An Information-Theoretic Approach to Accelerated Simulation of Hybrid-ARQ Systems

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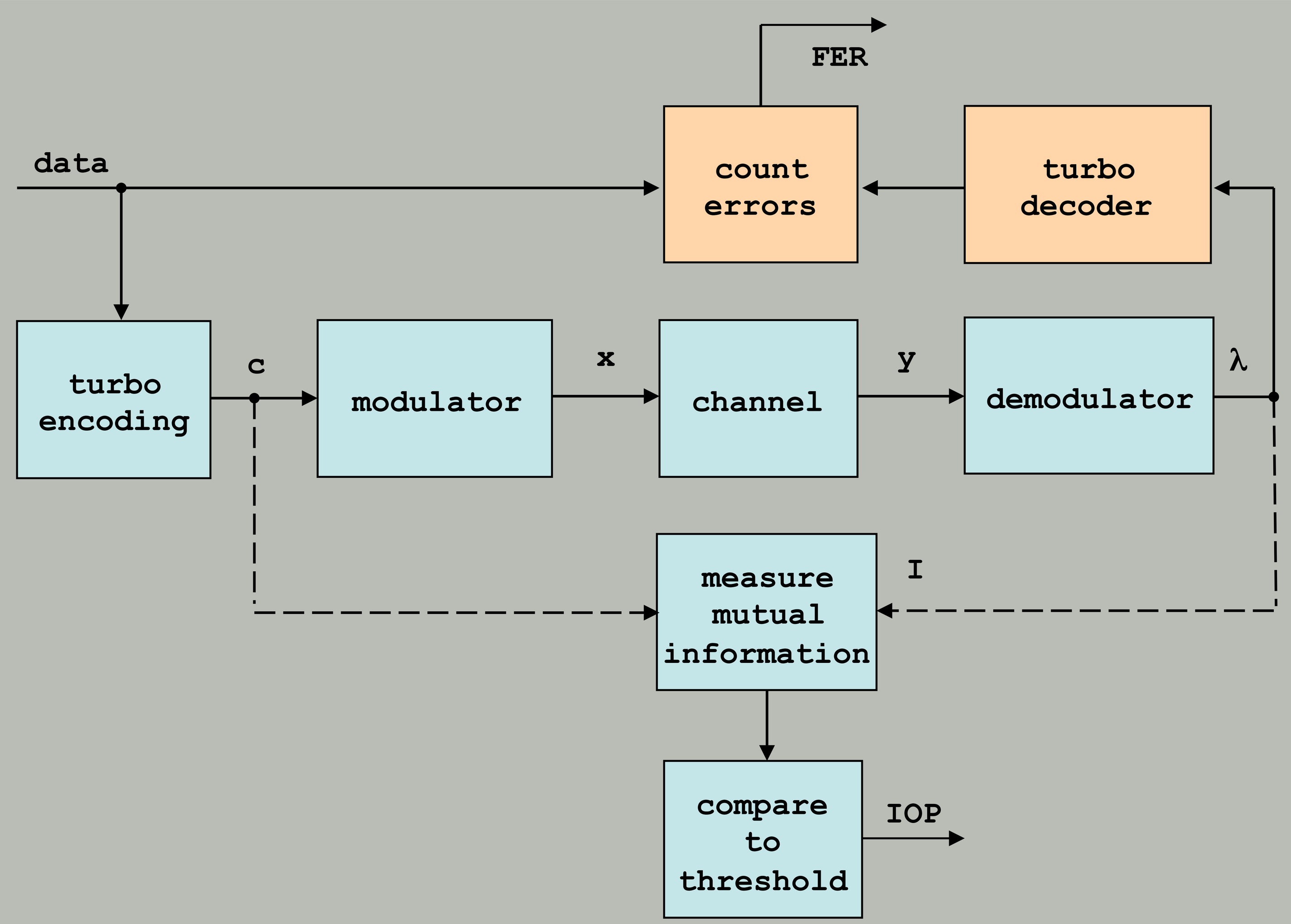
Introduction

- Simulation is a critical phase in the development cycle of modern communication systems.
  - Systems such as UMTS/HSDPA, LTE, LTE-A, and WiMAX are very complex and have many system settings to consider.
  - Wireless channels have many channel parameters that must be considered.
  - A fine-grain simulation of all settings and parameters is unfeasible.
  - Such systems use a channel-capacity code (turbo or LDPC), and it is channel decoding that often dominates simulation runtimes.
- In this paper:
  - The concept of information-outage probability is used to predict the performance of modern communication systems.
  - As a case study, we apply the methodology to analyze HSDPA.

