Not so random RLC AL-FEC codes

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Note well

- **we, authors, didn't try to patent** any of the material included in this presentation

- if you believe some aspects may infringe IPR you are aware of, then fill in an IPR disclosure and please, let us know

  http://irtf.org/ipr

Motivations and goals

Motivations

- RLC are naturally random
  - encoding vectors on a given Finite Field (FF) are random
  - it's easy, efficient, and enables coding *inside the net*

- but there are incentives to have "structured" codes
  - sparse codes are **faster** to encode/decode
    - an order of magnitude difference, because:
      - fewer XOR and/or FF symbol operations
      - fast ITerative (IT) decoding works better
  - certain **structures** are extremely **efficient**
      - e.g., LDPC-Staircase [RFC5170] [WiMob13]
      - e.g., irregular LDPC codes perform the best with IT decoding

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[WiMob13] V. Roca, M. Cunche, C. Thienot, J. Detchart, J. Lacan, ***"RS + LDPC-Staircase Codes for the Erasure Channel: Standards, Usage and Performance"***, IEEE 9th Int. Conf. on Wireless and Mobile Computing, Networking and Communications (WiMob), October 2013. http://hal.inria.fr/hal-00850118/en/

Goals of this work

- design codes that:
  - can be used as **sliding/elastic encoding window** (A.K.A. convolutional) and **block** codes
    - **there are use-cases for each approach**
  - can be used with encoding window/block sizes in **2-10,000s symbols** range
    - **very large sizes are beneficial to bulk file transfers while small values are useful for real-time contents**
  - can be used as **small-rate** codes
    - **can generate a large number of repair symbols**
      - even if it's rarely useful (e.g. it was not a selection criteria for 3GPP-MBMS [WiMob13]), it also simplifies performance evaluations ☺

Goals of this work… (cont')

- have excellent erasure recovery **performance**
  - **often a complexity versus performance tradeoff**
  - **it's good to be able to adjust it on a per use-case basis**

- enable **fast** encoding and decoding
  - **sender and/or receiver can be an embedded device**

- enable **compact and robust signaling**
  - **transmitting the full encoding vector does not scale**
  - **prefer the use of a function that, as a function of a key lists the symbols that are considered**
    - can be a PRNG + seed
    - can be a table + index
    - the function is known to both ends and the (e.g., 32-bit) key is carried in the packet header

Goals of this work… (cont')

- focus **only** on use-cases that require **end-to-end encoding**
  - "end" means either "host" or "middlebox", it's the same
    - **there's a single point for AL-FEC encoding/decoding**
  - because it simplifies signaling and code design
    - **intermediate node re-encoding requires having the symbols encoding vectors which does not scale**
  - sure, it's a subset of NWCRG candidate use-cases
    - **e.g., it's well suited to Tetrys** **http://www.ietf.org/proceedings/86/slides/slides-86-nwcrg-1.pdf**
    - **but also to FLUTE/ALC, FCAST/ALC, FCAST/NORM, FECFRAME protocols**

Our proposal

Experimental results of this presentation…

- …use our http://openfec.org open-source project
  - uses a mixture of CeCILL(-C) (GPL and LGPL like), "BSD like" licenses

OpenFEC.org
because open, free AL-FEC codes and codecs matter

- for the moment we've integrated Kodo RLC lib…
  - **…but we'll get rid of it ASAP**
    - because STEINWURF research license is not compatible with our goal of free, reusable software in any context, commercial or not

- all measurements are made in **block mode**
  - **because it's the way our http://openfec.org tools work…**
    - … but we'll update it

