Efficient Error Estimating Coding: Feasibility and Applications

Sigcomm ’10 (Best Paper)

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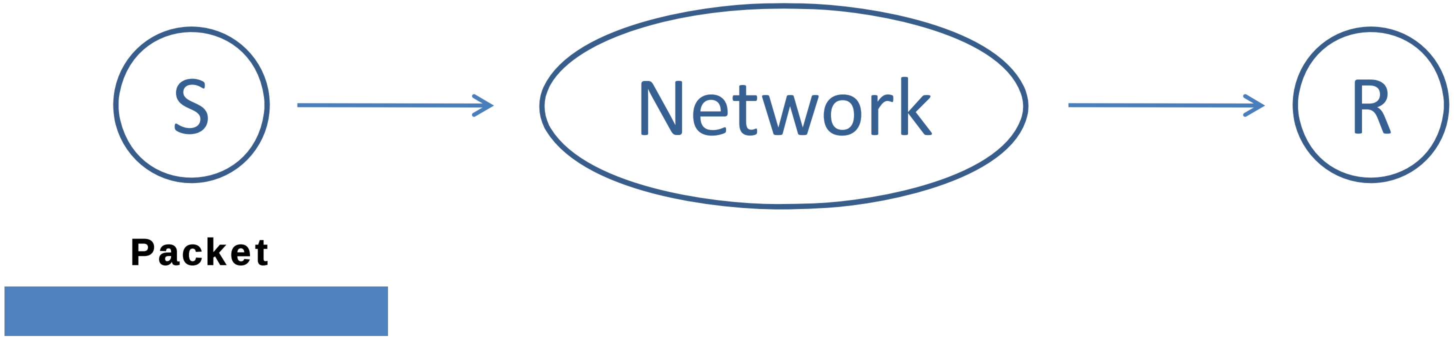
Outline

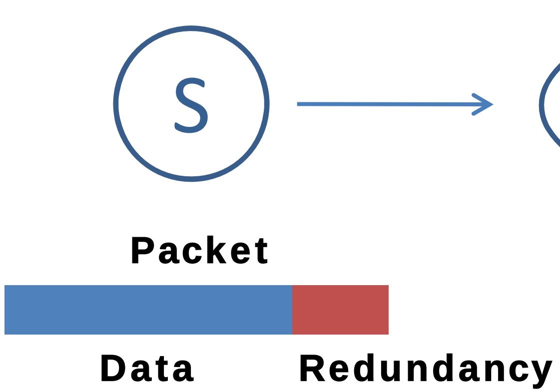
- Wireless Networking Background
- Motivation : Benefit of BER estimating
- EEC design
  - How to estimate BER with low computational overhead and redundancy ?
  - Complexity and Redundancy
- Conclusion

Trends in Wireless Networking



- Application/ Network use or relay **correct packet**
- Not correct : Request retransmission

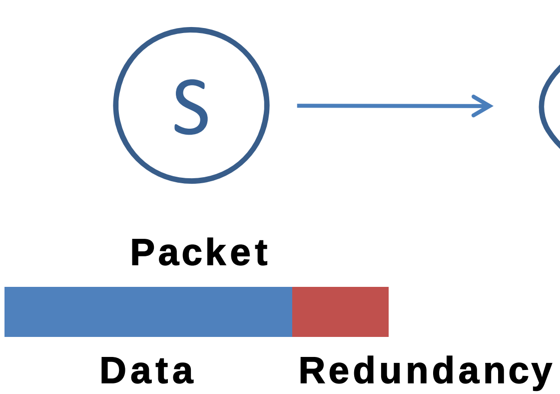
Trends in Wireless Networking



- Many designs to support **partially correct packet** with **Error Correction Coding**
  Ex) Incremental Redundancy ARQ
- Well-suited to delay-sensitive applications.

