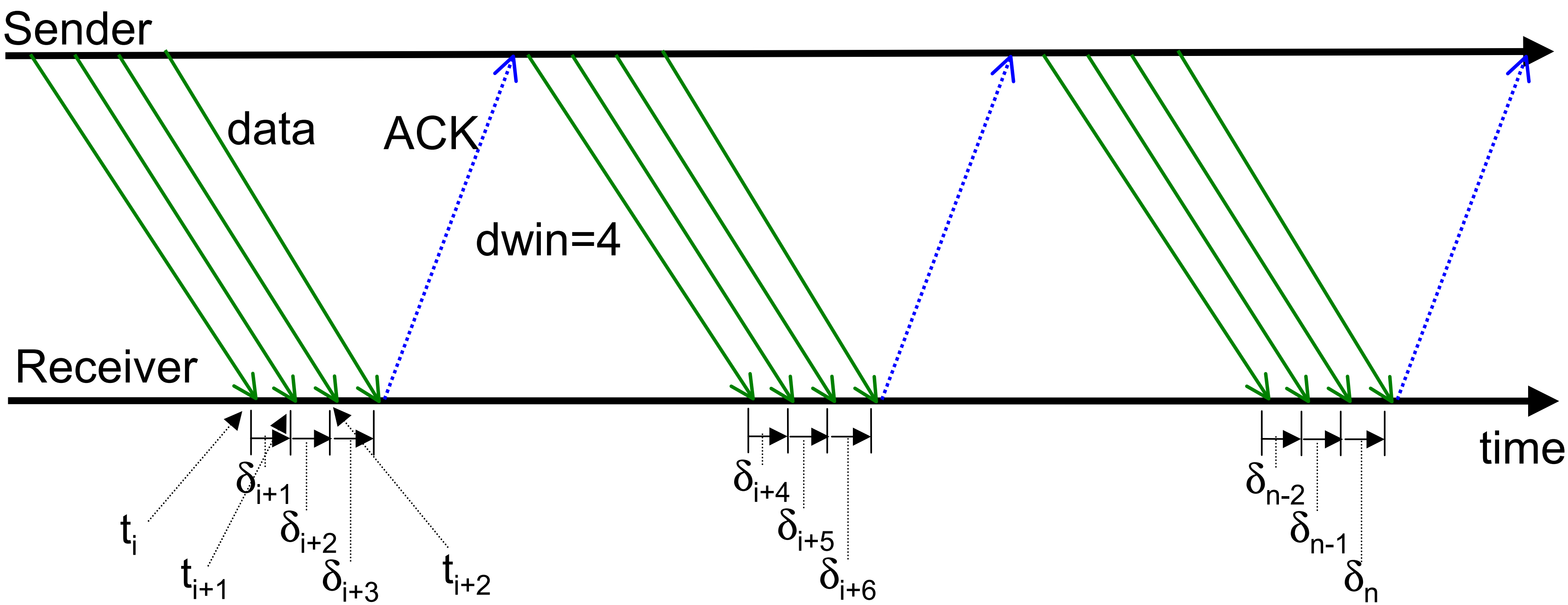
# DAA Mechanisms at the Receiver




- Receiver combines up to 4 ACKs (*dwin* = 4)
- Out-of-order packet or timeout triggers immediate ACK ! *dwin* := 2
- dwin is increased by 1 (by $\mu < 1$ if in startup phase)

  for each correctly received data packet (limit *dwin* = 4)
- Timeout interval T is adapted based on data packet inter-arrival time $\delta$

# Packet Inter-arrival computation




At $t_i$, $t_{i+1}$, $t_{i+2}$, … ⟶ start timer and increment delack counter (ack_count)

***Low-pass filter:***

$$\bar{\delta}_i = (1-\alpha)\,\bar{\delta}_{i-1} + \alpha\,\delta_i$$

$$T_i = (2+k)\,\bar{\delta}_i$$

- > $\bar{\delta}_i$ = smoothed pkt inter-arrival
- > $\bar{\delta}_{i-1}$ = sampled pkt inter-arrival
- > $\alpha$ = smoothing factor
- > $k$ = timeout tolerance factor
- > $T_i$ = timeout interval at arrival of pkt $_i$