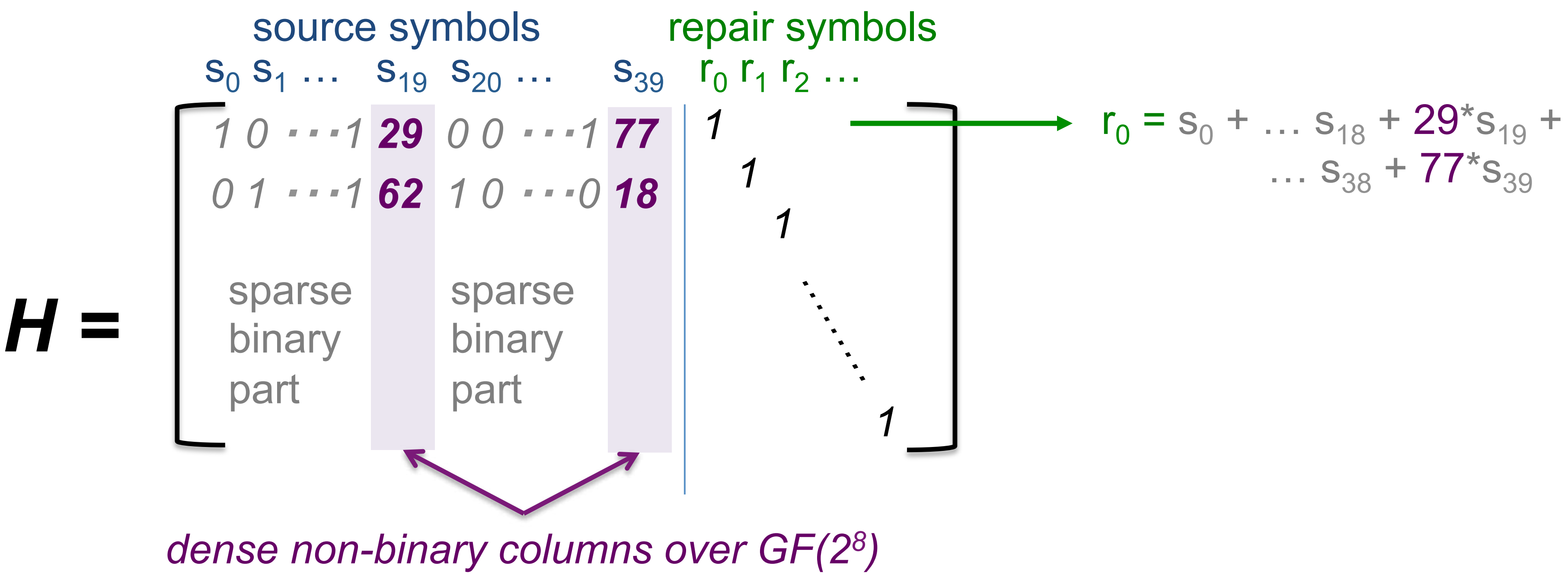
Idea 1: mix binary and non-binary

- mix binary and non binary
  - most equations are **sparse** and coefficients **binary**
  - a limited number of columns are **heavy**
    - **dense binary columns** ← not considered in the remaining
    - **dense non-binary columns (e.g., with coeff. on GF(2^8))**
- there are good reasons for that:
  - sparseness is a key for high encoding/decoding speeds
  - density/non binary are good for recovery performances
  - gathering dense coefficients in columns (i.e. to certain symbols) is a key for high speed decoding [WiMob13]

[WiMob13] V. Roca, M. Cunche, C. Thienot, J. Detchart, J. Lacan, ***"RS + LDPC-Staircase Codes for the Erasure Channel: Standards, Usage and Performance"***, IEEE 9th Int. Conf. on Wireless and Mobile Computing, Networking and Communications (WiMob), October 2013. http://hal.inria.fr/hal-00850118/en/

Idea 1: mix bin and non-bin… (cont')

- block code example
  - (sparse + non-bin. columns) only



Idea 1: mix bin and non-bin… (cont')

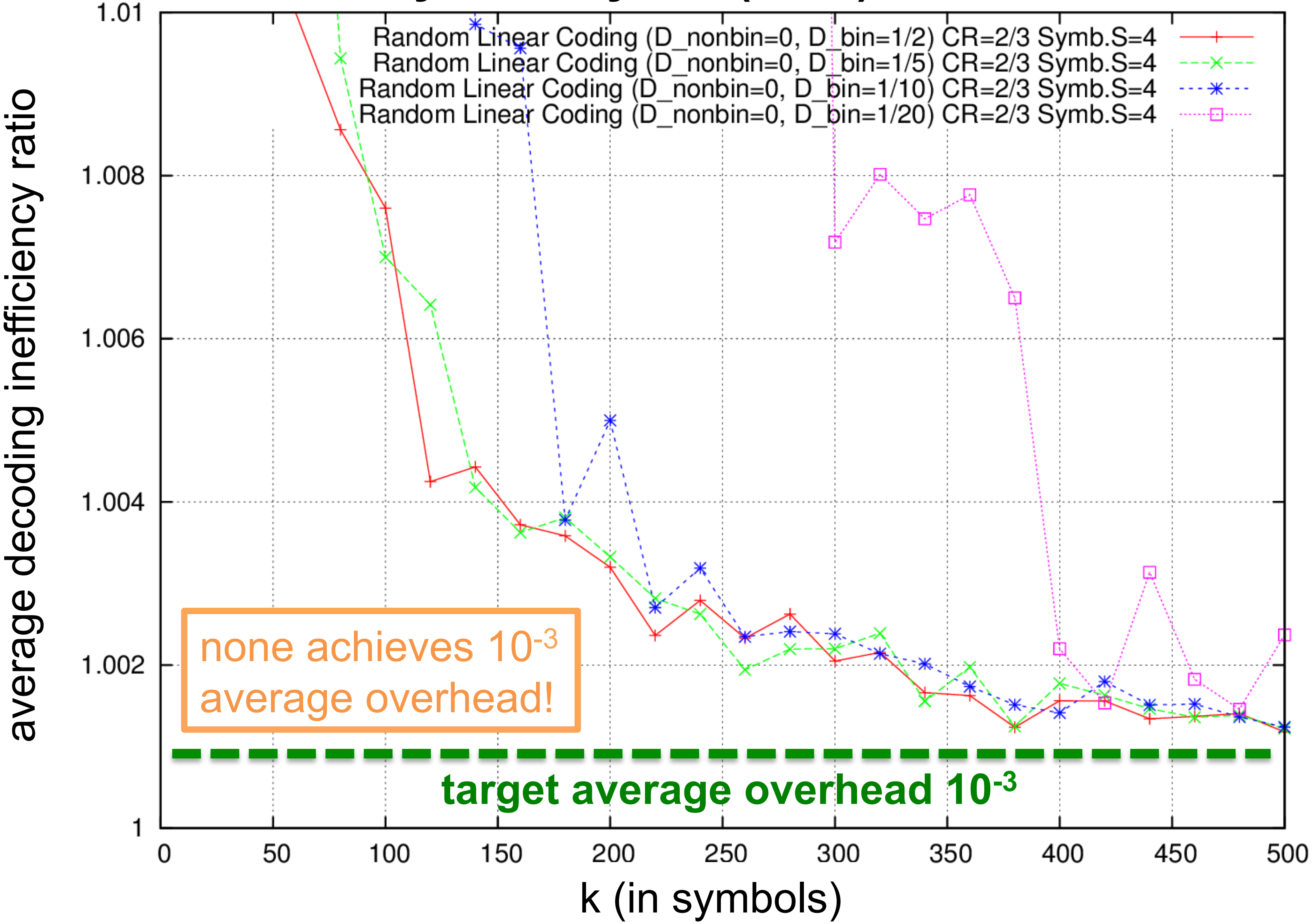
- convolutional code example
  - (sparse + non-bin. columns) only

```
/* r points to repair symbol to build */
memset(r, 0, pkt_sz);
for (each source symbol s in current encoding window)
      if (s identifier %(1/D_nonbin) == 0)
            /* non binary column */
            choose a non-bin coefficient, c;
            r ^= c * s;
      else
            /* binary part */
            do r ^= s with probability D_bin
```

