The throughput analysis of different IR-HARQ schemes based on fountain codes

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Overview

1. IR-HARQ with sparse graph codes: punctured vs. rateless approach
2. fountain codes: raptor and systematic raptor
3. two punctured + rateless IR-HARQ
4. optimization for the first one
5. employing systematic raptor design for the second one
6. achieved throughput in simulation results
Main references


Punctured IR-HARQ

transmitter

ACK/NAK

receiver

at the transmitter

transmission # 1

transmission # 2

transmission # 3

transmission # 4

at the receiver
IR-HARQ with punctured LDPC codes

\[ L(y) = \ln \frac{Pr(x=0|y)}{Pr(x=1|y)} \]
fountain codes

transmitter produces a potentially infinite number of fountain encoding symbols (random, equally important descriptions of the source) and sprays them across the channel
fountain codes

receiver collects encoding symbols and attempts decoding when “enough” symbols are received

$k$: size of information sequence

$k'$: “enough”

**erasure channel**: $k'$ should be only slightly larger than $k$

**noisy channel**: $k'$ should be only slightly larger than $k / \text{Capacity}$
LDPC vs. raptor IR-HARQ throughput
LDPC vs. raptor IR-HARQ throughput

[Graph showing throughput vs. SNR for different coding schemes including BPSK Capacity, Reg LDPC, Irreg LDPC, and Raptor with Reg LDPC at various rates.]
Combined schemes

(Scheme A)

- Simple concatenation of two approaches, precoded sequence is punctured for a near optimal rate reliable encoding at a very high SNR.
Combined schemes

(Scheme A)

- Simple concatenation of two approaches, precoded sequence is punctured for a near optimal rate reliable encoding at a very high SNR.
- If protection by precode is insufficient additional LT encoding bits are generated until decoding succeeds.
A priori information about bit nodes (unavailable for classical LT decoding).

Mother code parity symbols; LLRs based on the channel output.

Systematic symbols - actual information sequence; LLRs based on the channel output.

Raptor encoding symbols; LLRs based on the channel output.

Mother code parity checks; LLRs are set to +Inf.
Embedding side information into sum-product rules

\[ m_{v,f}^{(i)} = \begin{cases} 
L(y_v), & i = 0, \\
L(y_v) + \sum_{g \neq f} \mu_{g,v}^{(i-1)}, & i \geq 1.
\end{cases} \]

\[ \tanh\left(\frac{\mu_{f,v}^{(i)}}{2}\right) = \tanh\left(\frac{L(z_f)}{2}\right) \prod_{u \neq v} \tanh\left(\frac{m_{u,f}^{(i)}}{2}\right), \ i \geq 0, \]

Soft information is present at the both sides of the decoding graph.
A special case of: fountain coding with decoder side information (DSI)

An instance of distributed joint source-channel coding (DJSCC)
• By fixing the virtual channel SNR, one can tune the LP for optimization of fountain output symbol degree distribution to take DSI into account.

• The results are non-Soliton-like distributions.

• One of them:

\[ \Omega(x) = 0.0954x^5 + 0.1192x^6 + 0.1121x^7 + 0.12938x^8 + 0.1054x^9 + 0.0807x^{10} + 0.1109x^{11} + 0.2470x^{100}. \]
Simulation results: $k = 3140$
Combined scheme A vs. plain raptor IR-HARQ

Combined scheme A:
- Lower computational complexity - More than three times less output nodes in the successful decoding graph at the SNR of 4.5dB ($k=3140$) - 3 times less edges to process
- Higher throughput at high SNR

Raptor:
- Higher and more stable throughput at SNR lower than the LDPC threshold
another way to resolve fountain decoding with DSI: systematic raptor

$G_R = G_{LT}G_C$ is overall Raptor encoding, $G_{LT}$ - truncated LT matrix matrix. Set $G_k$ equal first $k$ rows of $G_R$.

Idea: if $G_k$ is invertible let $\hat{x} = G_k^{-1}x$ be the new input to be processed by standard Raptor.

First $k$ symbols of the output stream $y$ will be the same as the input!

diagram

text:
this kind of system is being adopted for application-layer FEC for 3GPP MBMS, IP-datacast for DVB-h…
(Scheme B)
Systematic symbols - actual information sequence:
- Mother code parity symbols; LLRs approximated after a fixed number of iterations
- LLRs based on the channel output
- Mother code parity checks; LLRs are set to ±inf

Raptor encoding symbols; LLRs based on the channel output
- Precoding parity checks; LLRs are set to +inf
Conclusion

• Study of two combined punctured LDPC + Raptor schemes for IR-HARQ through approaching the problem as fountain coding with DSI
• Optimization procedure for fountain output symbol degree distribution for the conceptually simpler, computationally cheaper version
• Application of systematic raptor to fountain coding with DSI and IR-HARQ scenarios