The Interaction of Forward Error Correction and Active Queue Management

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Plan

- Position of the problem
  - Forward Error Correction (FEC)
  - Active Queue Management (AQM)
  - Motivation
- Experiments
  - Experimental setup
  - Metrics
  - Results
  - Conclusions
- Analysis, Modeling and Explanations

Position of the problem

Two networking bricks:

- End-to-end Loss control techniques in packet networks
  - ARQ (Automatic Repeat reQuest)
  - and FEC (Forward Error Correction)
- Congestion control techniques for router buffers
  - Drop Tail
  - RED

Not designed in conjunction!

Is their combination working?

Forward Error Correction basics (1)

FEC used at the application level to protect ADUs from packet loss.

Consists in adding redundant information to the packet stream, thereby reducing the probability of losing all the information.

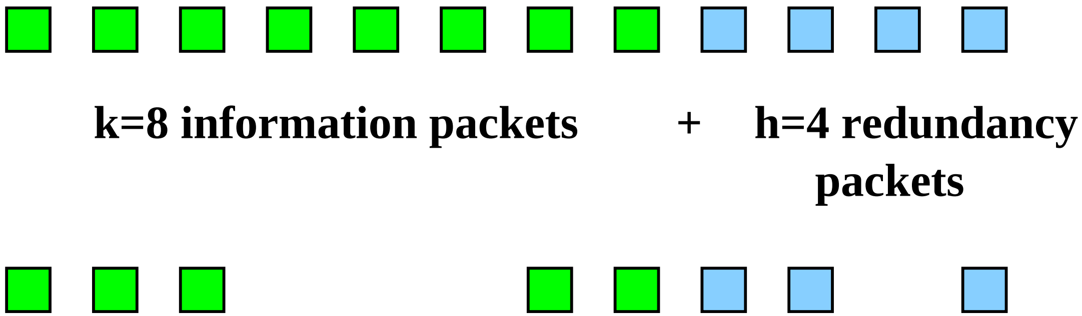
Suitable for streaming/interactive applications (voice, video), long-delay transmissions (satellite), contents distribution?...

Necessitates more bandwidth.

Forward Error Correction basics (2)

When FEC is used at the application level, there are no errors, just losses.

Reed-Solomon codes (and others) have the capacity to repair up to h lost packets with h redundancy packets.



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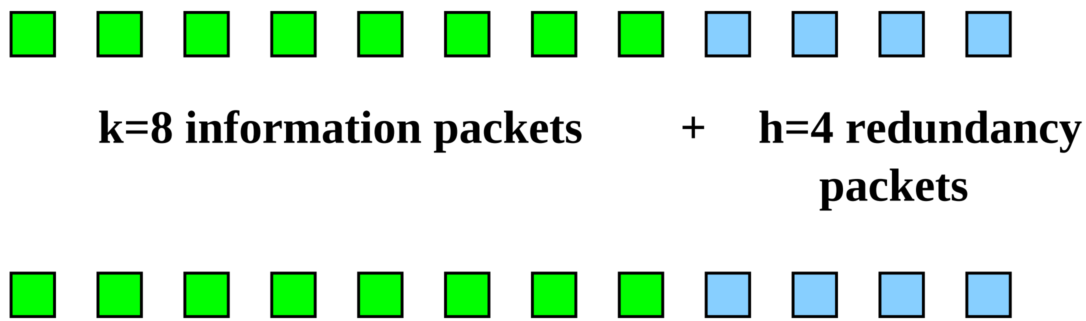

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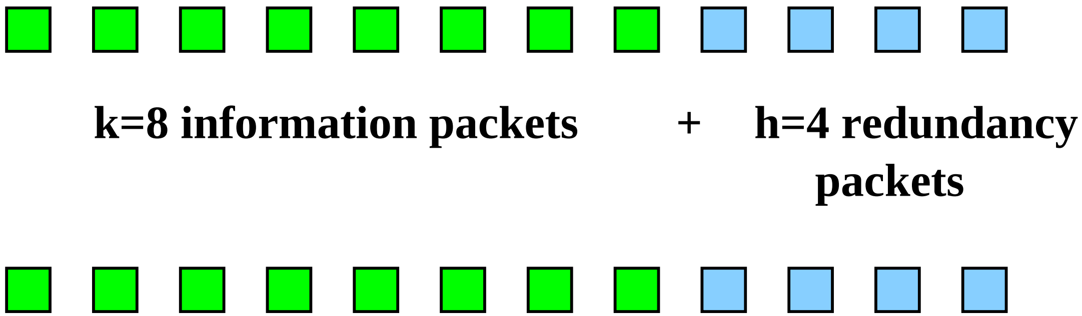


Queue Management (1)

Packets arrive at a router. They may or may not be queued in the buffer.