  - NB:
    - it's the same except that the encoding windows moves over the source symbol flow (convolutional mode) instead of being fixed (block mode)

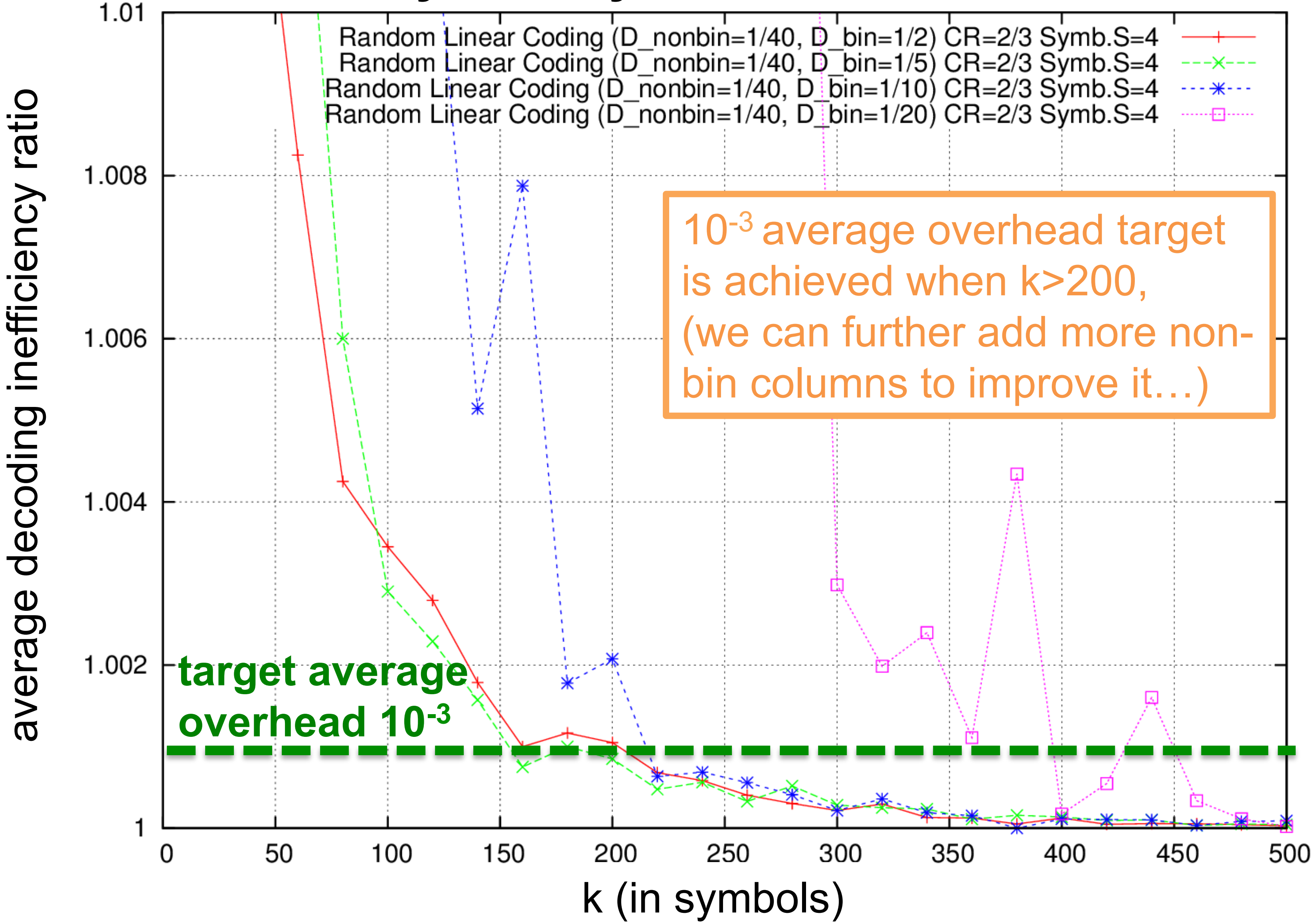
On the usefulness of non-bin columns

Test 1: **no dense non-binary column**
binary density 1/2 (RLC), 1/5, 1/10, 1/20



On the usefulness of non-bin cols… (cont')

