Simulation-based study of link-level hybrid FEC/ARQ-SR for wireless links and long-lived TCP traffic

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WiOpt'03: Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks

March 4, 2003

TCP and wireless links

- Wireless links: WLAN, GSM, GPRS, UMTS, satellite, etc.
- Characterized by a high bit error rate compared to wired links (non-congestion losses):
  - Different sources: Signal attenuation, interference, multi-path fading, shadowing, rain, handoff, etc.
- Negative impact on TCP performance:
  - TCP considers the loss of a packet as a congestion signal and reduces its window unnecessarily.
  - TCP throughput is known to be inversely proportional to the square root of the packet loss rate.

Overview of solutions

- Clean links by correcting non-congestion losses locally:
  - Use of link-level FEC, ARQ, hybrid FEC/ARQ, more power, etc.
  - Achieve a TCP friendly network where packets are only lost in routers.
- Help TCP to distinguish non-congestion losses:
  - ELN, loss predictors, Vegas, ECN, etc.
- Split the TCP connection, isolate the noisy link, and transmit data over the noisy link using an optimized transport protocol:
  - I-TCP, MTCP, Snoop protocol, STP, etc.

Our work focuses on the link-level FEC/ARQ-SR solution …

FEC: pros and cons

- FEC incomes:
  - Reduces the packet loss rate.
  - Correct packets on the fly, which eliminates any interaction with TCP retransmission timer as in the case of ARQ.
  - FEC is of particular interest on long delay links and at high loss rates.
- FEC cost:
  - Processing overhead, delay, maximum bit rate.
  - The redundant information consumes bandwidth, which may reduce the throughput of TCP if added in large amounts.
- What is the amount of FEC that leads to the best TCP throughput?

Chadi Barakat, Eitan Altman, "Bandwidth tradeoff between TCP and link-level FEC", Computer Networks, vol. 39, no. 2, pp. 133-150, June 2002.