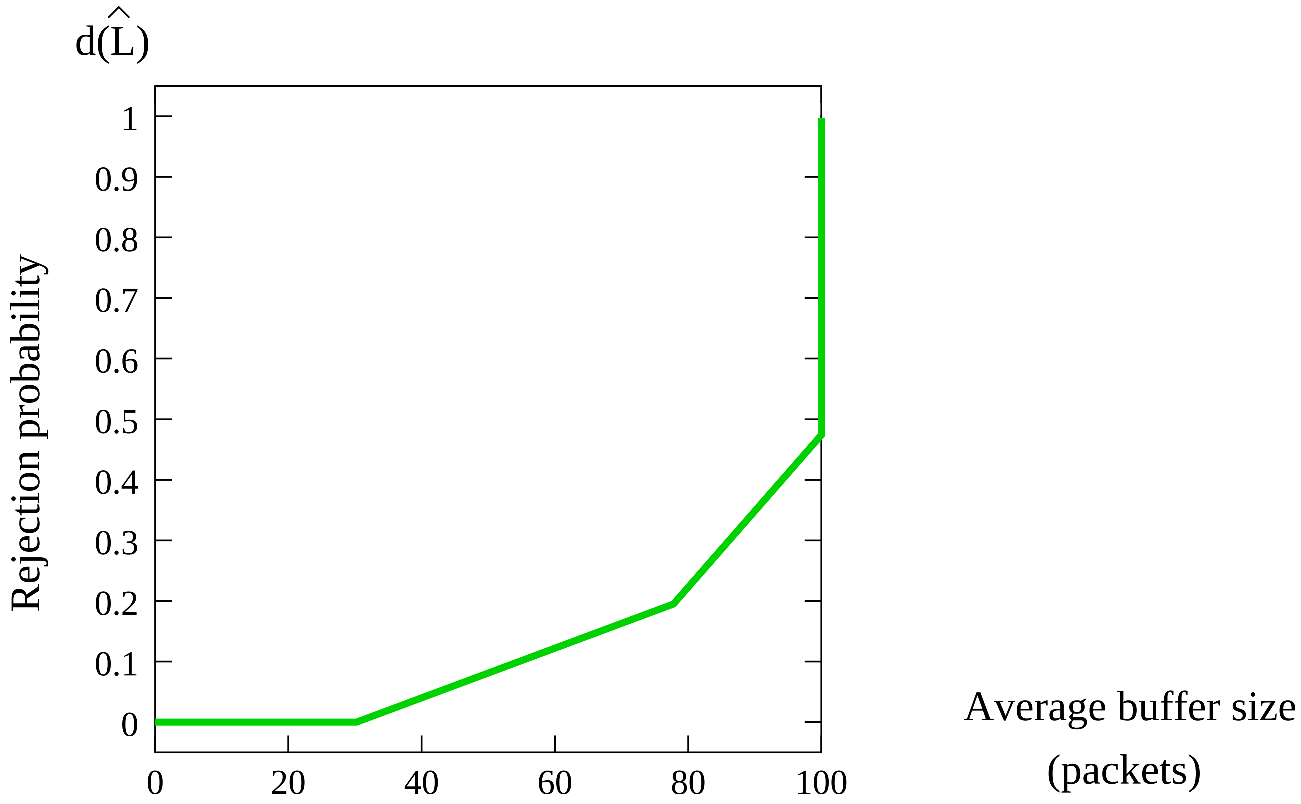
Drop Tail: a “passive” queue management mechanism

- If the queue is full, the arriving packet is accepted
- Otherwise it is rejected.

RED (Random Early Detection): an “active” queue management mechanism

- The average queue length $\hat{L}$ is constantly estimated;
- The packet is rejected with probability $d(\hat{L})$

Queue Management (2)



A typical rejection function $d(\hat{L})$ (RED in “gentle” mode).