The IOP Concept



- A fine-grain simulation requires a turbo decoder.
- The Information-Outage Probability (IOP) concept is to bypass the decoder.
- View the system as a binary channel (BICM) and compute the mutual information between the input code bit c_j and output LLR λ_j,

$$I_j = 1 + \log_2 p(c_j|\lambda_j) = 1 + \frac{\max*(0, \lambda_j(-1)^{c_j})}{\ln(2)}.$$

- The mutual information of a length-n code block is its average,

$$\bar{I} = \frac{1}{n}\sum_{j=1}^{n} I_j.$$

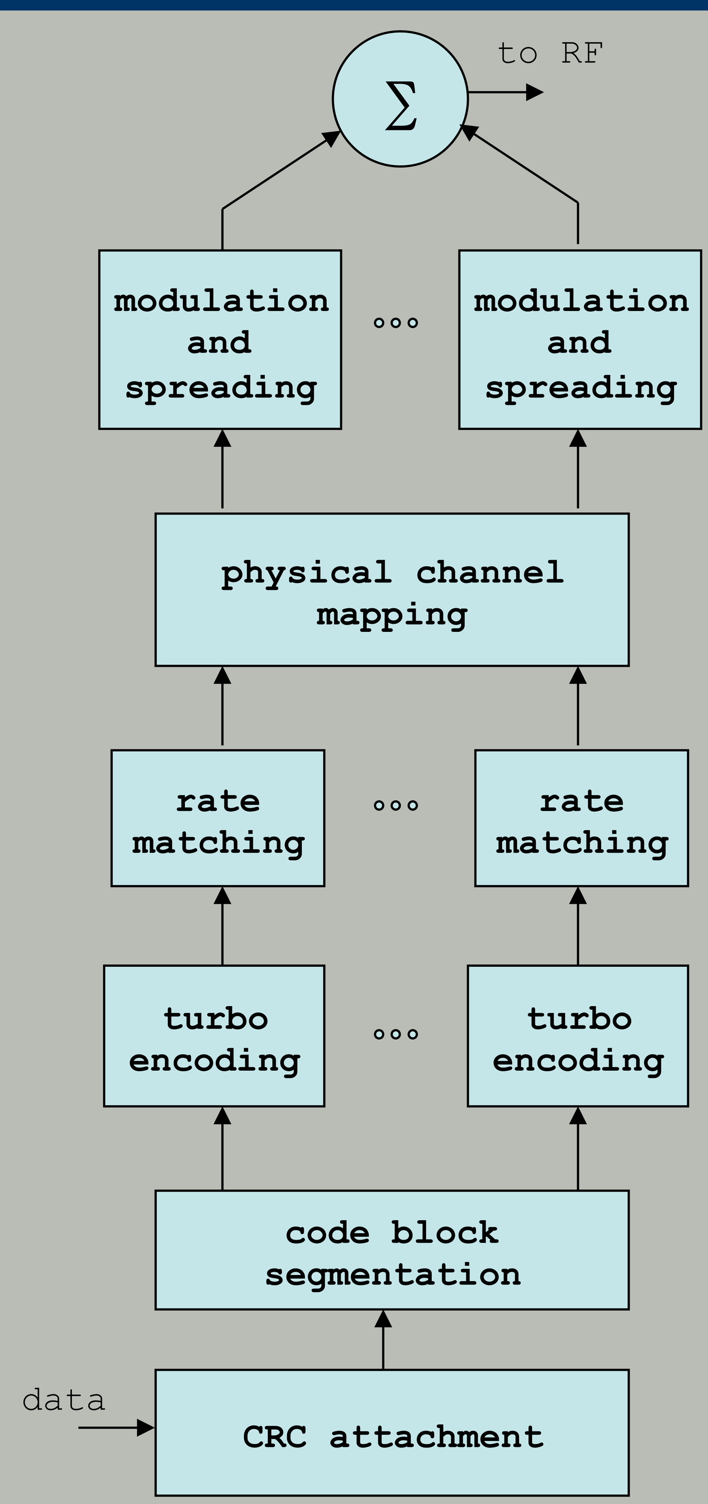
- An outage occurs when the MI of a code block is below the rate,