Test 2: **with dense non-binary column (1 every 40 cols)**
binary density 1/2, 1/5, 1/10, 1/20



Idea 2: add a structure

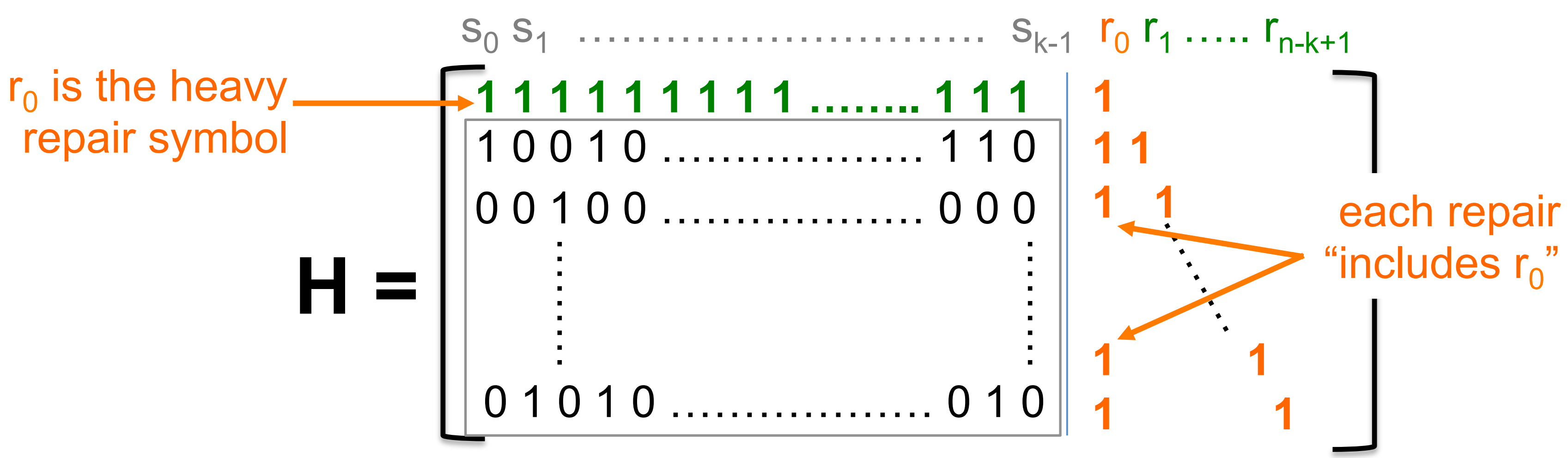
- technique 2: add a structure to the right part of H
  - we know that a “staircase” (A.K.A. double diagonal) is highly beneficial…

$$
\begin{array}{c}
\qquad s_0\ s_1\ \cdots\cdots\ s_{k-1}\ \ r_0\ r_1\ \ldots\ r_{n-k+1} \\
H = \left[\begin{array}{l|l}
0\,1\,0\,0\,1 \ldots\ldots 0\,0\,1 & 1 \\
1\,0\,0\,1\,0 \ldots\ldots 1\,1\,0 & 1\,1 \\
0\,0\,1\,0\,0 \ldots\ldots 0\,0\,0 & \quad 1\,1 \\
\quad\ \vdots \qquad\qquad\quad \vdots & \qquad \ddots \\
 & \qquad\quad 1\,1 \\
0\,1\,0\,1\,0 \ldots\ldots 0\,1\,0 & \qquad\qquad 1\,1
\end{array}\right]
\end{array}
$$

  - … but when used in convolutional mode, **signaling** turns out to be **prohibitively complex**
    - the problem lies in the reliable description of what symbols are part of all the previous repair packets, in case they are lost, when the encoding window moves in a non predictive way (e.g., Tetrys/elastic encoding window)