# Adjustments at the DAA Sender

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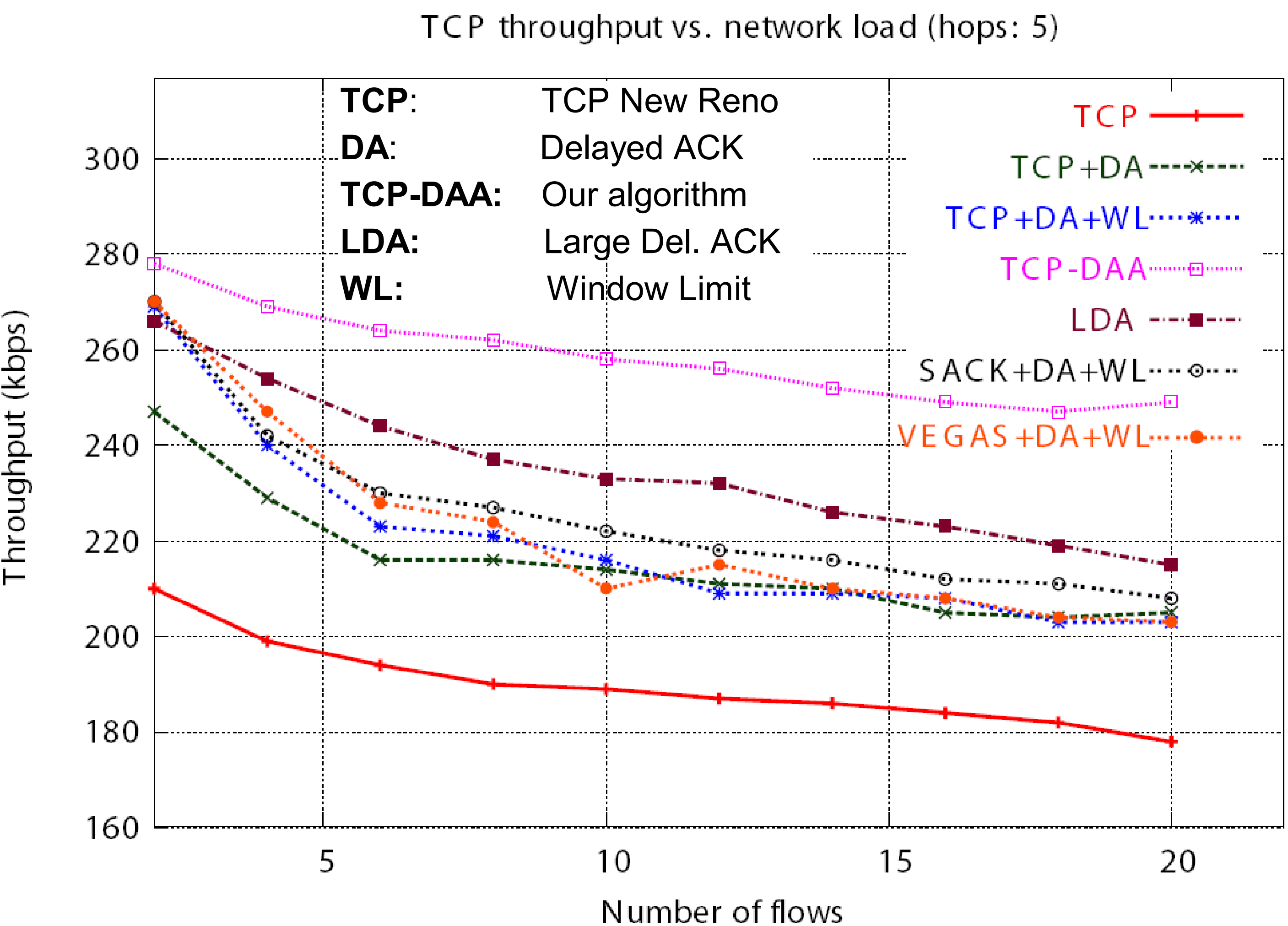
- Fivefold retransmission timeout interval (newRTO=5*RTO)
- Fast retransmission for 2 duplicate ACKs
- Maximum congestion window = 4

  (enough to as many as 10 hops)