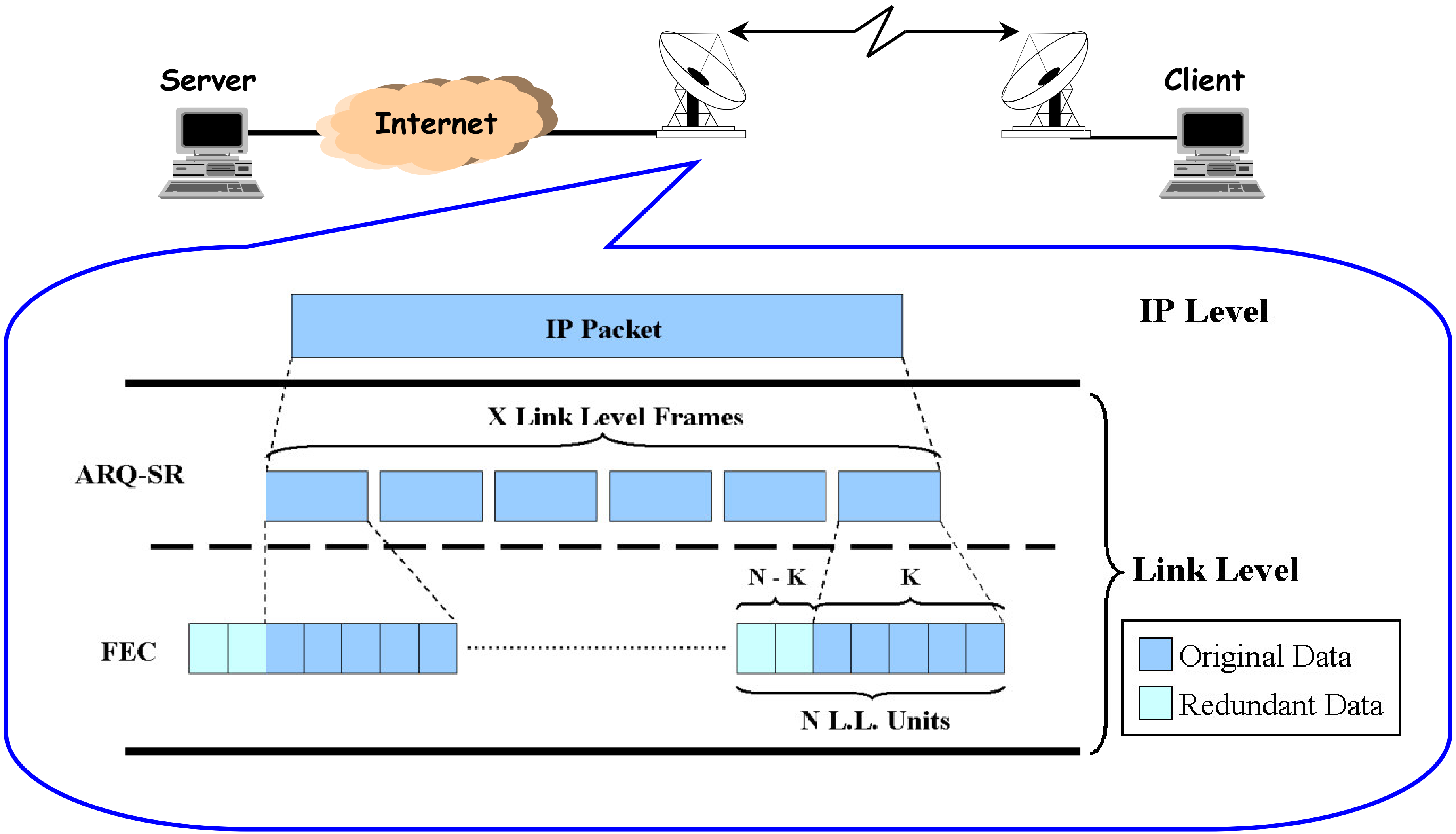
ARQ: pros and cons

- ARQ is interesting on short delay links and at low loss rate:
  - Incomes: Bandwidth is only wasted when packets are lost.
  - ARQ cost:
    - Introduce jitter, which is harmful for real time applications.
    - Introduce burstiness when an in-order delivery is supported.
    - Introduce reordering when an out-order delivery is supported.
    - Interfere with TCP timeout mechanism when persistency is high.
  - ARQ Selective Repeat:
    - Complex compared to Stop-And-Wait and Go-Back-N.
    - But, allows higher utilization of the available link capacity.

FEC/ARQ-SR: objective of the study

- By combining FEC, ARQ-SR and an in-order delivery of packets at the output of the wireless link, better performance can be achieved.
- Objective of the study: How to optimize such an error recovery mechanism to obtain the best TCP throughput ?
  - Main focus on the amount of FEC and the persistency of ARQ.
- Outline:
  - Model of the study.
  - Simulation-based study using the NS simulator.
  - Conclusions, perspectives.

