Polar Coding for the Large Hadron Collider: Challenges in Code Concatenation

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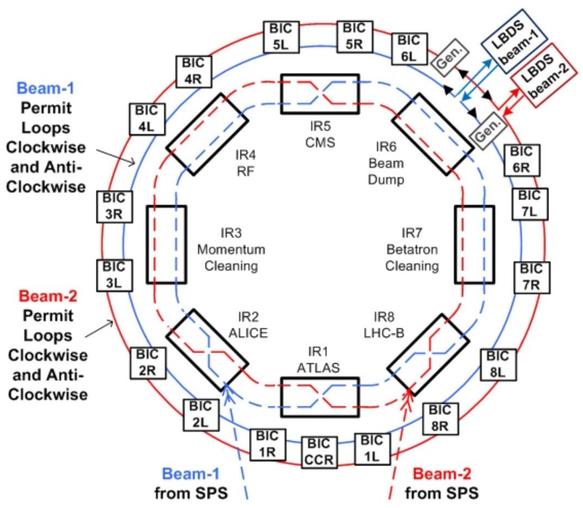
Introduction & Motivation

- Total energy of proton beams in the Large Hadron Collider (LHC) at CERN: up to **1380 MJ** (similar to kinetic energy of a Boeing 747-8 at landing).
- In case any of the sub-systems of the LHC fails, the beam has to be dumped within a few hundred microseconds.
- The **Beam Interlock System** (BIS) is a frequency modulated ring network that transmits a single bit called the **beam permit**.

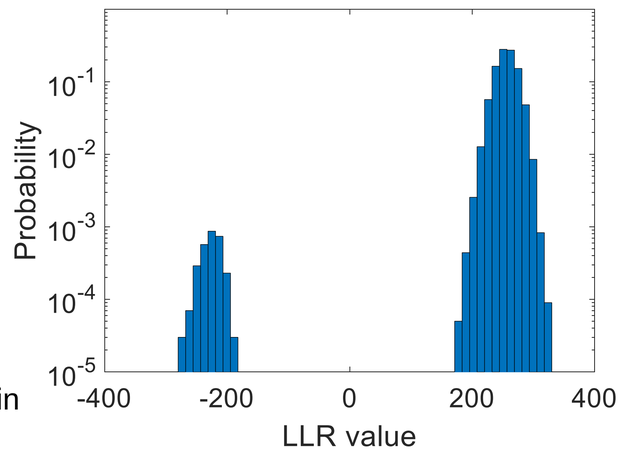
Beam Interlock System v. 2

- The BIS v. 2 is currently under design.
- **Topic of study:** to transmit additional information (e.g., for low-latency monitoring) instead of only beam permit.
- Beam permit needs to be **extremely reliable**, monitoring information can be **less reliable**.
- ➔ **ECC with unequal error correction!**



Problem 2: Decision LLR Distribution

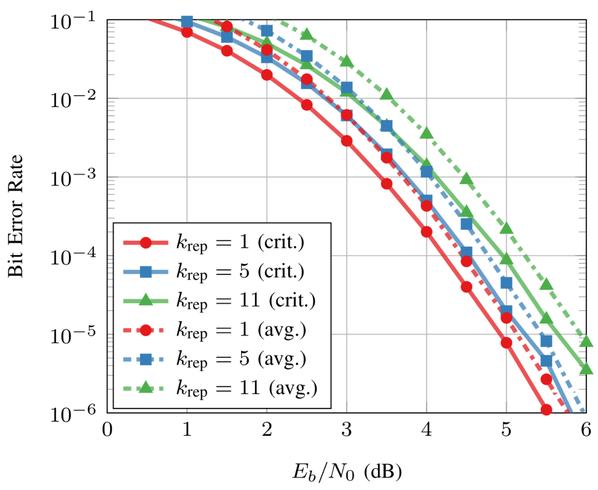
- Standard soft repetition decoder assumes that its input LLRs are **independent and identically distributed**.
- We already saw that they are **not independent!**
- **Even worse:** Information bits in polar code have **different reliabilities** leading to **different distributions per** information bit.
- **LLR histogram example** shows that wrong decisions are "**very wrong**".
- "Very wrong" LLRs can not be counterbalanced by correct LLRs in the repetition code.



Solution: Hard Decoding of Repetition Code

Polar Code + Repetition Code?