Preliminary Analysis

A priori considerations:

FEC: It is “well known” that FEC works better if losses are isolated. If the losses occur in bursts, it takes more redundancy for an equal protection.

AQM: The dropping process of TD and RED is known to have the following characteristics:

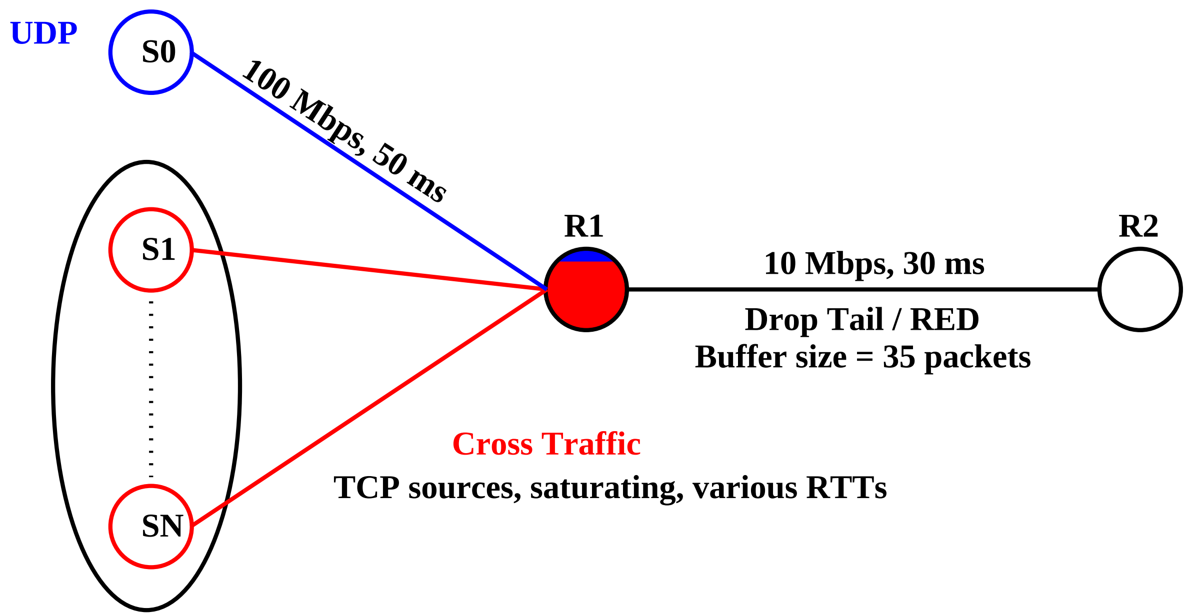
- TD drops packets more in bursts
- RED drops packets more randomly
- the loss rate of RED is larger than that of TD... but not too much.

Intuition $\Rightarrow$ FEC should work better with RED!

Experimental setup

Simulations with the `ns-2` program.

- Source of UDP packets (smooth), 5-10% of the BW
- Background traffic (TCP flows, bursty), saturating the BW.