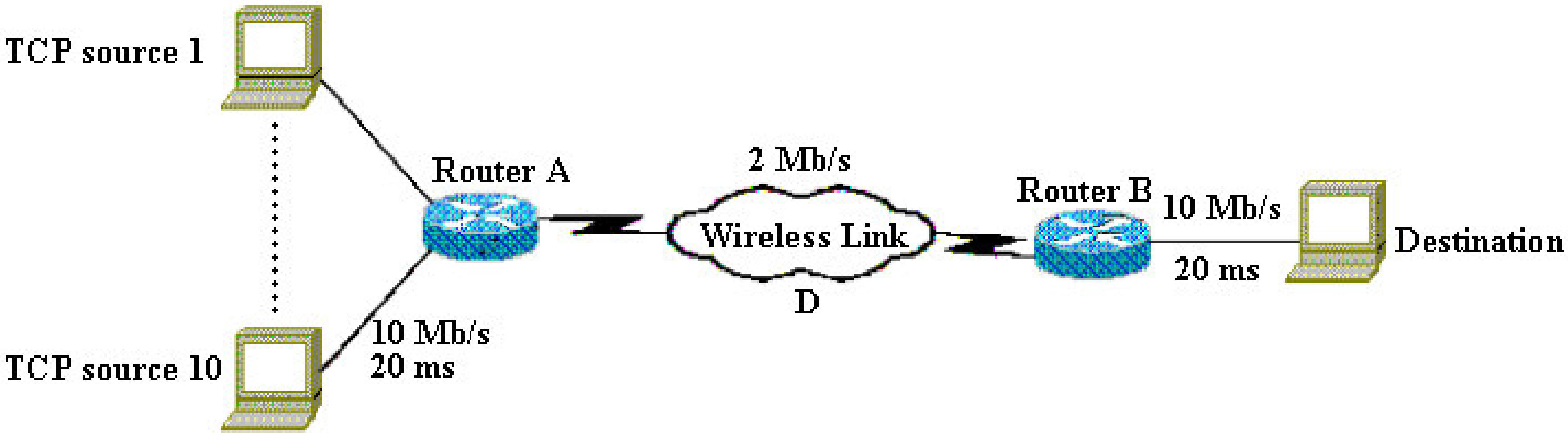
FEC/ARQ-SR model



FEC/ARQ-SR model

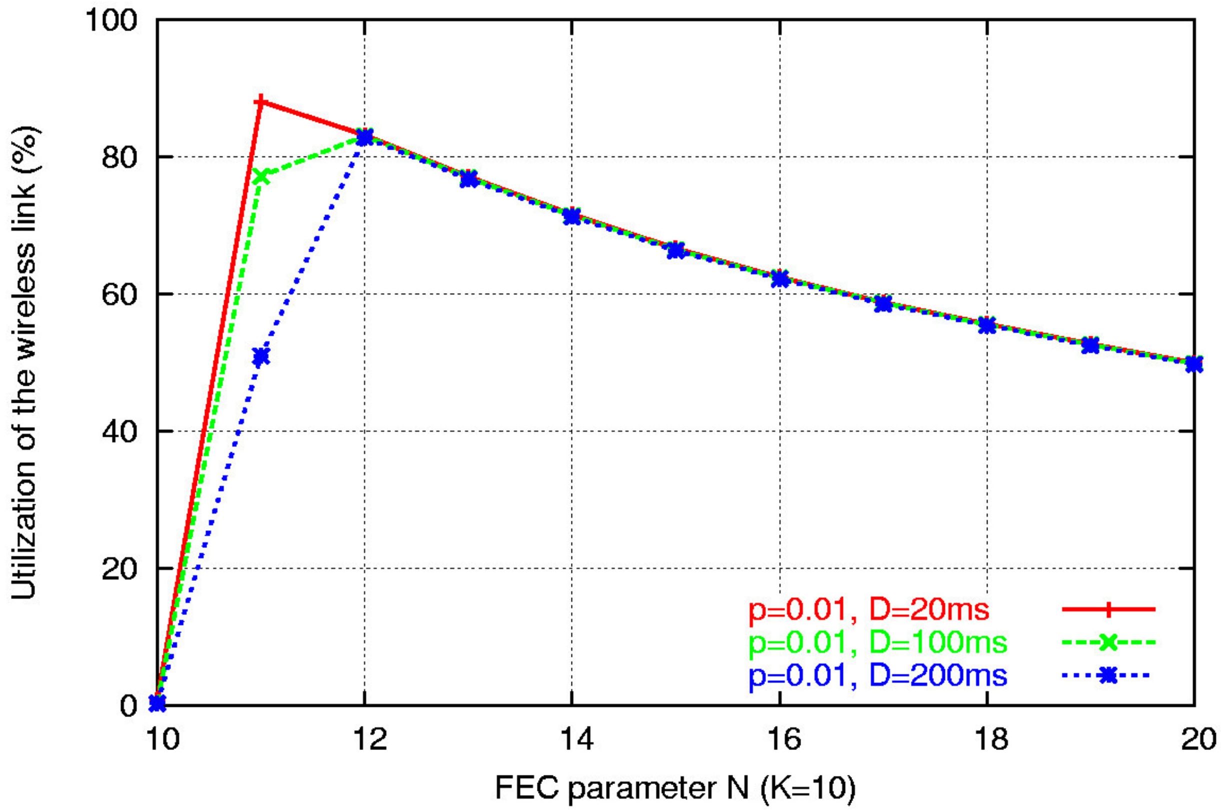
- FEC: Erasure block code, a frame is recovered if the number of erroneous units is less than (N - K), K/N being the code rate.
- ARQ-SR:
  - A TCP/IP packet is divided into X frames.
  - If a frame is not recovered by FEC, it is retransmitted by ARQ-SR.
  - The maximum number of retransmissions is δ (persistency of ARQ).
  - A link-level NACK is sent for each erroneous frame. The frame is quickly retransmitted and given priority over all frames.
  - A packet is discarded when FEC and ARQ-SR fail to recover one of its frames.
  - Packets are delivered in-order at the output of the wireless link.

