Bandwidth tradeoff between TCP and link-level FEC

Chadi Barakat & *Eitan Altman*

INRIA - Sophia Antipolis, France

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Outline

- Introduction:
  - Problem of TCP over wireless links.
  - FEC as a promising solution.
  - Bandwidth tradeoff between TCP and FEC.
- Our analytical model:
  - Memorlyess wireless links.
  - Bursty wireless links.
- Numerical and simulation results.
- Concluding remarks.

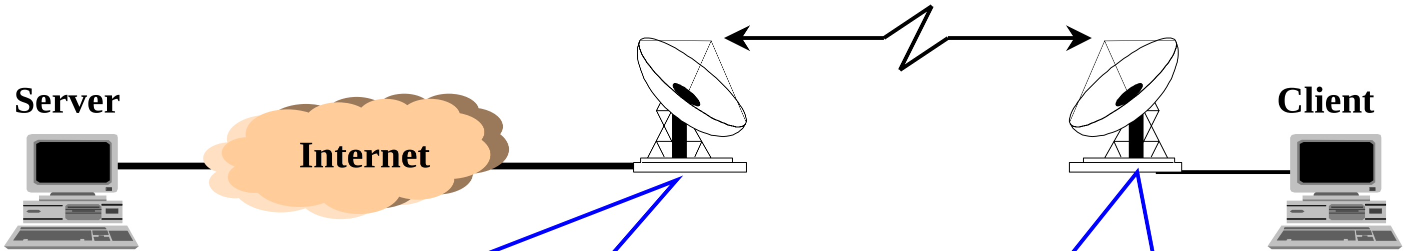
TCP and FEC over wireless links

- TCP suffers from transmission errors since it interprets them as congestion signals (unnecessary reduction of the transmission rate).
  - TCP throughput known to be inv. prop. to $\sqrt{\text{Packet Loss Rate}}$

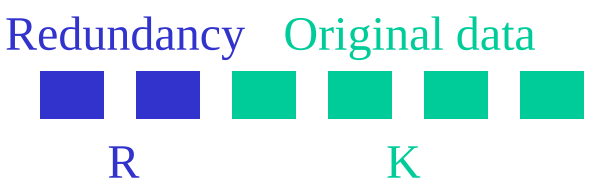
- Forward Error Correction shields TCP from transmission errors by correcting them locally without the intervention of TCP.

  - FEC is very promising since errors are corrected on runtime without any retransmission or disordering of packets. This eliminates any interferences with TCP congestion control mechanisms.

A model for FEC



Division of a TCP packet into K link-level units (e.g., ATM cells) and addition of R units of redundancy



N= K + R

Relative amount of FEC = N/K

Delivery of a packet to higher layers if at least K of its N link-level units are correctly received.

A TCP packet can now resist to the loss of up to R units without being discarded.

Bandwidth tradeoff

- The Addition of FEC reduces the loss rate and improves the throughput of TCP until a point where TCP is able to fully utilize the available bandwidth.
- Any addition of FEC beyond this point will deteriorate the performance of TCP.
- **Our objective:** Find the amount of FEC that leads to the best TCP throughput.
  - Optimize the amount of FEC when the wireless link is the bottleneck and when only one TCP connection is running.
  - The solution to this particular case will also be the solution to the most general case (multiple connections, non-congested wireless link).

The model

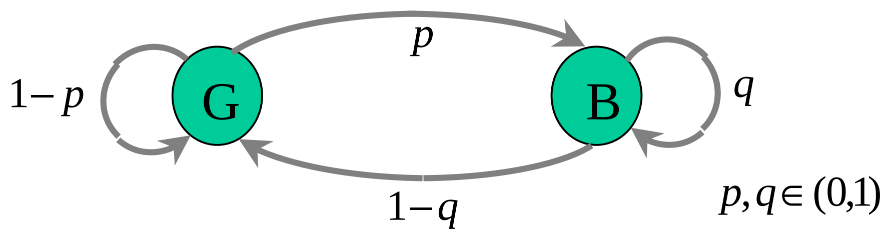
- **P** = Loss probability of a TCP packet on the wireless link.
- μ = Total bandwidth of the wireless link in terms of link-level units per second.
- f**(P,RTT)** = TCP throughput without bandwidth limitation (e.g., square root formula $\frac{1}{\text{RTT}}\sqrt{\frac{3}{2\text{P}}}$).