# Throughput

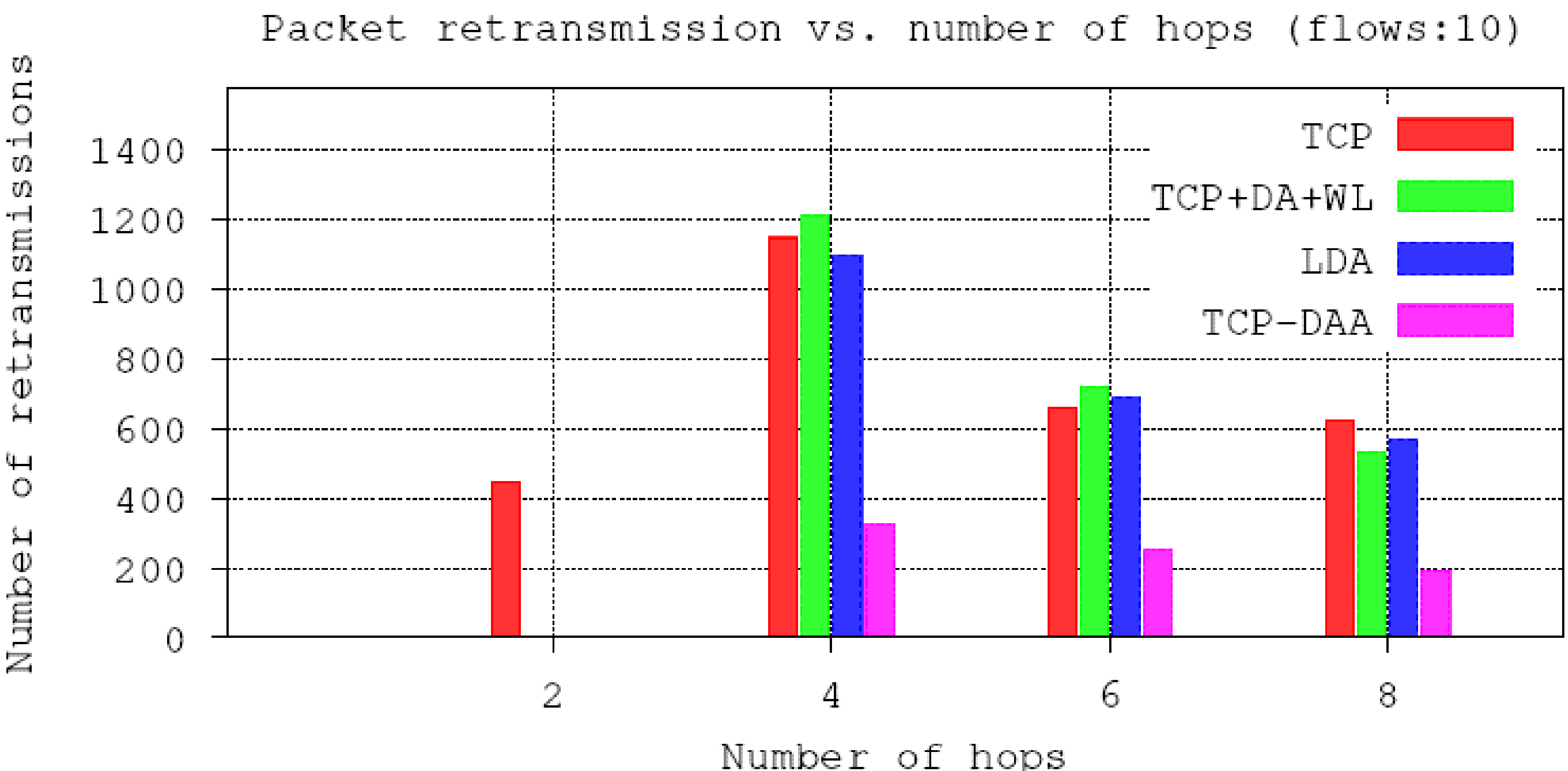



**Simulation scenario**

- chain topology
- loss due to collisions by MAC protocol only
- duration: 300 seconds

# Retransmissions

- Lower traffic overhead leads to fewer retransmissions
- Energy consumption benefits are considerable



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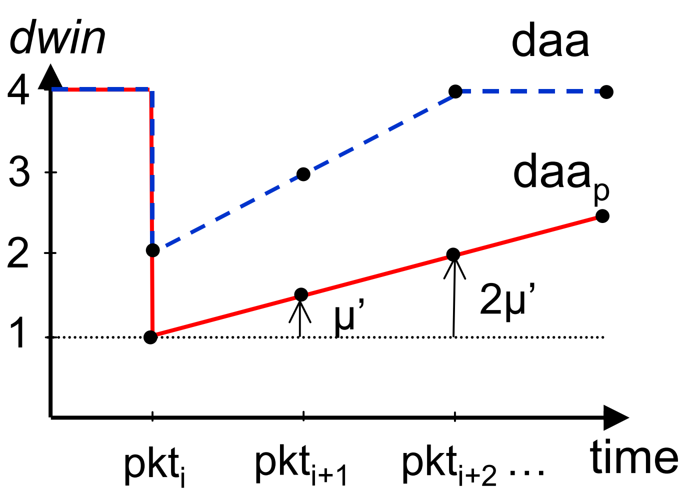
# A Modified dwin strategy for Robustness in Highly noisy Environments (DAAp)

- *dwin* decreases more and increases slower than basic algorithm
- Sender regular RTO is doubled