Simulation scenario



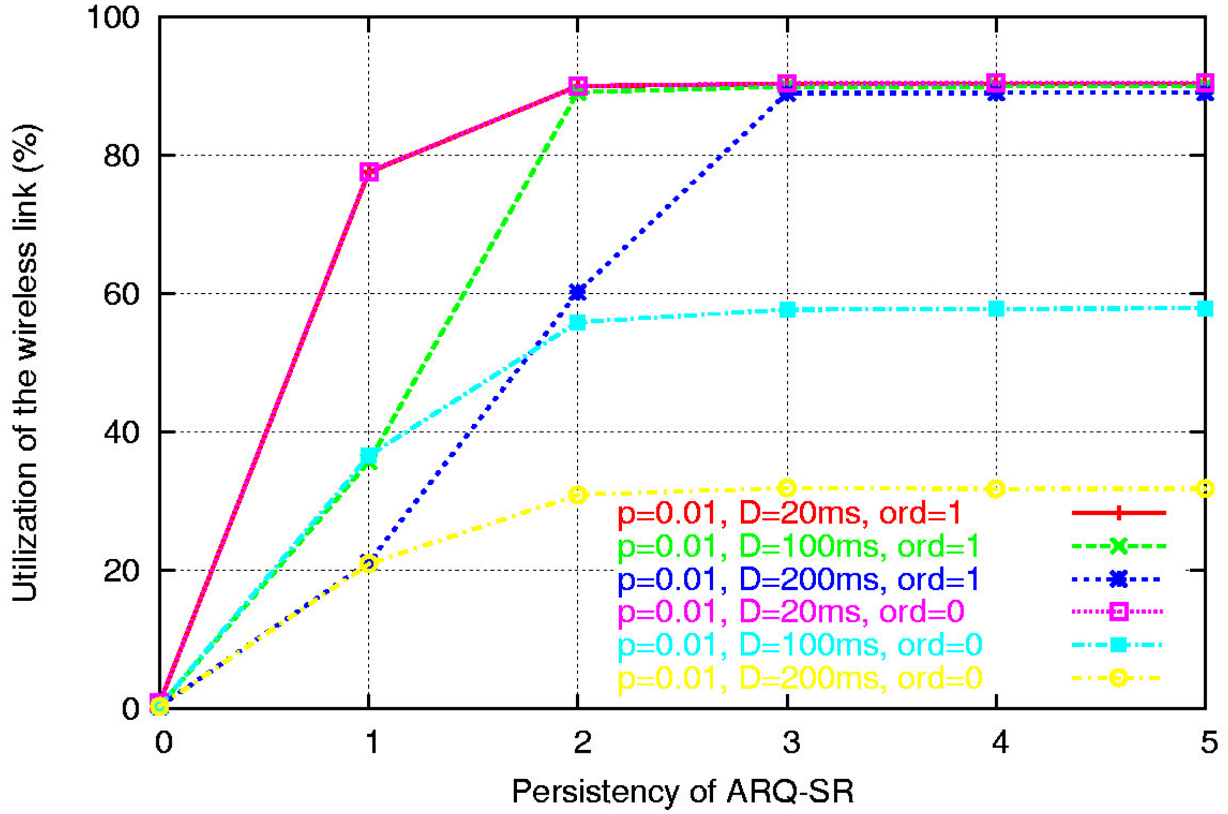
- Long-lived TCP connections.
- The wireless link is the bottleneck for the TCP connections:
  - No congestion losses before the full utilization of the wireless link.
- Errors are assumed to be Bernoulli without memory:
  - Link-level units are dropped with the same probability p.
- Without loss of generality: X = 6, packets = 1500 Bytes, units = 25 Bytes, K = 10.