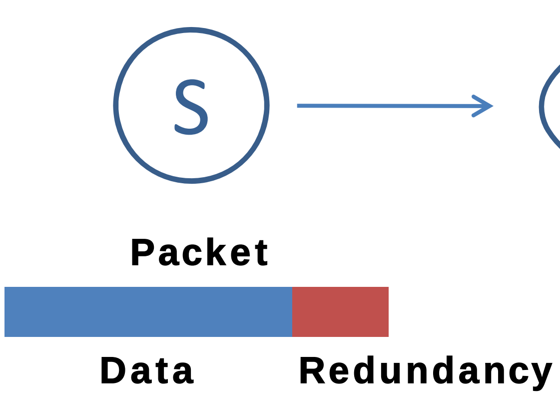
Benefits of BER at **Relaying Node**

- BER-aware packet retranmission
  - Add maximum BER that Error-Correction Code can tolerate
- BER-aware packet scheduling
  - Prioritize the fowarding of packets with lower BER
- BER-aware packet forwarding
  - Decode-and-Forward vs Amplify-and-Forward



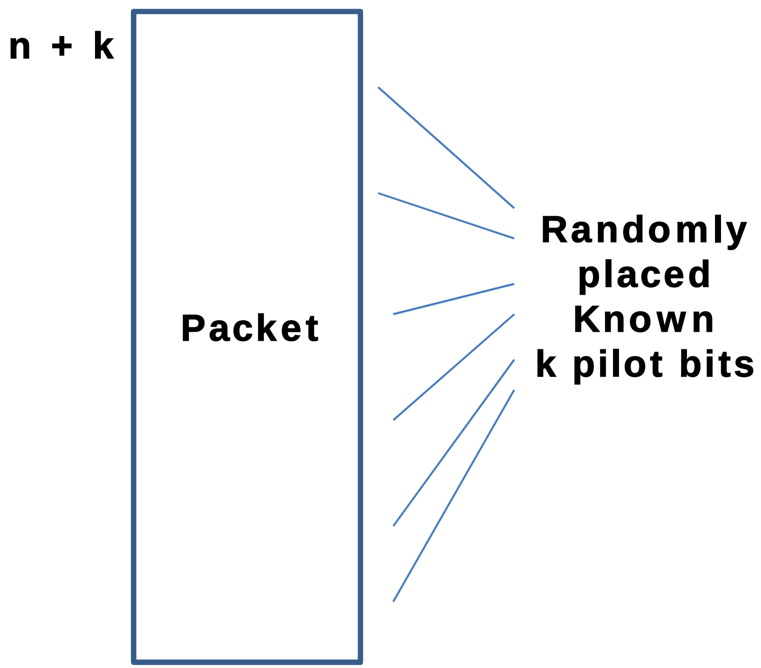
Benefits of BER at **Sender**

- Rate adaptation
  - Better adapt its rate by a feedback based on BER.
- BER-aware routing
  - Instead of optimizing for minimizing the expected number of transmission, we can optimize for maximizing the goodput of end-to-end route.



EEC Design

- How to make structure to estimate BER**?**
  1. **Naive sampling with known pilot**



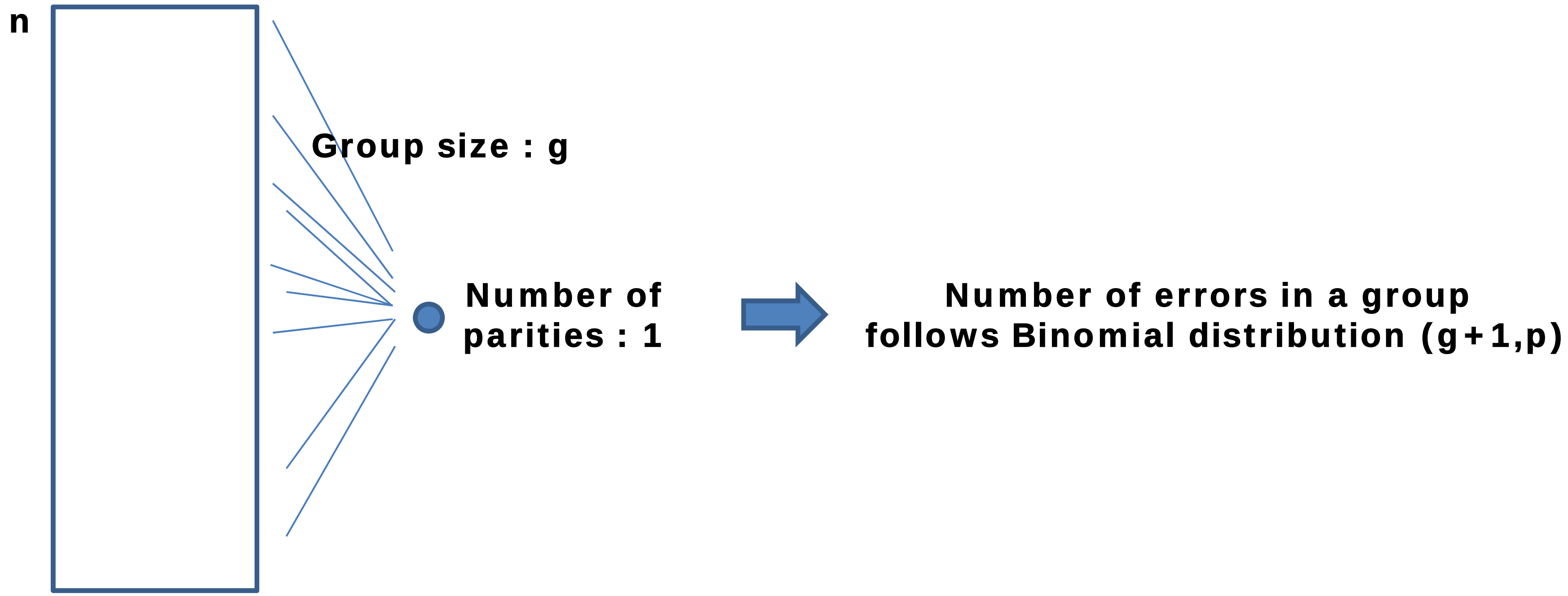
Redundancy
for similar estimation quality when BER is small