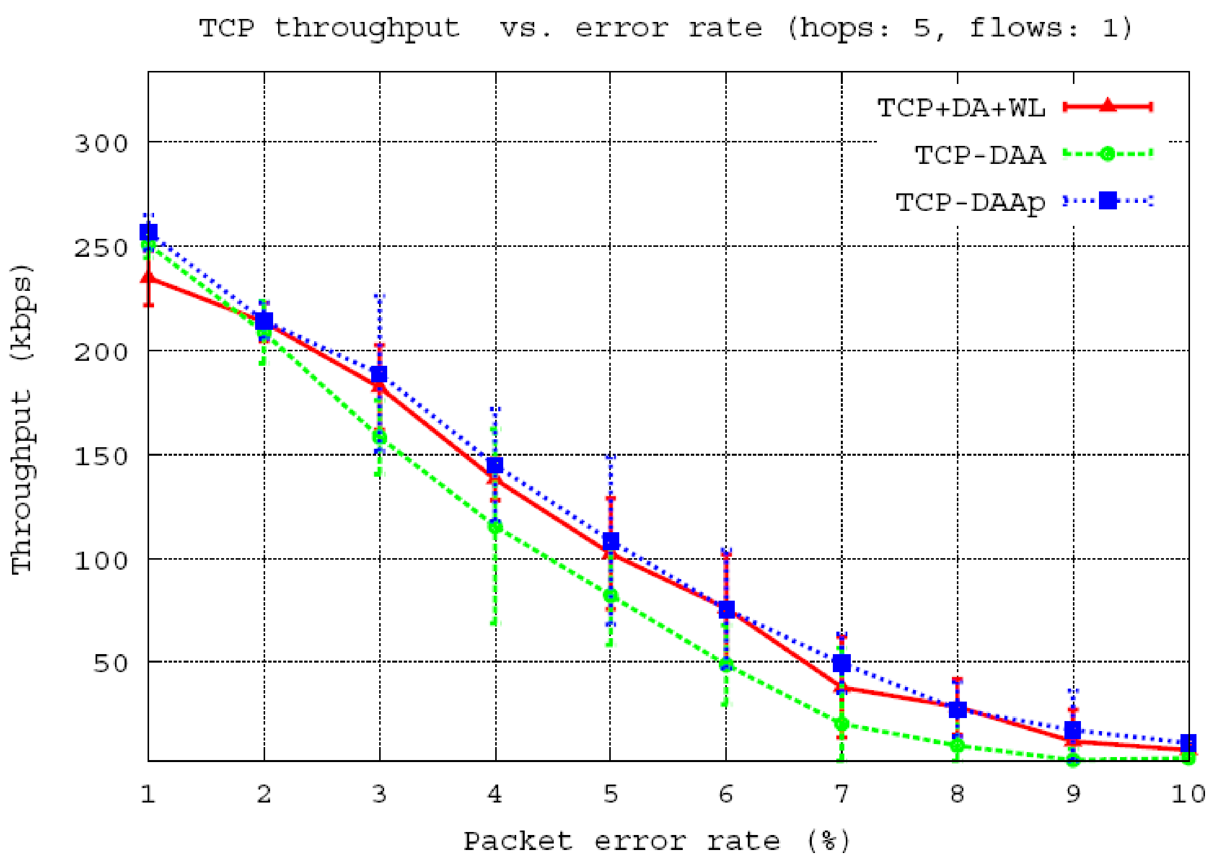
(W: cumulative value of cwnd)




- $$cwnd_i = cwnd_{i-1} + \frac{1}{cwnd_{i-1}}$$
- $$W = cwnd_0 + \sum_{i=1}^{n} \frac{1}{cwnd_i}$$
- for W=4 (max cwnd) → n=7 → $\mu' = 0.3$
- $$dwin_i = \begin{cases} dwin_{i-1} + \mu, \text{if in startup} \\ dwin_{i-1} + \mu', \text{otherwise} \end{cases}$$

# Throughput under external disturbances

Comparison with adjusted TCP NewReno




- DAAp prevents the sender from missing ACKs
- DAAp sender reacts faster than DAAp
- Switching mechanism is useful

# Summary of the Smart Acknowledgment Approach

- The proposed mechanism improves throughput and energy consumption in a variety of scenarios
- It outperforms related approaches in many situations
- It is proper for environments under moderate loss rates

Future work

- A tailored sender side algorithm
- Optimization of the configuration parameters

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# Conclusions and outlook

- The IEEE 802.11 is feasible for short-range networks
- Existing protocols can be fine tuned to enhance 802.11 performance
- Complex modeling are mostly unfeasible here
- Proactive and reactive approaches should be combined
- End-to-end approaches facilitate deployment

- *An alternative MAC protocol for long-range ad hoc networks is very much needed*
- *TCP will have to be adjusted to such a new protocol*
- *Cross layer design seems to be the way*