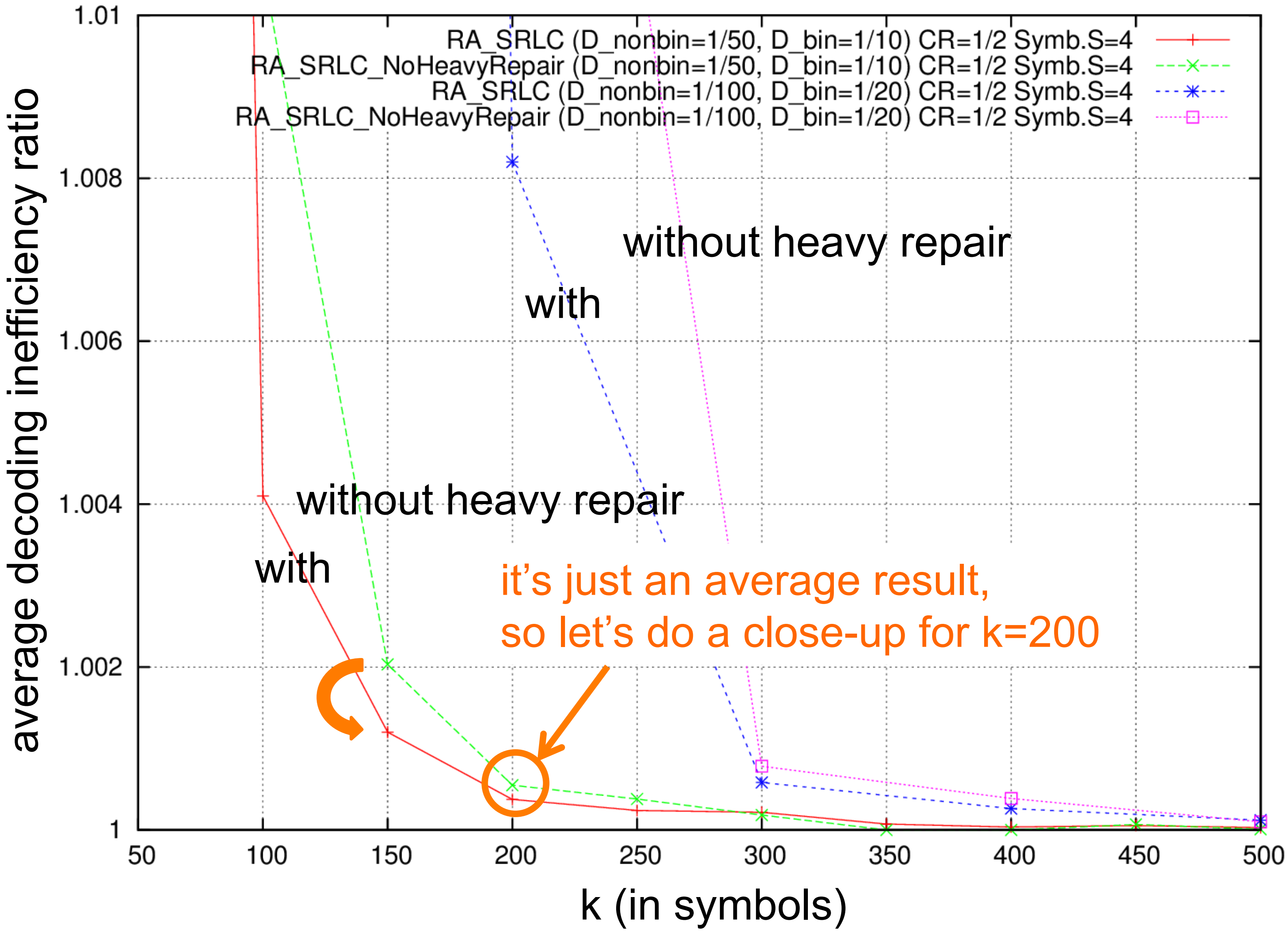
Idea 2: add a structure… (cont')

- so we add a **single heavy row** and make **all repair symbols depend on it**
  - **it's now quite simple, even when used in convolutional mode**
    - several sums will be transmitted (e.g., periodically), and it is sufficient to identify the last symbol of the sum in the signaling header
  - **it's efficient (see later), at the price of extra XOR operations**



- **NB: other ways to define heavy rows are feasible (e.g., with random coefficients over GF(2^8)…**

On the usefulness of heavy repair symbols



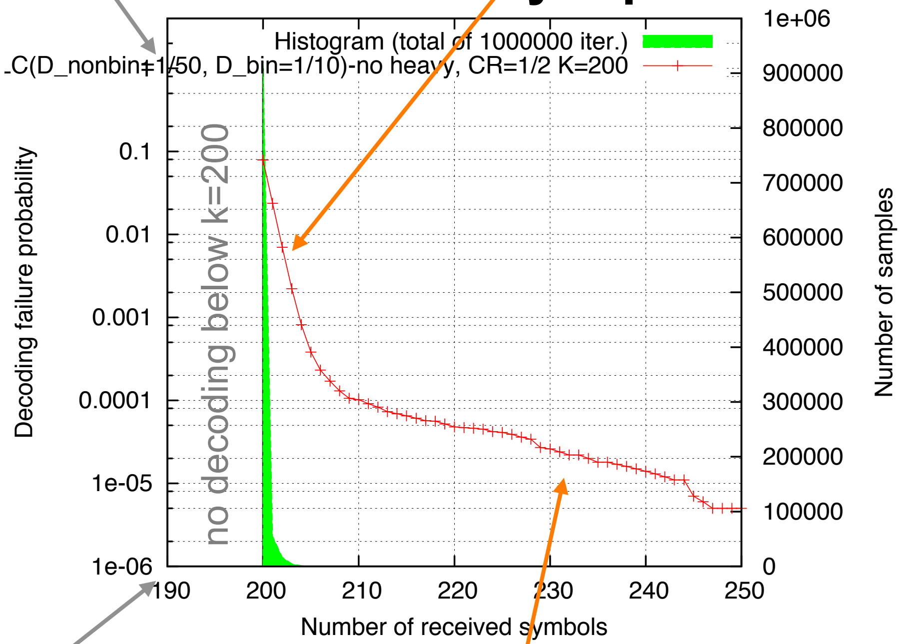
On the usefulness of heavy repair… (cont')