EEC : 2%

Naïve : 40%

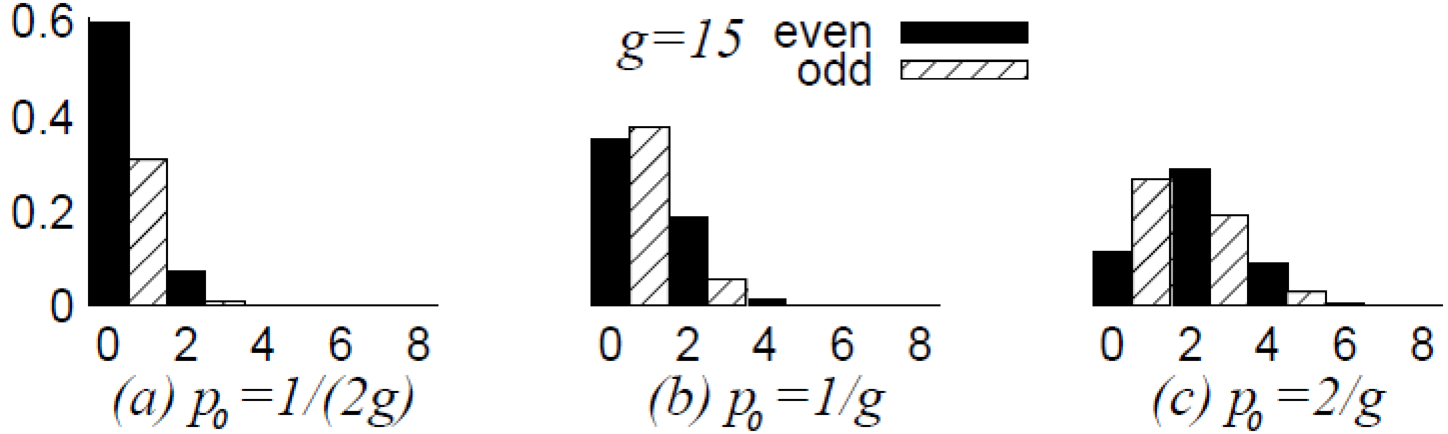
EEC Design

- How to make structure to estimate BER?
  2. **Sample a group of data bits with a single bit**
     - **Assume each bit has a probability of error p.**