FEC alone



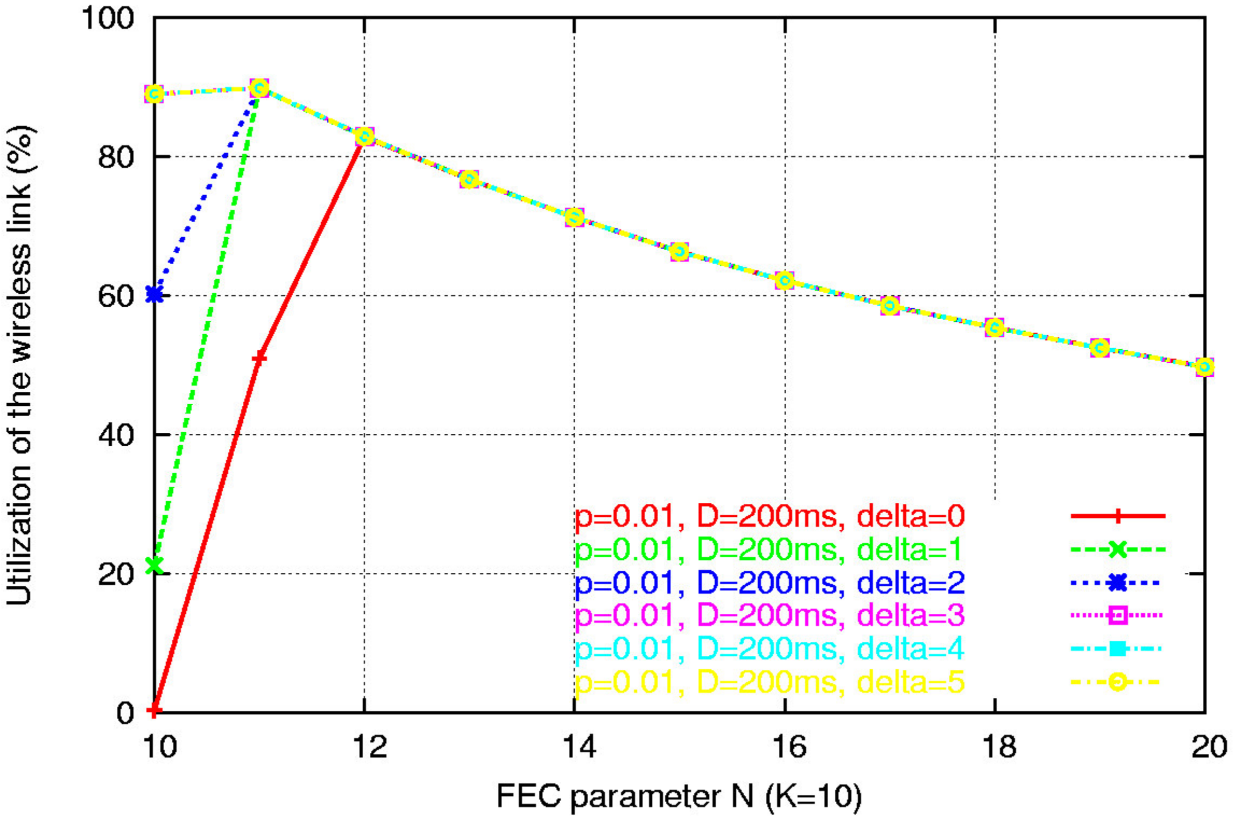
- Performance improves with FEC then deteriorates (there is an optimum).
- More FEC is needed when the delay is large (same thing for loss rate).

ARQ alone



- Performance always improves with δ (even in the extreme case of large delay) !
- At large delay, the in-order delivery of packets is essential for good performance.

And if we combine both ?



- The best performance can always be achieved with ARQ alone.
- For small values of d, some units of redundancy are needed for a full utilization.