- decoding failure probability = f(# symbols received)
  - ❍ **enables in-depth analysis, catching rare events**

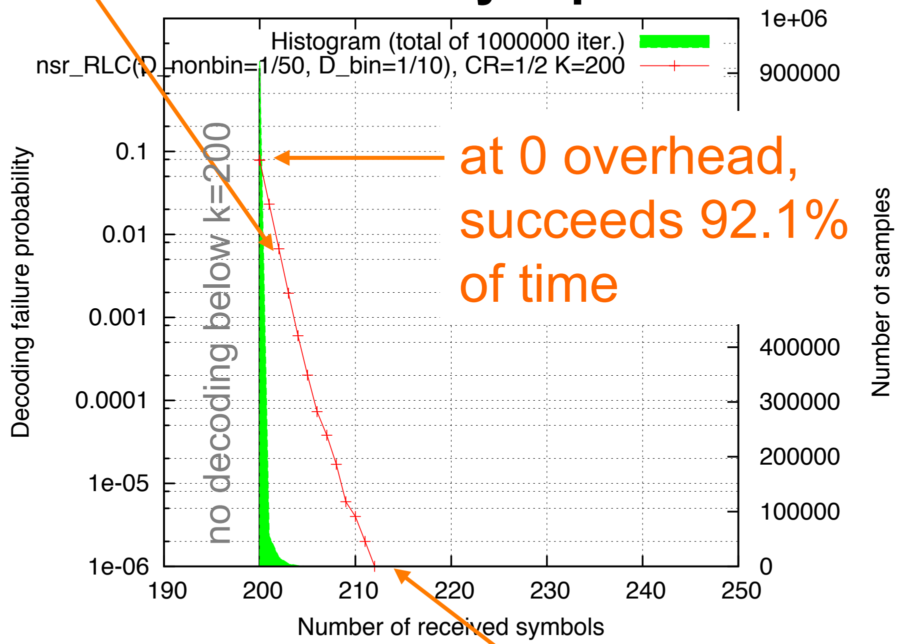
1 ⇒ no decoding

similar behaviors for very low overheads

without heavy repair



with heavy repair



at 0 overhead, succeeds 92.1% of time

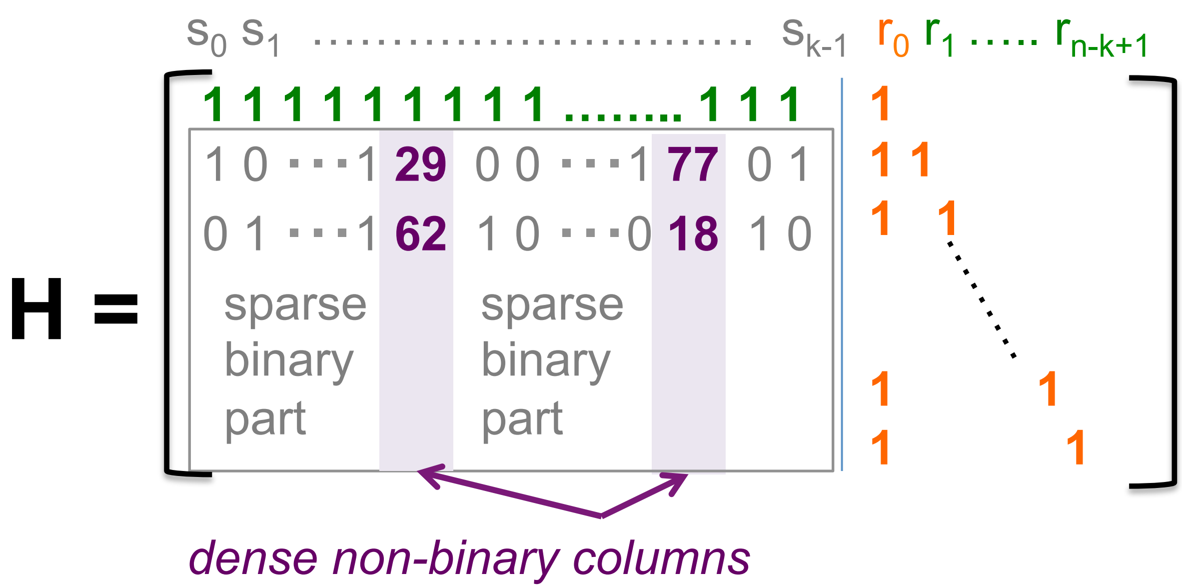
small failure prob.