EEC Design

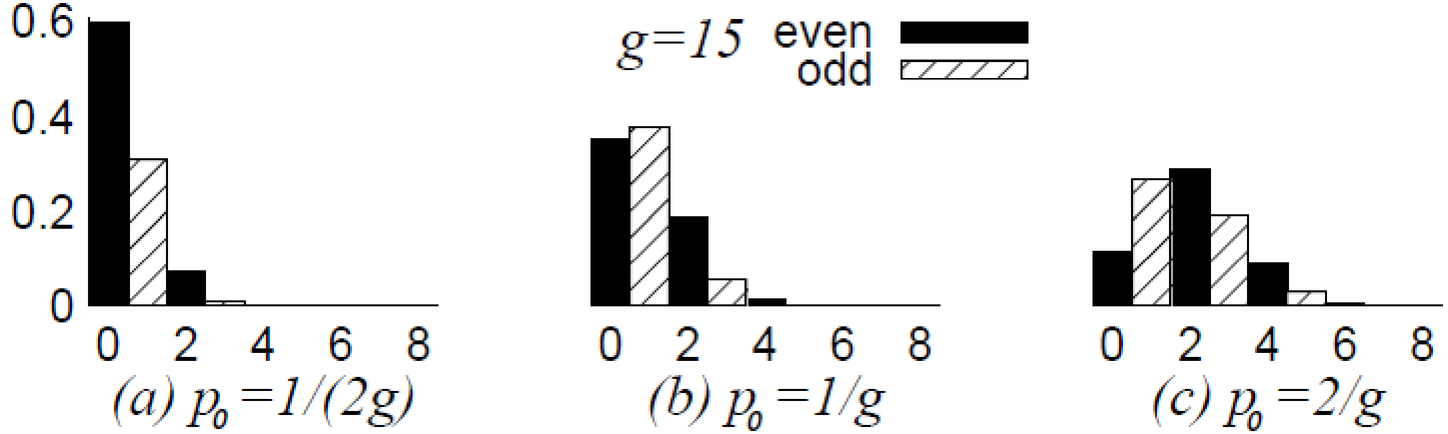
- How to make structure to estimate BER?
  2. **Sample a group of data bits with a single bit**



Parity information is sufficient,
when p is small enough

EEC Design

- How to make structure to estimate BER?
  2. **Sample a group of data bits with a single bit**



Sum of odd terms and even terms are comparable,
when p is not small enough

EEC Design : Brief Summary

- How to make structure to estimate BER?
  2. **Sample a group of data bits with a single bit**

$\phi(g+1,p)$: sum of the odd terms

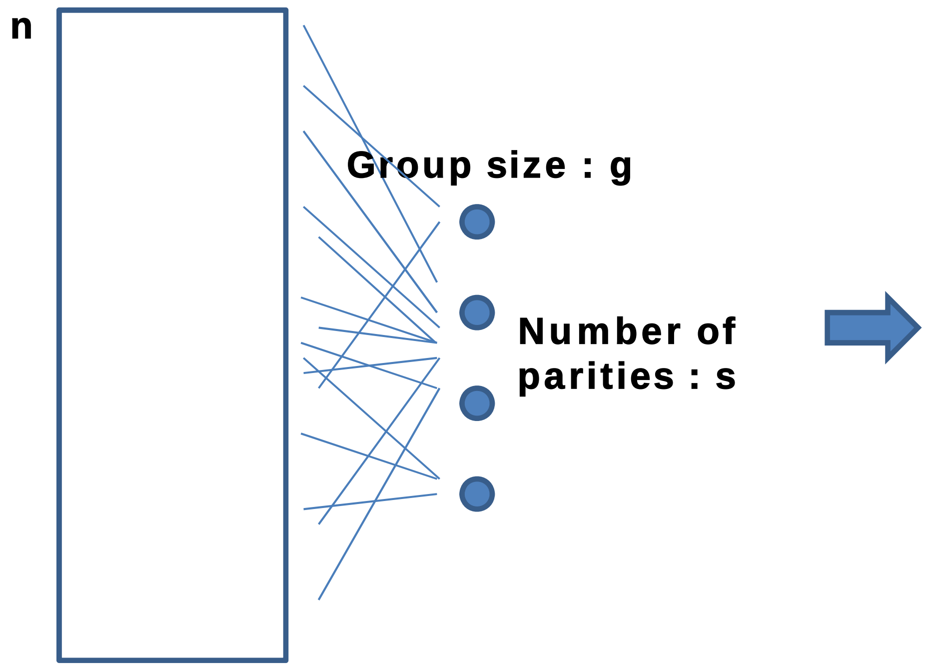
- when p is small enough,
  parity information is sufficient and $\phi(g+1,p)$ **smaller**

- when p is not small enough,
  $\phi(g+1,p)$ and sum of even terms are **comparable**

Single-level EEC

- How to know sum of odd terms $\phi(g+1,p)$?