$$P_0 = \Pr[\bar{I} \le R].$$

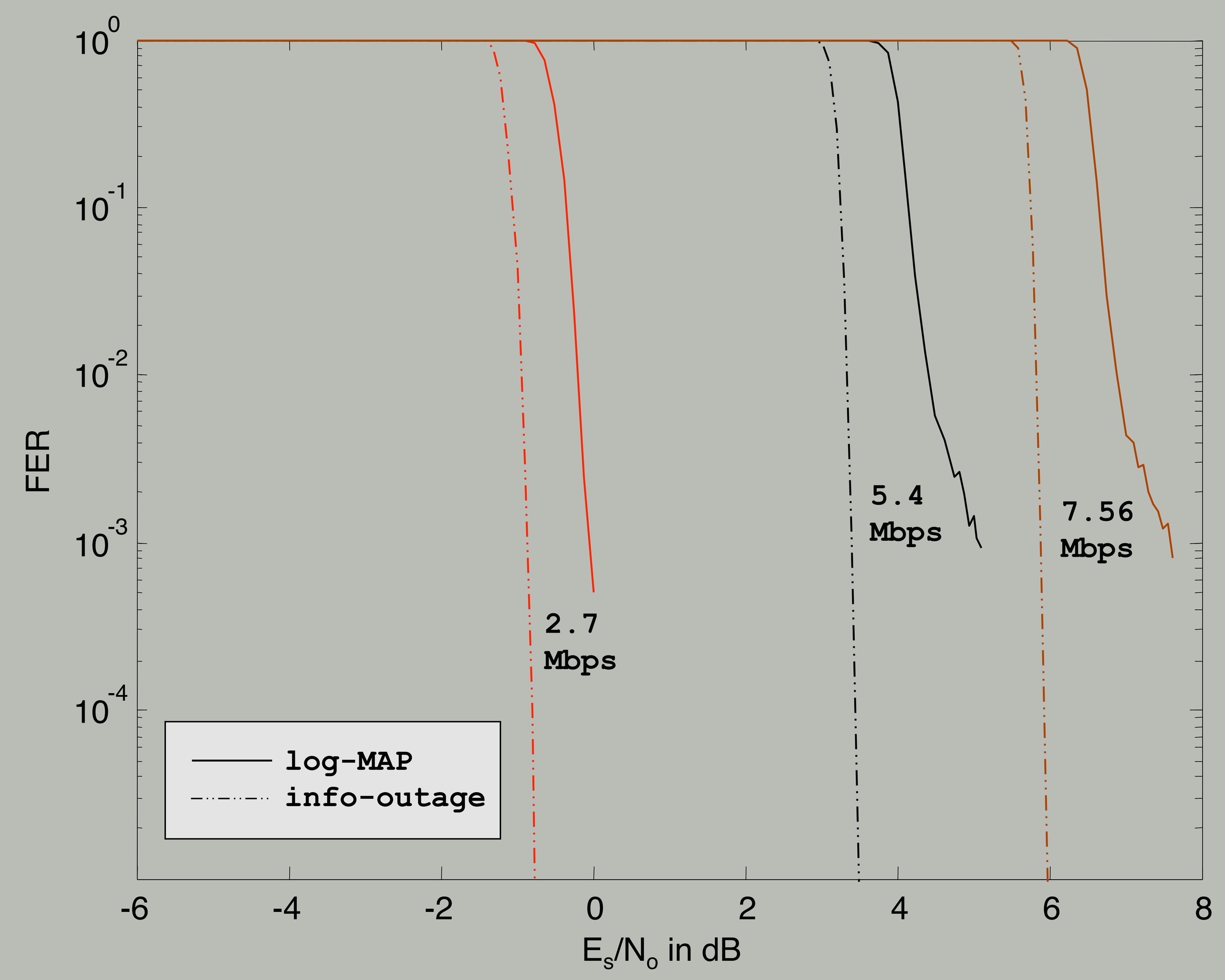
- IOP is a good prediction of FER with capacity-approaching coding.

Case Study: HSDPA

- Time is divided into 2 msec TTI's.
- During each TTI, a message is encoded by a turbo code.
- The codeword is mapped onto up to 15 physical channels.
  - Each operates at $R_s = 240$ kbaud.
  - Spread by length-16 Walsh code.
  - Chip rate of $R_c = 16 \times 240 \times 10^3 = 3.84$ Mchips/sec.
- Modulated using QPSK or 16-QAM.
  - Two or Four bits per baud.
  - Operation up to 14.4 Mbps is possible.
- Hybrid-ARQ for retransmissions.
  - Chase Combining (CC) or Incremental Redundancy (IR).
  - Constellation rearrangement.
  - Parallel HARQ processes.