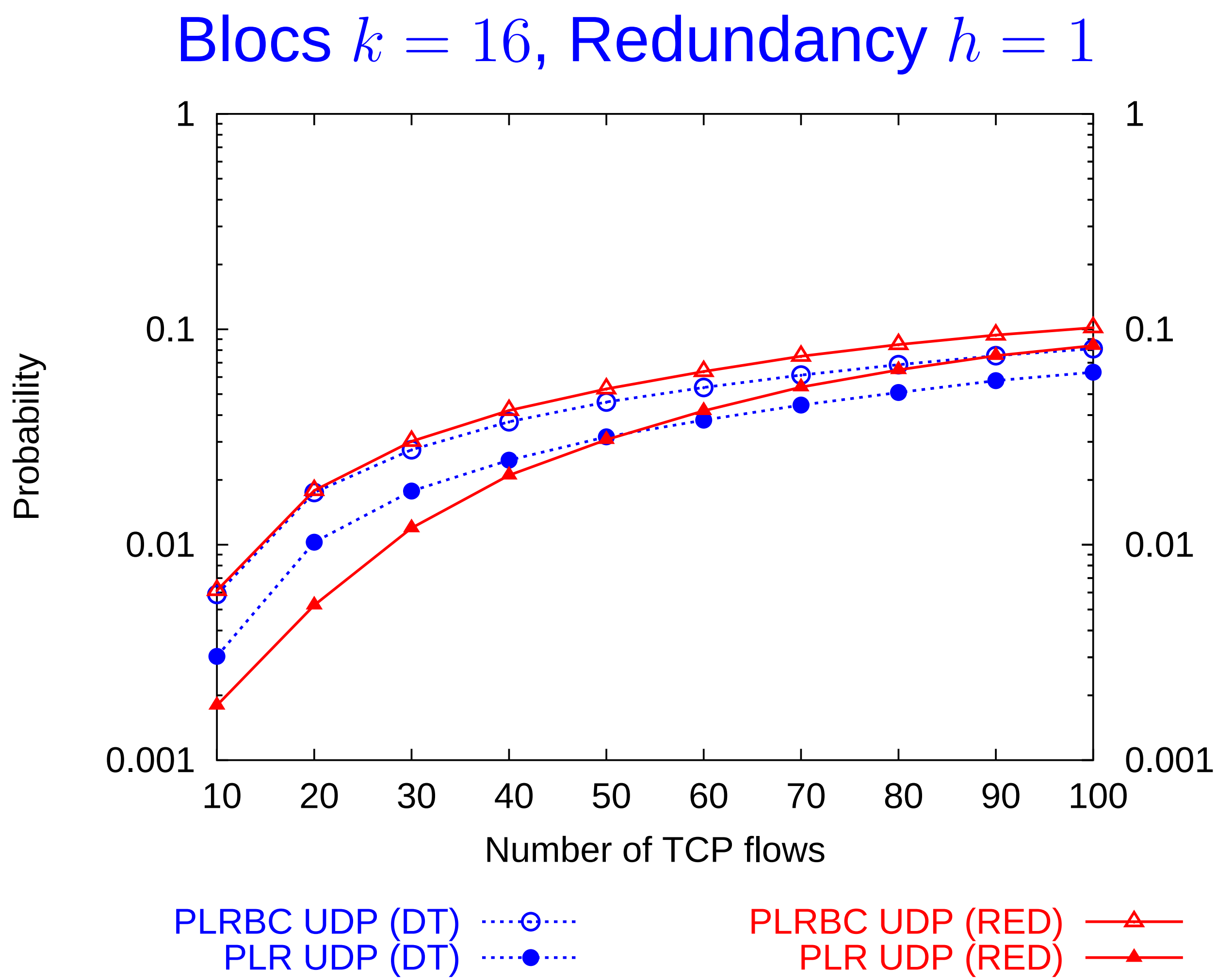


Measurements

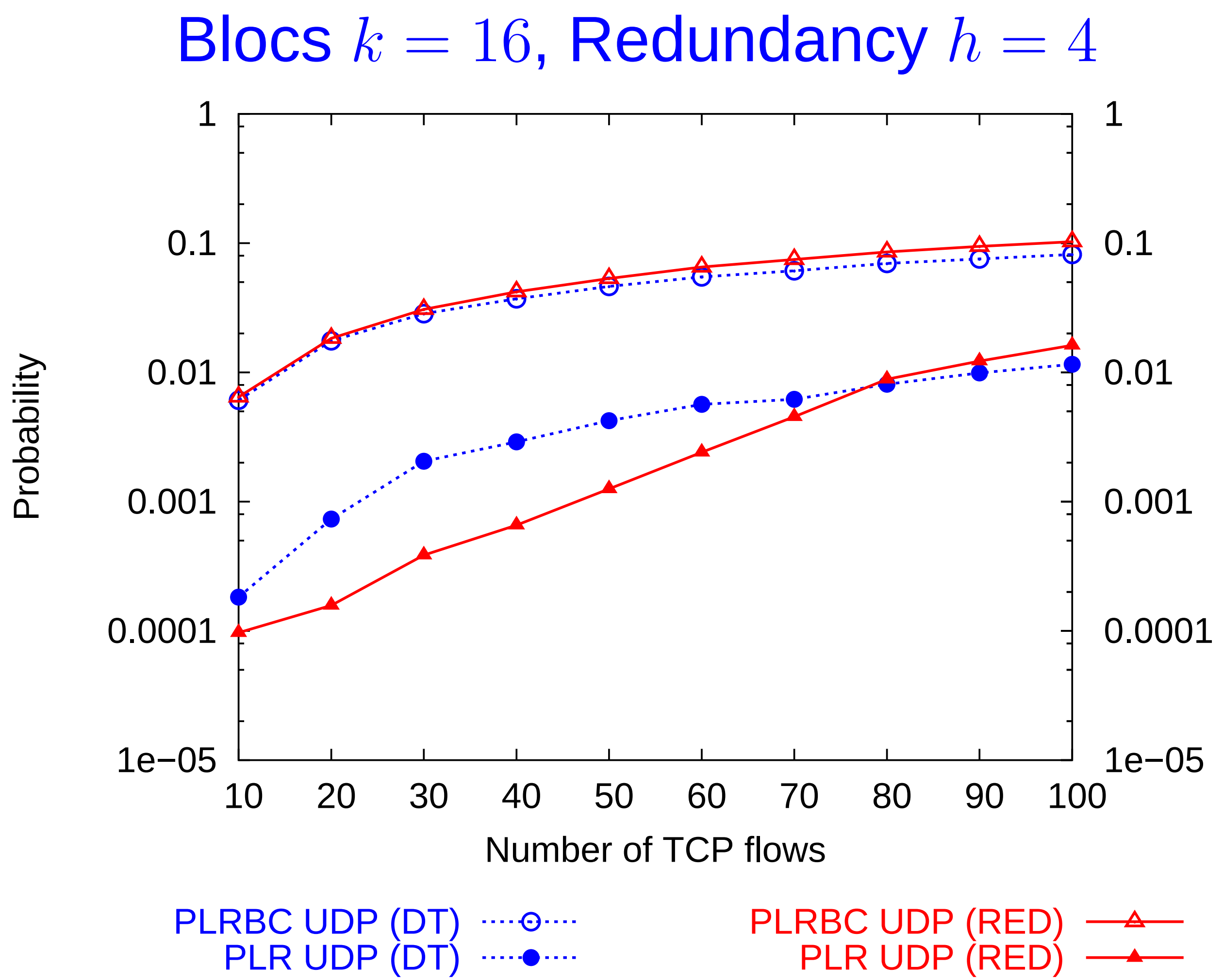
Statistics collected about:

- aggregate throughput,
- queueing delay, jitter,
- packet loss rate before correction (PLRBC)
- packet loss rate after correction (PLR)
- loss run length (LRL)

Results: Influence of the cross traffic (1)



Results: Influence of the cross traffic (2)



Analysis of the results

- $\text{PLRBC}_{\text{RED}} > \text{PLRBC}_{\text{DT}}$ as expected
- $\text{PLR}_{\text{RED}} < \text{PLR}_{\text{DT}}$ up to a threshold
- This threshold depends on the redundancy number h
- Similar cross-over phenomena observed with the block size k.