$$\text{TCP throughput} = \min(f(\text{P}, \text{RTT}), \tfrac{K}{N}\mu)$$

- **Problem:** Calculate **P** as a function of the amount of FEC and the loss process of link-level units (two-state Gilbert model to account for burstiness).

p = Prob{Unit ***n*** lost | Unit ***n-1*** not lost}

q = Prob{Unit ***n*** lost | Unit ***n-1*** lost}



The analysis

- Non-bursty case (Bernouilli):

P = Prob{more than R losses in a frame of N units} = $\sum_{i=0}^{K-1} \binom{N}{i} (1-p)^i p^{N-i}$

- Bursty case:
  - Only one burst of losses can hurt a packet at a time.
  - The wireless link converges quickly to its stationary regime.

P = Prob{a burst of more than R losses hurts somewhere the packet}

$\approx q^{N-K} L\ ((1-q)K+q)$

with L being the average loss rate equal to $p/(p+1-q)$

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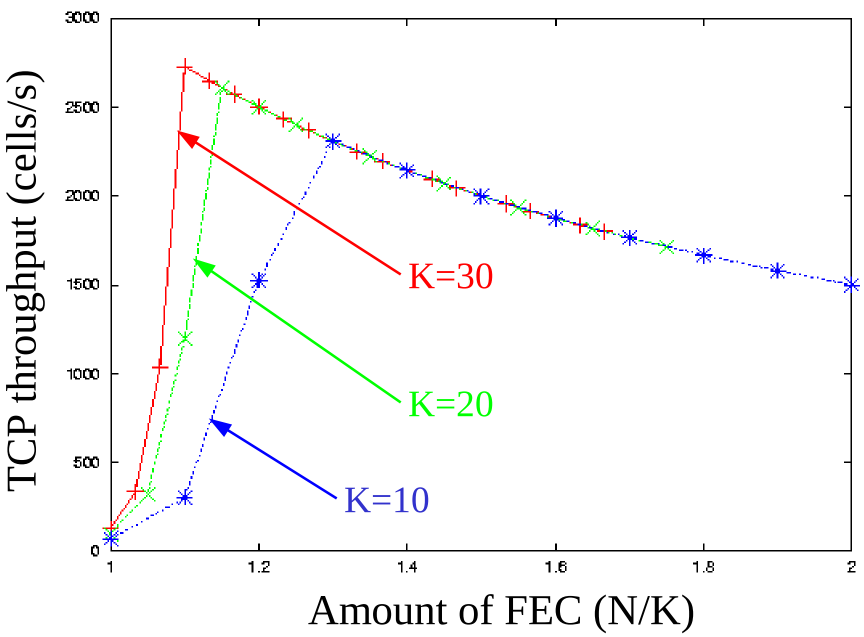
Results: Non-bursty case (1)

Case study: Long-life TCP connection over a 1.5 Mbps wireless ATM link.

All numerical results validated with `ns` simulations.

- TCP throughput increases with the amount of FEC until the optimal point, then starts to decrease.
- For the same amount of FEC, large frames (large packets) give better performance due to a faster TCP window increase.