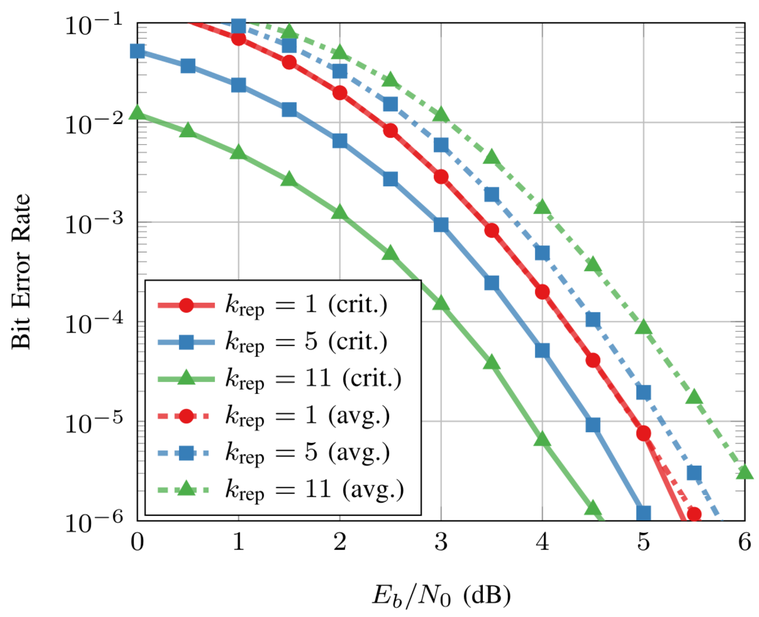
- **Polar codes** are ideal candidates:
  1. **No error floor** (provably).
  2. **Low-complexity** successive cancellation (SC) decoding.
- Additional protection of **beam permit** with a long **concatenated repetition code.**



- **Repetition code:** $k_{rep} = 1, 5, 11.$
- **Polar code:** $N = 128,\ R = 0.5 + \frac{k_{rep}-1}{N}$
- **Concatenated scheme:** use most reliable polar code locations to repeat beam permit k_{rep} times.
- **Decoding:** first decode polar code using SC decoding, then use soft decision log-likelihood ratios (LLRs) to decode repetition code.

Longer repetition code ➔ worse performance! Why?

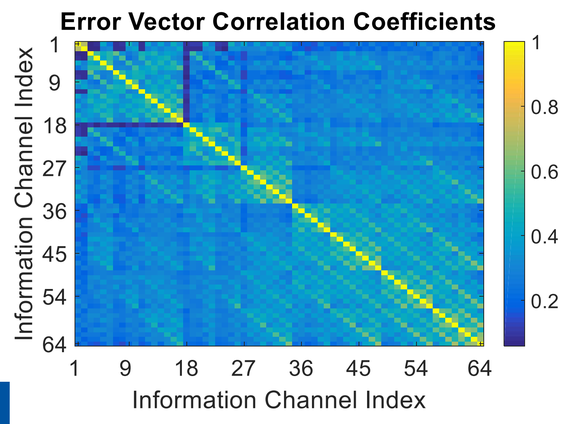
Performance w/ Systematic Coding and Hard Decoding



- **Concatenated scheme:** use most reliable **systematic** polar code locations to repeat beam permit k_{rep} times.
- **Decoding:** first decode polar code using SC decoding, then use **hard decisions** to decode repetition code.
- **Success!**
  1. Longer repetition code improves performance on critical beam permit bit.
  2. Average performance also improved due to systematic coding.

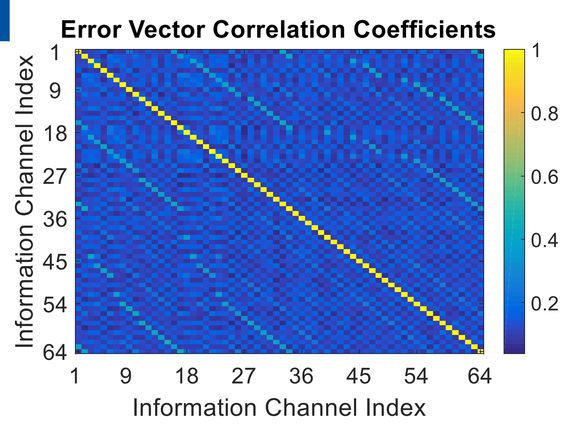
Problem 1: Information Bit Error Correlation

- Due to the nature of the SC decoder, polar code information bit errors are **highly correlated**.
- Limited diversity for repetition code!
- Correlation coefficients of information bit errors ➔



Solution: Systematic Coding

- Systematic polar coding slightly decreases the bit error rate.
- We found that systematic decoding also **decreases the information bit error correlation.**
- Correlation coefficients of information bit errors for systematic polar code ➔



Conclusions & Future Work

Conclusions:
1. Information bit error correlation and unusual LLR distribution make **outer repetition code ineffective**.
2. Systematic polar coding and hard decoding of outer repetition code **significantly improve performance.**

Future Work:
1. Better way to decode outer repetition code: **hard decoding is naïve approach**.
2. Show **why** systematic polar coding decreases information bit error correlation.
3. Extend to more complex concatenated coding schemes, e.g., with **LDPC codes**.

References

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