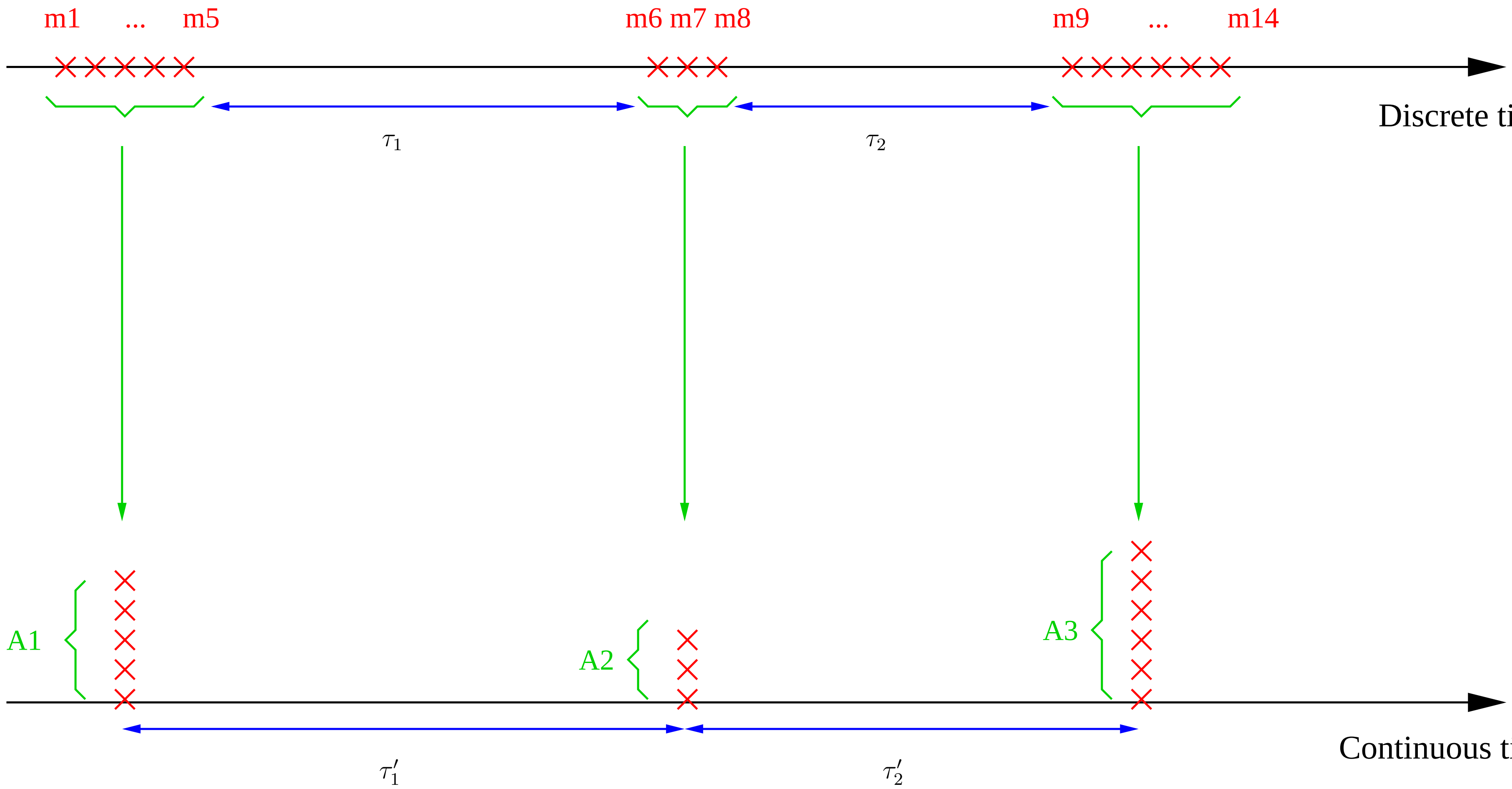
Ref: T. Alemu,
Performance evaluation of Quality of Service mechanisms in the Internet,

Ph.D. thesis, Univ. Montpellier 2, 2004.

Conclusion

- The initial intuition is not always confirmed: it depends
  - on the cross traffic (on the loss probability?)
  - on the block size and the quantity of redundancy
- Finally, RED may work well with UDP/FEC although initially meant to work with TCP!!
- Finally, RED may be not be favorable to interactive/unresponsive flows!!

A model (1)



m1 ... m5
m6 m7 m8
m9 ... m14
Discrete ti
τ_1
τ_2
A1
A2
A3
Continuous t
τ'_1
τ'_2

A model (2)

Process of loss:

- groups of losses occur according to a Poisson process with rate λ,
- groups have random sizes with identical distribution and mean a.

Global loss rate: $p = \lambda \times a$

Distribution of the number of losses:

$$\sum_k z^k P(k \text{ losses in } [0, t)) \; = \; e^{\lambda(A(z)-1)} \; .$$

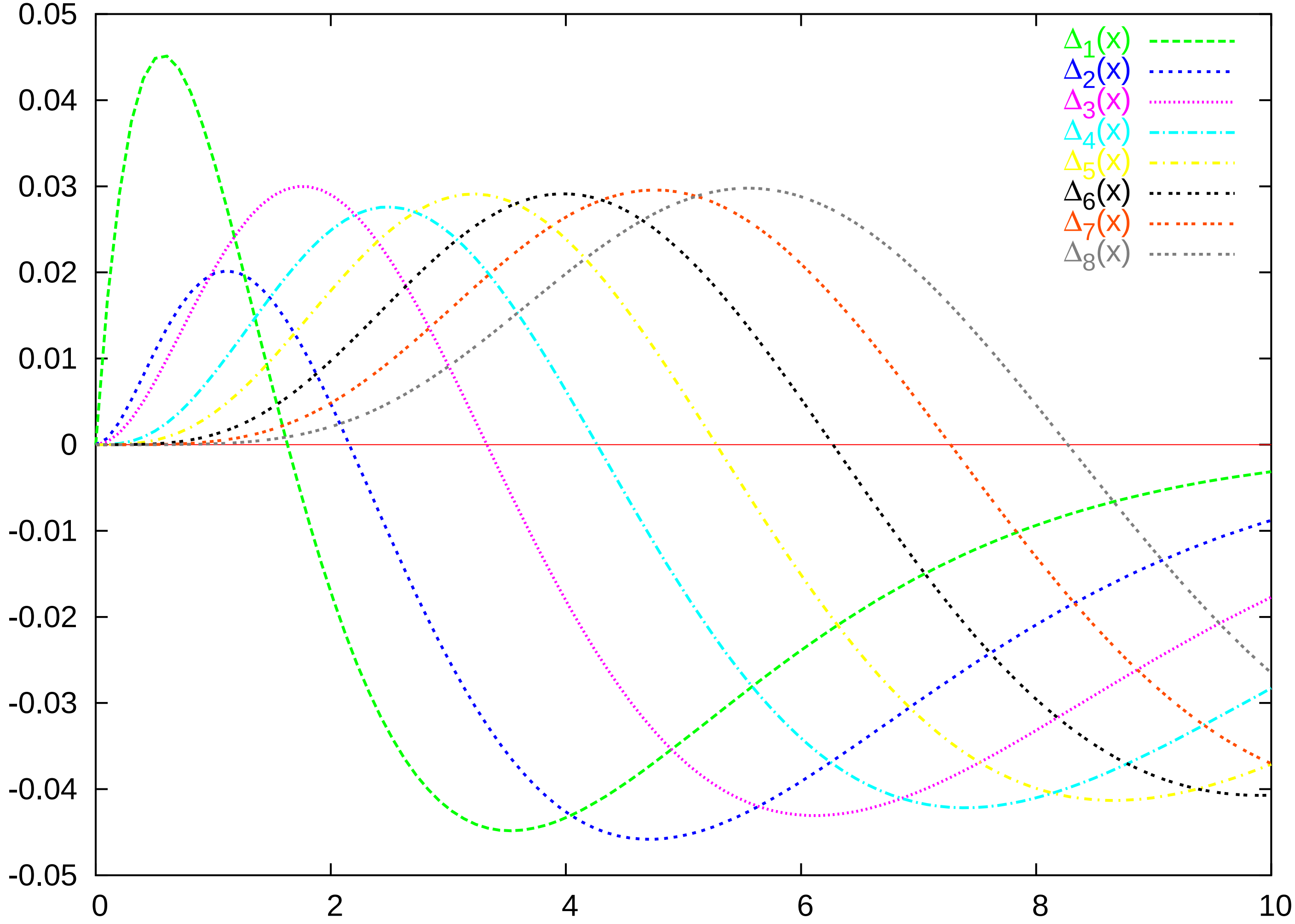
Comparison (1)

Comparison of two cases:

- Case “RED”: losses of
  1 with proba 0.9,
  2 with proba 0.1
- Case “Tail Drop”: losses of
  1 with proba 0.6,
  2 with proba 0.4
- Same average packet loss number $x = p \times (h + k)$

$$\begin{aligned} \Delta_h(x) &= P(\text{ message saved in case “RED” with } h \text{ FEC}) \\ &- P(\text{ message saved in case “TD” with } h \text{ FEC}) \end{aligned}$$

Comparison (2)



Comparison (3)

Empirical evidence (+ Analysis!) shows: RED is better if:

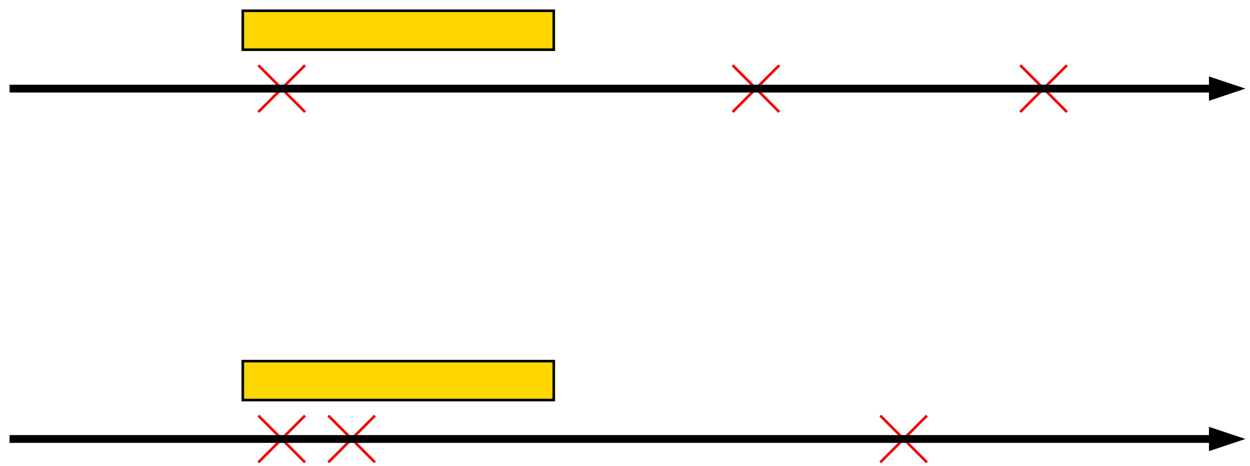
$$x \leq h + C$$

for some constant C.
Equivalently, RED better if:

$$\begin{aligned} k &\leq \frac{1-p}{p}\,h + \frac{C}{p} \\ \frac{h}{k} &\geq \frac{p}{1-p} - \frac{C}{1-p}\frac{1}{k} \\ p &\leq \frac{h+C}{h+k}\,. \end{aligned}$$

An Explanation

There is a compromise between loss “burstiness” and loss rate. Assume blocks protected with $h = 1$ packet.



Low loss rate/small blocks

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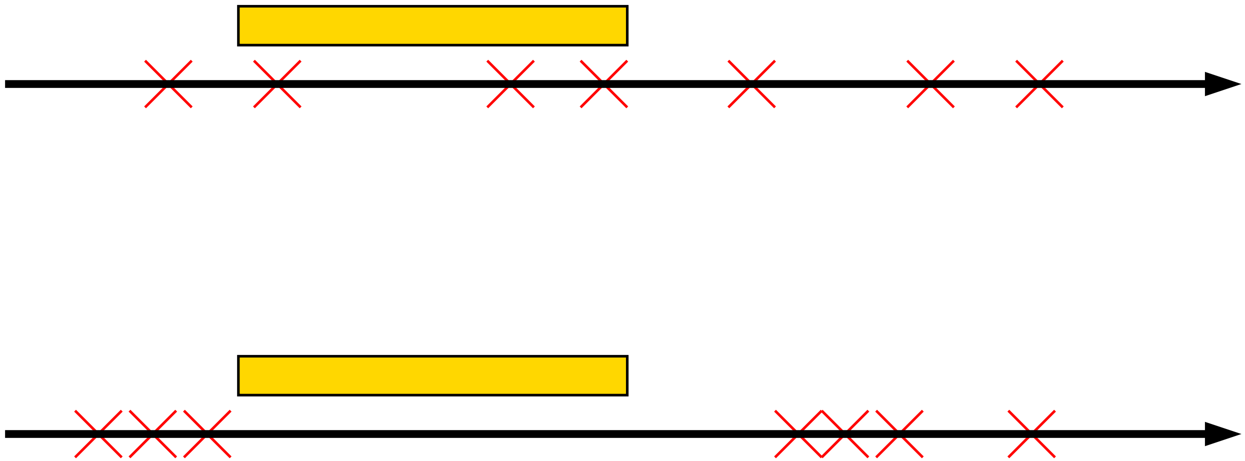

High loss rate/large blocks