

White Paper: MeshCore Coding Rate (CR) Architecture, Limits, and Operational Behavior

1. Introduction

Coding Rate (CR) in MeshCore is a LoRa physical-layer forward-error-correction (FEC) parameter. Although MeshCore defines routing, timing, and reliability semantics at higher layers, the LoRa radio determines how bits are encoded, protected, and recovered.

This paper clarifies:

- How CR is defined and interpreted
- What Semtech does and does not document
- The theoretical limits imposed by Hamming distance
- The LoRa **H matrix** used for parity generation
- How the LoRa **physical header** communicates CR
- The overhead and airtime impact of higher CR
- Why CR is **not forwarded** through MeshCore repeaters
- Why CR is strictly a **one-hop** radio setting
- How CR selection applies to **Sparse, Medium, Dense, and Regional** repeaters

2. Coding Rate in LoRa: What It Actually Is

LoRa supports four coding rates:

LoRa Setting	Common Name	FEC Ratio	Parity Bits per 4 Data Bits
CR = 5	4/5	1	1
CR = 6	4/6	2	2
CR = 7	4/7	3	3
CR = 8	4/8	4	4

These correspond to shortened Hamming-like block codes applied to each 4-bit nibble.

✓ **Semtech's documentation only explicit statement: CR5 is parity**

Semtech does *not* document the internal structure of CR6–CR8, but they *do* explicitly state:

CR = 4/5 uses 1 parity bit for every 4 data bits.

This is the only CR mode where Semtech directly describes the parity mechanism.

✓ What Semtech does *not* document

Semtech does **not** publish:

- the parity-check matrix
- the syndrome decoding algorithm
- the correction capability of CR6–CR8
- the minimum Hamming distance of each CR

Thus, deeper analysis must be derived from theory and reverse-engineering.

3. Theoretical Limits: Hamming Distance and Error Correction

For any block code, the maximum number of correctable bit errors is:

$$t = \left\lfloor \frac{d_{\min} - 1}{2} \right\rfloor$$

Where:

- d_{\min} = minimum Hamming distance
- t = correctable bit errors per block

LoRa's FEC uses a shortened Hamming code with:

- 4 data bits
- 1–4 parity bits depending on CR
- Maximum theoretical $d_{\min} = \text{parity bits} + 1$

Thus:

CR	Parity Bits	Theoretical d_{\min}	Max Correctable Errors t	Notes
5	1	2	0	Semtech confirms: parity only
6	2	3	1	Not documented by Semtech
7	3	4	1	Not documented by Semtech
8	4	5	2	Not documented by Semtech

CR5 is the only mode where Semtech's documentation matches theory.

3A. Additional Hamming Theory for LoRa CR

Hamming Codes and Their Relevance to LoRa

LoRa's FEC engine is built on the principles of **linear block codes**, specifically shortened Hamming codes. These codes are designed to detect and correct bit errors introduced by noise, interference, or fading.

a. Hamming Distance and Error Correction

The **minimum Hamming distance** d_{\min} determines:

- how many bit errors can be **detected**
- how many bit errors can be **corrected**

The fundamental relationships are:

$$t = \left\lfloor \frac{d_{\min} - 1}{2} \right\rfloor$$

$$\text{Detectable errors} = d_{\min} - 1$$

b. Why LoRa Uses Shortened Hamming Codes

A full Hamming code typically uses:

- k data bits
- r parity bits
- $n = k + r$ total bits

LoRa uses a **shortened** version:

- Always **4 data bits**
- 1–4 parity bits depending on CR
- Total block length = 5–8 bits

Shortening preserves the error-correction properties while reducing block size to match LoRa’s symbol structure.

c. Theoretical Hamming Distances for LoRa CR

Because each additional parity bit increases the number of linearly independent rows in the parity-check matrix H , the theoretical minimum distance is:

$$d_{\min} = r + 1$$

Thus:

CR	Parity Bits r	Theoretical d_{\min}	Correctable Errors t	Detectable Errors
5	1	2	0	1
6	2	3	1	2
7	3	4	1	3
8	4	5	2	4

4. Why CR8 Has a Unique Advantage

CR8 is the only LoRa CR with:

- $d_{\min} = 5$
- ability to correct **two** bit errors per block
- ability to detect **four** bit errors

This is why CR8 is uniquely suited for:

- long-distance
- low-SNR
- mountain-top

- regional backbone links

5. Practical Implication: More Bits = Higher Probability of Error

A fundamental property of digital communication is:

The probability that a packet contains at least one bit error increases with packet length, assuming bit errors are statistically uniform across the transmission.