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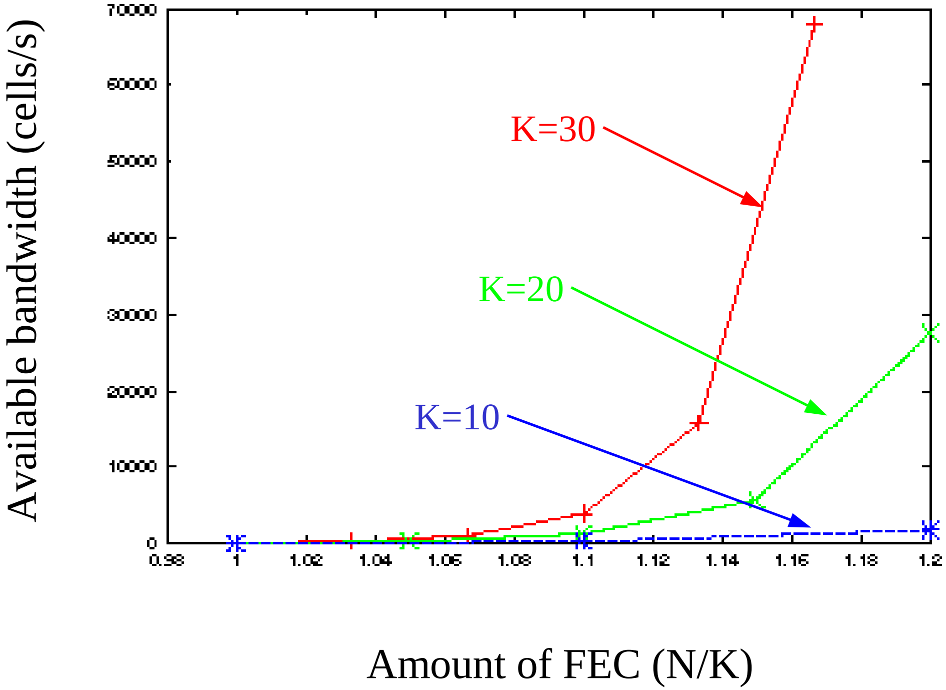
Results: Non-bursty case (2)

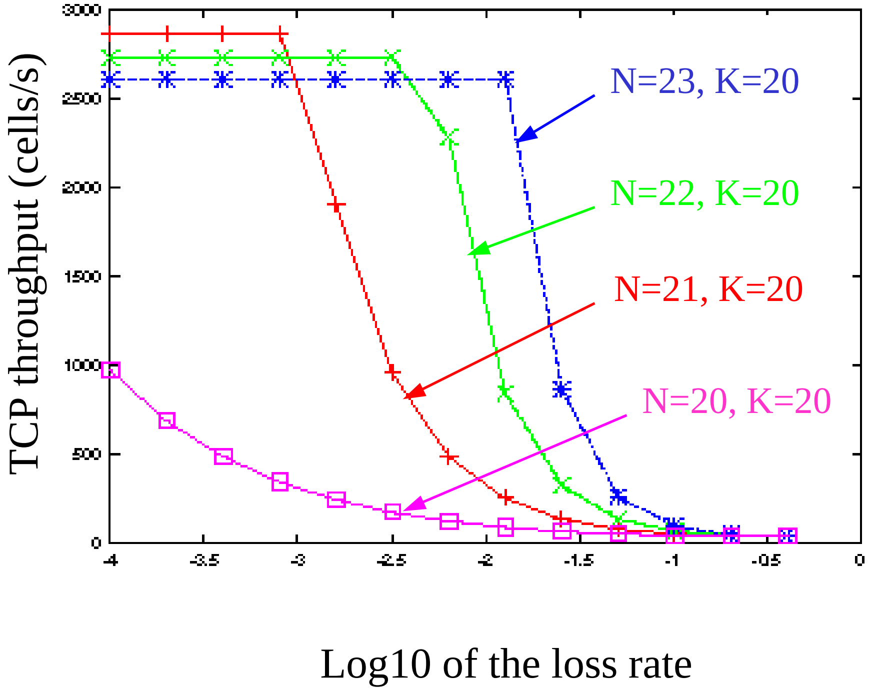
Optimal amount of FEC for a rate of losses equal to 1% :



Results: Non-bursty case (3)

- The more the FEC, the better the resistance of TCP to an increase in the loss rate.

- The cost for a large amount of FEC is a smaller TCP throughput at low loss rates.