  - When s is large, the fraction of #1 parities ~ $\phi(g+1,p)$



Since parity is sufficient at small p

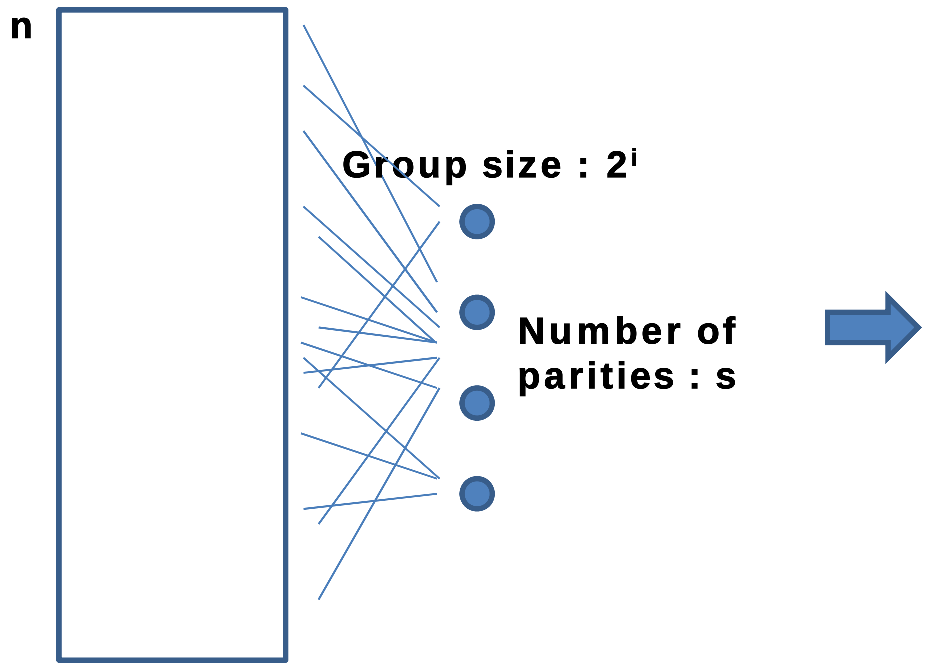
for $\phi(g+1,p) < c_2$

BER estimation is possible by

$\phi(g+1,p)$ / (g+1)

Multi-level EEC

- How to estimate BER for [1/n, 1/4]?
  - Total $\lfloor \log_2 n \rfloor$ levels each with 2^i group size



$\phi(2^i, p)$ is montonically increasing with i and p

Multi-level EEC

- How to estimate BER for [1/n, 1/4] ?

  - Find the suitable constants c_1 and c_2 such that there always exists some level i such that $\phi(2^i, p)$ falls within (c_1, c_2) for all p in [1/n, 1/4]

$\phi(2, p) < c_2$ for all $p \leq 1/4$ guarantees $\phi(2^i, p) < c_2$ at least at the first level

$\phi(2^{\lfloor \log_2 n \rfloor}, p) > c_1$ for all $p \geq 1/n$ guarantees $\phi(2^i, p) > c_1$ at least at the last level

$\phi(2^{j+1}, p) < c_2$, where j is the largest i such that $\phi(2^i, p) \leq c_1$

$$c_1 < 0.3,\ c_2 > 0.375, \text{ and } c_2 > 2c_1(1 - c_1)$$

$\phi(2^i, p)$	$i = 1$	2	3	4	5	6
$p = 0.25$	0.38	0.47	0.50	0.50	0.50	0.50
$p = 0.05$	0.095	0.17	0.28	0.40	0.48	0.50
$p = 0.01$	0.020	0.039	0.075	0.14	0.24	0.36

Multi-level EEC

- How to estimate BER for [1/n, 1/4] ?

  - Since such sum of odd terms within (c_1, c_2)

    ~ expected number of errors per group,

$$\hat{p} = \phi(2^i, p)/2^i$$

EEC Redundancy and Computational Overhead

Redundancy

- O(logn) levels with O(1) parity bits per level ~ O(logn)
- For BER range [1/1000 , 0.15]
  - 9 EEC levels , 32 parity bits per level.
  - Relative redundancy to 1500-byte packet = 2.4%

Computation Overhead

THEOREM 2. *The EEC encoding, decoding, and estimating time complexity are all* $O(n)$.

Conclusion

- Benefit of BER estimating in different scenarios
- Design criteria for Error-Estimation code
  - Estimation quality, Low redundancy and computational overhead
- Structure of EEC
  - The property of sum of odd terms with a single parity, when BER is small