This means:

- Adding parity bits increases airtime, which increases exposure to noise, interference, and collisions.
- Every additional transmitted bit is another opportunity for corruption.
- Therefore, higher CR values increase the raw probability of error, even though they also increase the ability to correct errors.

This creates a tradeoff:

- Higher CR → more bits → more chances for corruption
- Higher CR → more parity → more ability to correct corruption

The optimal CR depends on which effect dominates:

- In dense networks, airtime and collision probability dominate → CR5 is optimal.
- In regional long-range links, error-correction capability dominates → CR8 is optimal.

6. Why Lower CR Modes Fail on Critical Links

If a CR5–CR7 block experiences more errors than its theoretical limit:

- the syndrome does not map to a valid error pattern
- the decoder cannot correct the block
- the entire LoRa packet must be discarded

This is why:

- **CR5–CR7 often require retries** on marginal links
- **CR8 succeeds on the first attempt**
- **Total airtime is lower with CR8** on critical backbone paths

a. The LoRa Parity-Check Matrix (H Matrix)

$$H = \left[\begin{array}{cccc|c} 1 & 0 & 1 & 1 & p_1 \\ 0 & 1 & 1 & 1 & p_2 \\ 1 & 1 & 0 & 1 & p_3 \\ 1 & 1 & 1 & 0 & p_4 \end{array} \right]$$

Rows are truncated depending on CR:

- CR5 uses only the first row
- CR6 uses first two
- CR7 uses first three
- CR8 uses all four

b. How CR Is Communicated: The LoRa Physical Header

The PHY header contains:

- Modulation parameters
- Payload length
- CRC enable
- **Coding Rate (CR)**

CR is encoded as:

Bits Meaning

00 4/5

01 4/6

10 4/7

11 4/8

The receiver reads these bits and configures its FEC decoder accordingly.

7. Airtime and Overhead Impact of Higher CR

CR FEC Ratio Airtime Increase vs CR5

CR FEC Ratio Airtime Increase vs CR5

5	4/5	baseline
6	4/6	+20%
7	4/7	+40%
8	4/8	+60%

8. CR Behavior in MeshCore Networks

- CR is **not included** in MeshCore packets
- CR is **not forwarded** through repeaters
- CR is strictly a **one-hop** physical-layer parameter

9. Operational Guidance for MeshCore Deployments

9.1 General Recommendations

- **CR5** for general mesh traffic
- **CR6–CR8** for impaired or long-range links

9.2 CR Selection by Repeater Class

Sparse Repeaters

Recommended CR: CR5 (CR6 if marginal) Low collision probability → minimize airtime.

Medium Repeaters

Recommended CR: CR5 or CR6 Balance airtime vs reliability.

Dense Repeaters

Recommended CR: CR5 only Airtime dominates; higher CR increases collisions.

Regional Repeaters

Recommended CR: CR8 Long-range, low-SNR, mountain-top backbone links benefit from maximum parity.

CR8 is more airtime-efficient than CR5–CR7 because retries cost more airtime than a single CR8 transmission.

10. Summary

Topic	Key Point
Semtech documentation	Only CR5 is explicitly described as parity
H matrix	Shortened Hamming-like code
CR signaling	Passed in LoRa PHY header
Overhead	CR6/7/8 add 20/40/60% airtime
Repeaters	Do not forward CR
Scope	CR is one-hop only
CR8 usage	Ideal for long-range, low-SNR repeater-to-repeater links
Density-based CR selection	Sparse: CR5/6 • Medium: CR5/6 • Dense: CR5 • Regional: CR8