Results: FER in AWGN

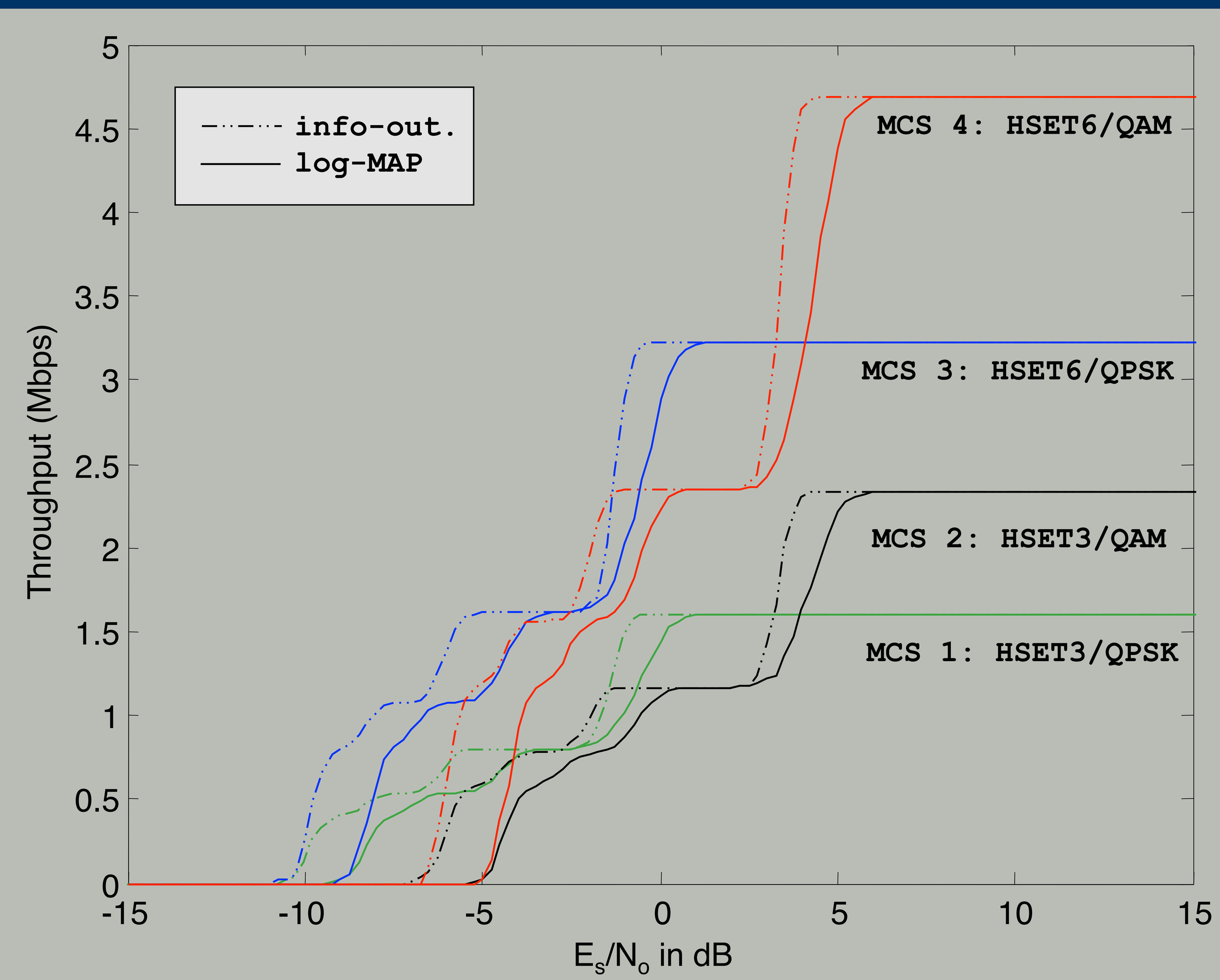


- IOP compared against FER with 14 iterations of log-MAP turbo decoding.
- Channel is AWGN.
- Three links considered:

Date Rate	Modulation	Physical Channels	Code Rate
2.7 Mbps	QPSK	14	0.4018
5.4 Mbps	16-QAM	15	0.3750
7.56 Mbps	16-QAM	15	0.5250

- IOP is about 1 dB away from the FER.

Results: Throughput in Fading



- Comparison of throughput.
  - Throughput assumes up to 4 HARQ transmissions (using IR).
  - Retransmission probability from IOP or FER with 14 decoder iterations.
- Channel is time and frequency selective.
  - Rayleigh fading.
  - Signal decorrelation time: $\tau_0 = 100/R_s$.
  - Frequency-selective bandwidth $f_0 = 0.1 \times R_c$.
  - 3 receive antennas, each with 4-branch rake receiver.
- Four links considered:

MCS	Date Rate	Modulation	Physical Channels	Code Rate
1	1.601 Mbps	QPSK	5	0.6671
2	2.332 Mbps	16-QAM	4	0.6073
3	3.219 Mbps	QPSK	10	0.6706
4	4.689 Mbps	16-QAM	8	0.6105

Conclusions

- Bypassing the turbo decoder allows IOP-based simulations to be approximately 30 times faster than those based on FER.
- IOP predicts performance with approximately 1 dB accuracy.
- The IOP accounts for code length, modulation type, channel parameters, and receiver implementation.
- Idea can be used for other codes (LDPC) and systems (WiMAX, LTE, etc.).

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