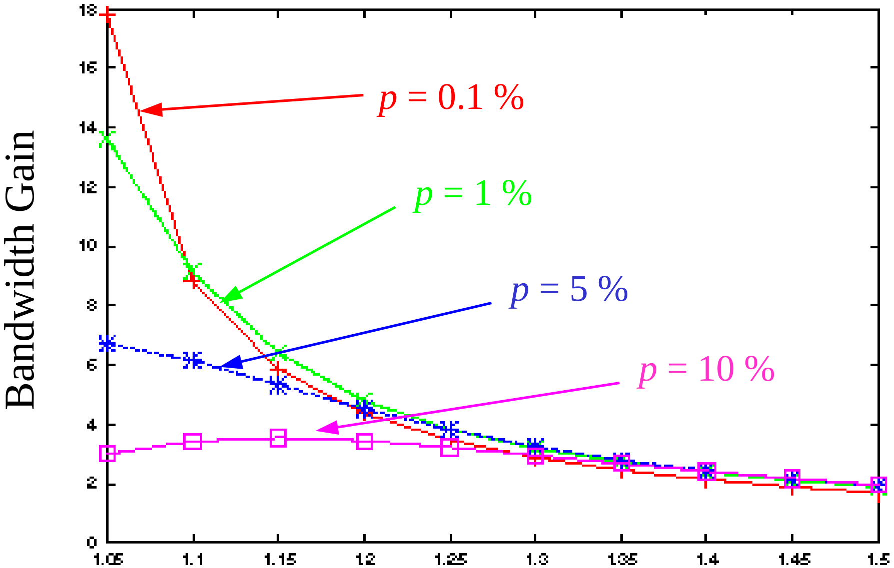


Results: Non-bursty case (4)

- Define the gain of a FEC scheme as:

$$\frac{\text{Gain in TCP throughput}}{\text{Bandwidth consumed by FEC}}$$

- The gain decreases with the addition of FEC, with a high gain for low loss rates.



Amount of FEC N/K

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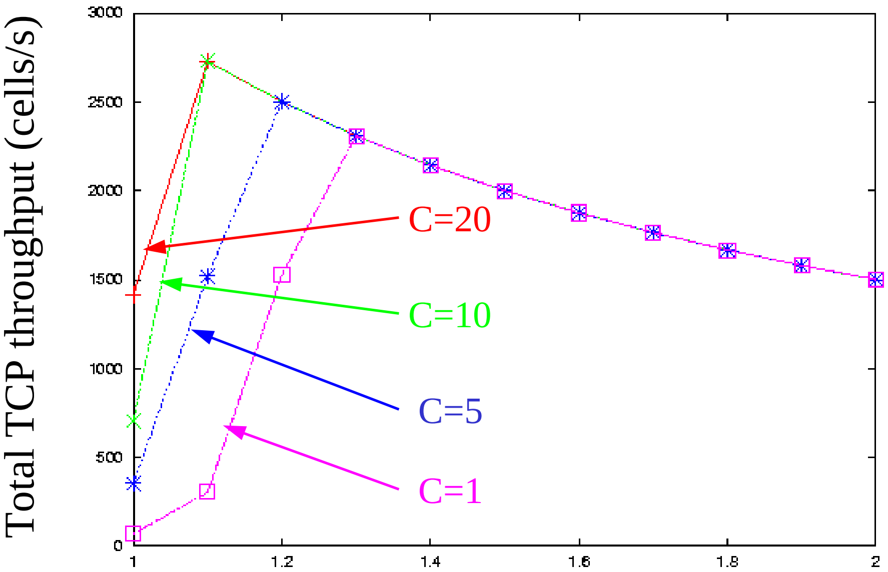
Results: Non-bursty case (5)

C = Number of TCP connections

- Better gain can be obtained if we use a small amount of FEC and open many TCP connections to fully utilize the available bandwidth.