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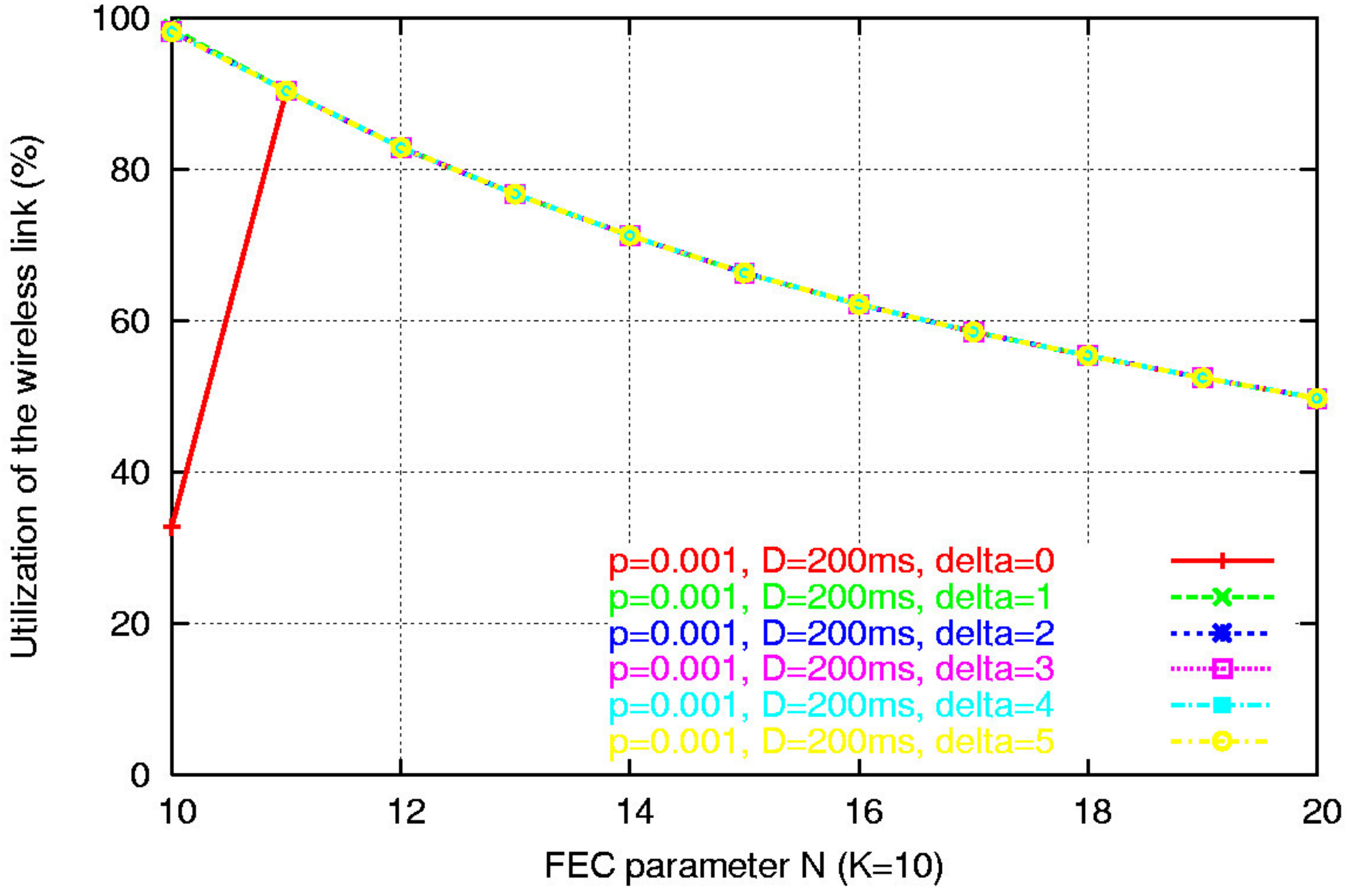
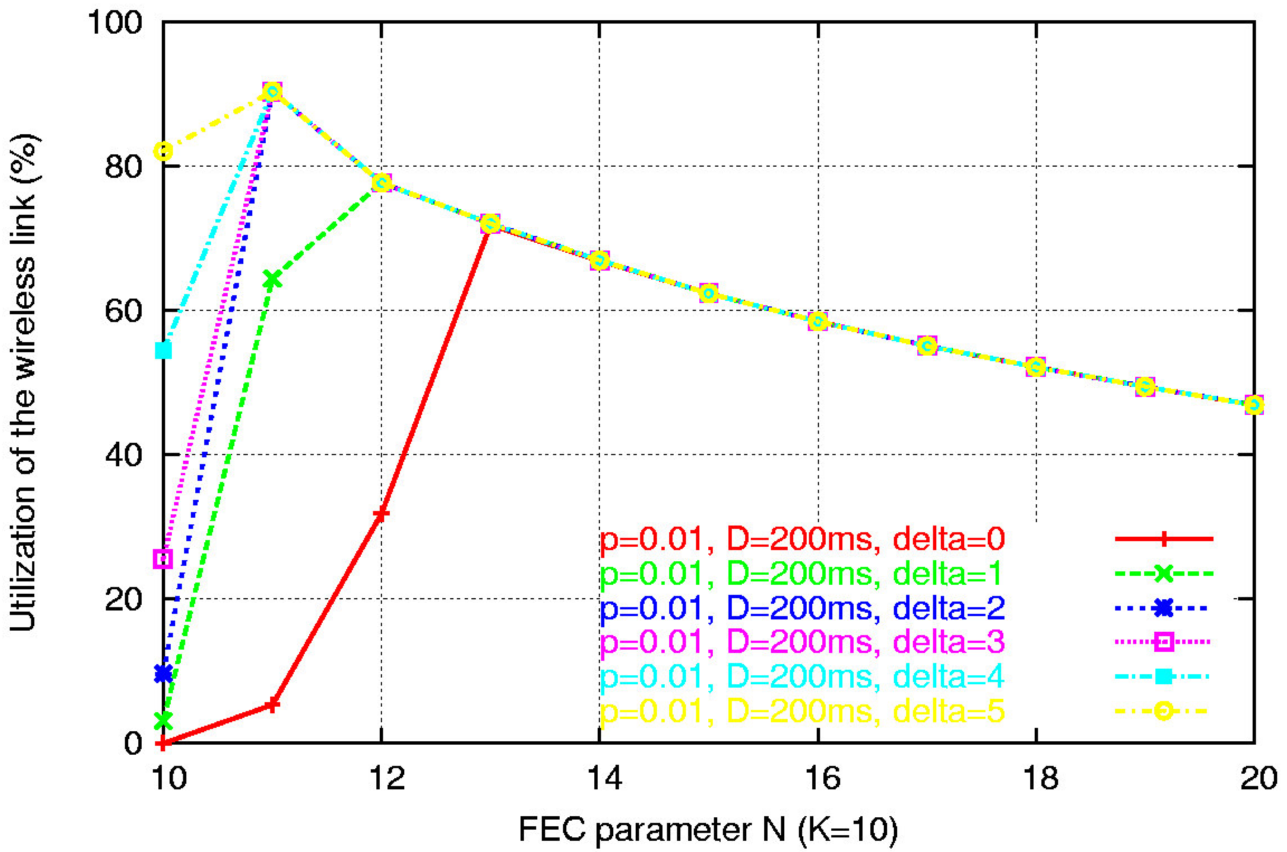
ARQ is even more interesting in less challenging scenarios