but significant number of tests fail for higher overheads ☹

with a heavy repair symbol, **there's no such behavior ☺**

Let's put ideas 1 and 2 together

- 3 key parameters
  - **k: source block or current encoding window size**
  - **D_nonbin: controls number of heavy non-binary columns**
    - D_nonbin = nb_non-binary_coeffs / k
  - **D_bin: controls the density of the sparse sub-matrices**
    - D_bin = nb_1_coeffs / total_nb_coeffs_in_binary_submatrix
  - **{D_nonbin, D_bin} depend on k and target max. overhead**



Finding the right (D_nonbin, D_bin) values

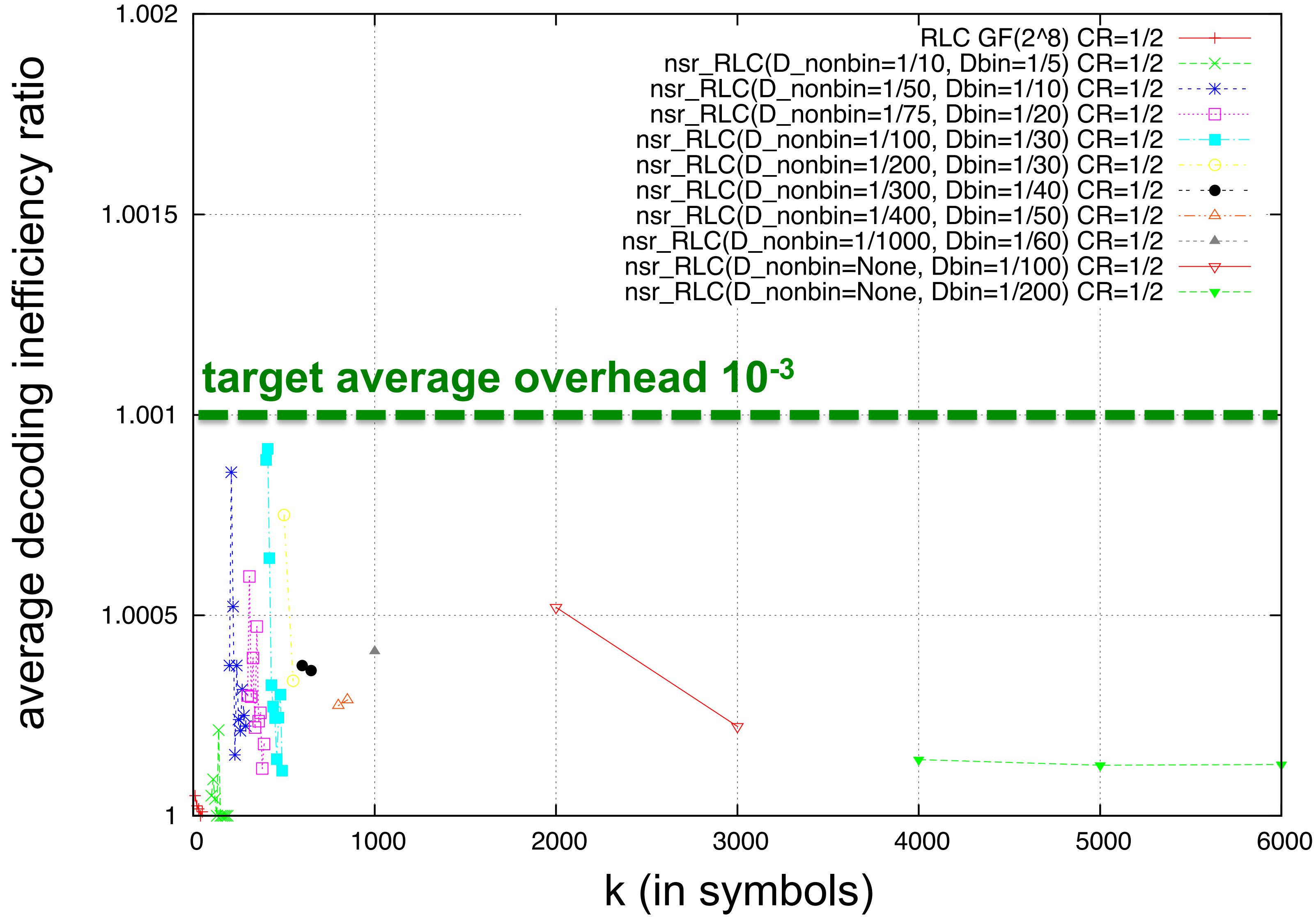
- set a target average overhead (e.g., 10^{-3})
- then:

```
for (k in [2, 10 000])
    carry out experiments with fixed D_bin=1/2,
    increasing D_nonbin until we achieve an average
    overhead below α*10^-3, where α < 1 is a
    "security margin";
    for this D_nonbin, carry out experiments by
    reducing D_bin as much as possible while
    remaining below target overhead 10^-3
```

- store all results in a table

- basically:
  - **only non-bin columns for very small k**
  - **only bin columns for very high k**
  - **a mixture of both in between…**