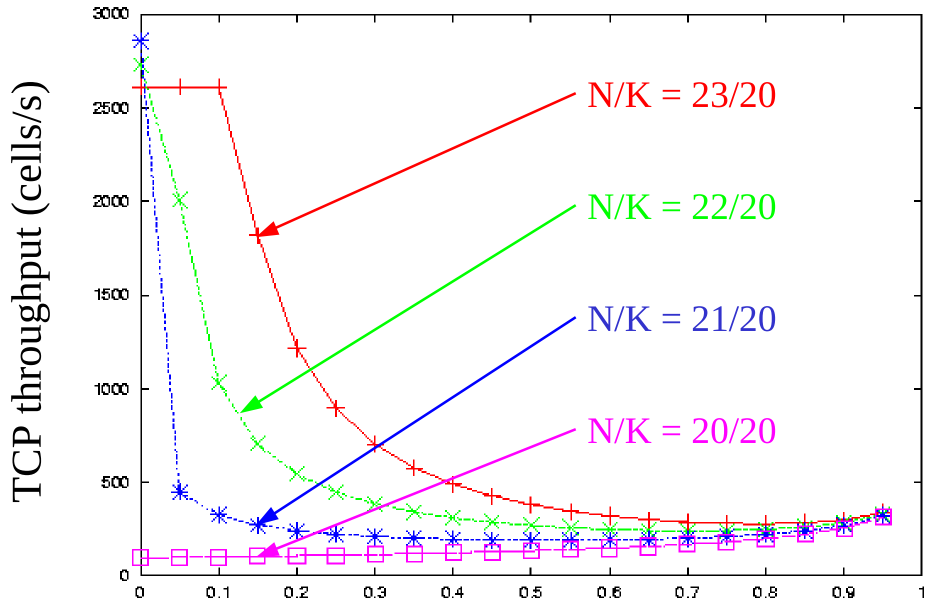


Amount of FEC

Results: Bursty case (1)

For an average loss rate of 1% , we increase the burstiness of transmission errors:

- A large amount of FEC resists better to a clustering of losses, but at the expense of a smaller TCP throughput when transmission errors stop being clustered.

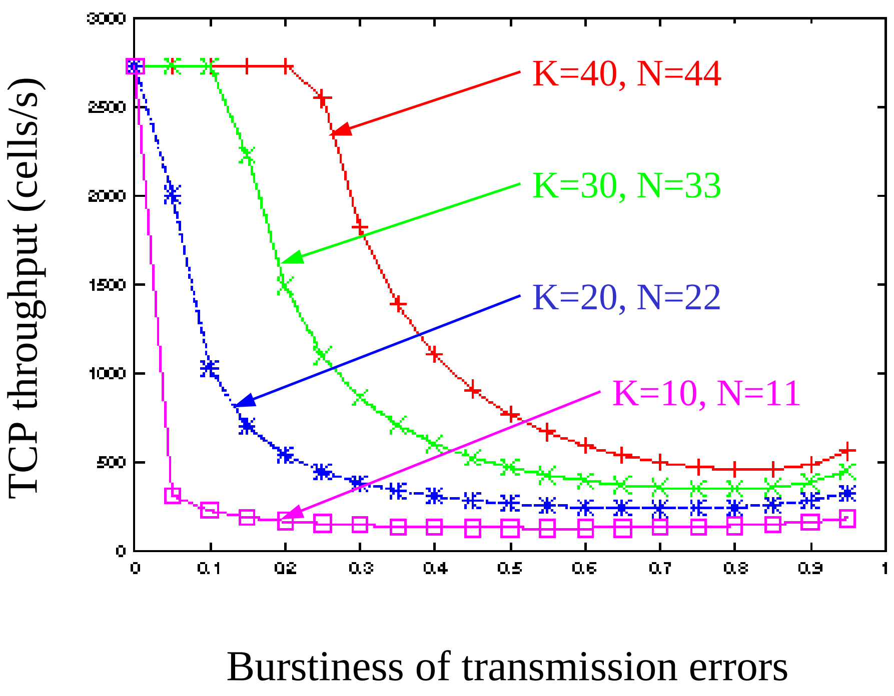


Burstiness of transmission errors

Results: Bursty case (2)

For the same amount of FEC, we study the impact of the frame size:

- A large frame size results in a better performance due to a faster window increase and a larger number of redundant units per TCP packet.
- The advantage of increasing the frame size is that we will not lose in performance when transmission errors stop being bursty.



Conclusions

- Guidelines for the implementation of a 'TCP-friendly' FEC:
  - Choose first the maximum possible frame size.
  - Then, add FEC so that a single TCP connection is able to full utilize the available bandwidth (using for example the result of our model).
- Future work:
  - Study some kind of adaptive FEC scheme that permits to change the amount of redundancy as a function of the load and the burstiness of errors.
  - Consider the needs of non-TCP flows (e.g., audio flows) in the optimization of FEC.