And if we take less connections ?



- The same result holds for one connection (advantage of ARQ-SR over FEC).
- Intuitively, more effort is needed to clean the wireless link.

Discussions

- ❑ Counter-intuitive result: ARQ-SR almost better than FEC !
  - The decrease in the packet loss rate with ARQ-SR is much more important than the increase in the end-to-end delay.
  - TCP adapts its Timeout value to the delay caused by ARQ.
- ❑ Same results obtained with an analytical model:

  Chadi BARAKAT, Alaeddine AL FAWWAL, "Analysis Of Link-Level Hybrid FEC/ARQ-SR For Wireless Links and Long-Lived TCP traffic", INRIA Research Report No 4752, February 2003.
- ❑ If there is a lesson:
  - Choose first the maximum possible persistency level for ARQ-SR.
  - Then add FEC to correct the remaining errors.
  - FEC has to be adapted, ARQ-SR is adaptive by nature !

Future research

- What happens when we use a more realistic model for the traffic ?
  - ARQ may be harmful for short TCP connections since they do not have enough time to adapt their timeouts.
  - And what about multimedia applications ?
  - What about a QoS-aware tuning of FEC/ARQ-SR (use of DiffServ classes ?)
- What happens when losses are bursty ? The channel is dynamic ? And how to adapt ?