Preliminary results

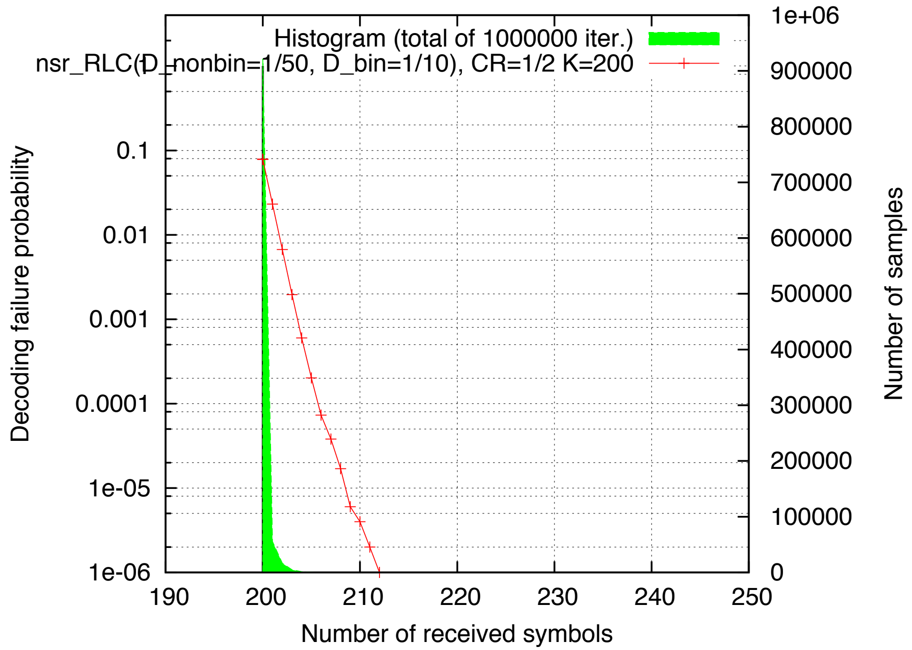


NB: results are presented here as the concatenation of small curves…
In practice it will be a single curve for a single code

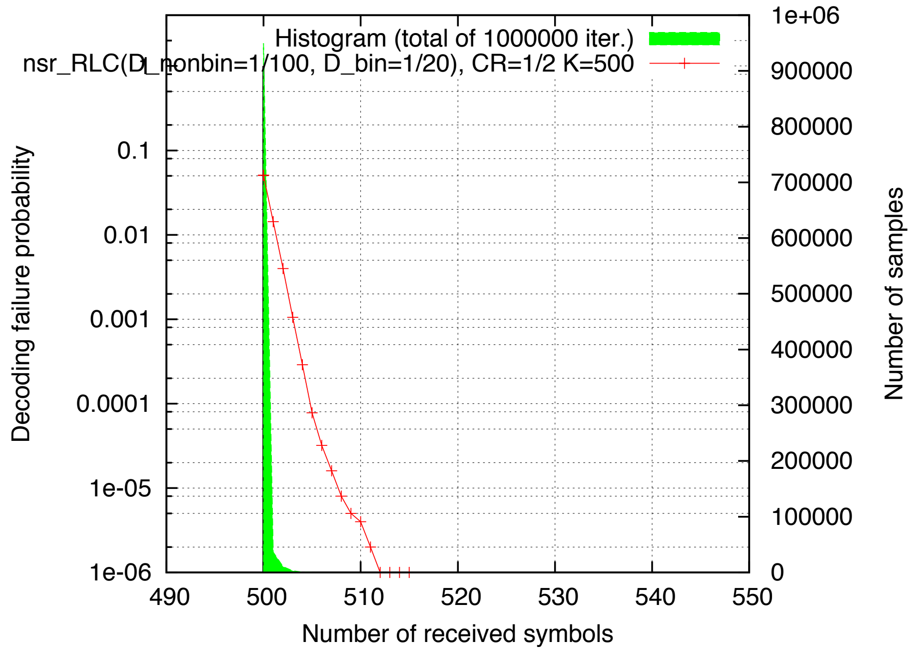
Two close-ups

- decoding failure probability curves for k=200, 500
  - **no visible error floor at 10^{-6} failure probability, which is excellent ☺**

k=200



k=500



Conclusions and Future Works

Conclusions

- our proposal tries to take the best of RLC
  - **use the right technique (bin vs. non-bin) at the right time, in the right way**
    - find balance between erasure recovery perf. and complexity
- our proposal tries to fill in the gap between sliding/elastic encoding window and block codes
  - **side question: what about ALC and FECFRAME versions capable of using convolutional codes**
    - instead of being stuck to block AL-FEC?
- our proposal has a more limited scope than RLC
  - **but it is suited to concrete use-cases**
    - in IRTF/NWCRG (e.g., Tetrys)
    - in IETF/RMT and FECFRAME

Conclusions… (cont')

- many key questions remain
  - what are the **performances** when used in sliding or elastic encoding window?
    - e.g. with Tetrys
  - how **fast** is it?
    - e.g., compared to our optimized LDPC-Staircase/RS codecs
  - how does it **scale** with k?
    - e.g., compared to our optimized LDPC-Staircase codec
  - define **signaling** aspects
    - FEC Payload ID (in each packet sent)
    - FEC Object Transmission Information (per object/session)