PE1HVH

LoRa Modulation

Technical Documentation

From OSI model to radio signal

Chirp Spread Spectrum, Spreading Factors and Demodulation

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1. LoRa in the Network Layers

LoRa and MeshCore can be mapped to the well-known OSI model. The table below shows how the different components relate to the network layers.

OSI Layer	LoRa/MeshCore Equivalent
7. Application	MeshCore Companion App, chat, GPS
6. Presentation	— (not really present)
5. Session	— (no persistent sessions)
4. Transport	MeshCore ACKs, retries, fragmentation
3. Network	MeshCore routing, hops, Room addressing
2. Data Link	LoRa packet: preamble, sync word, header, CRC
1. Physical	LoRa PHY: chirps, SF, BW, the radio itself

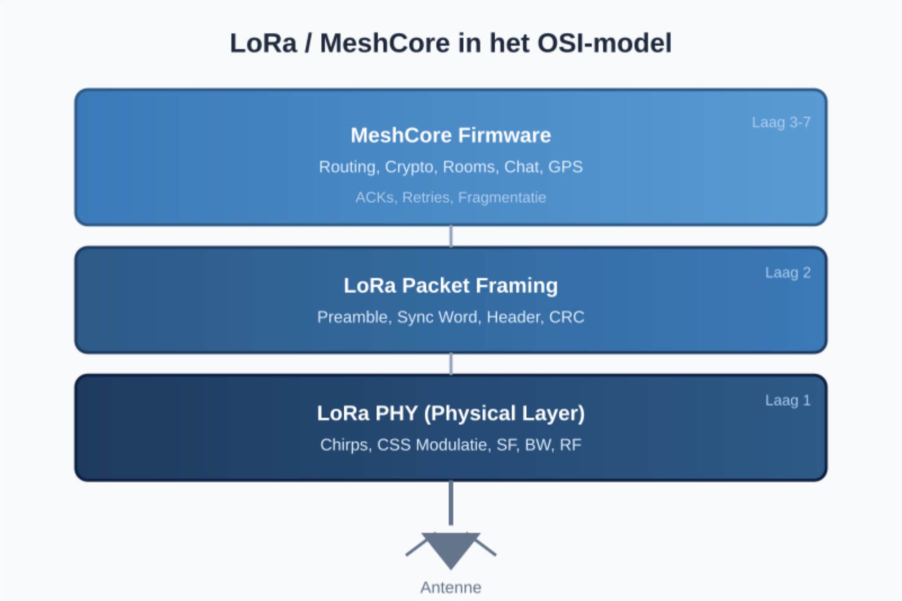

Figure 1: LoRa and MeshCore in the OSI layer model

1.1 Handshaking per Layer

Just like with Ethernet or TCP, there is a clear separation between the physical layer and the higher layers:

Protocol	Layer 1-2 (physical)	Layer 3+ (network)
Ethernet	No handshake, broadcast	ARP, IP, TCP handshake
WiFi	Beacon/probe	TCP/IP does the rest
LoRa	Preamble sync, no handshake	MeshCore ACKs, routing

The physical layer is always "dumb" — just bits into the air. The intelligence (reliability, addressing, acknowledgment) resides in the layers above.

2. Synchronization without Handshake

There is no handshaking in LoRa. The transmitter transmits, and whoever listens, listens. Synchronization happens via the preamble — a series of identical chirps at the beginning of each packet.

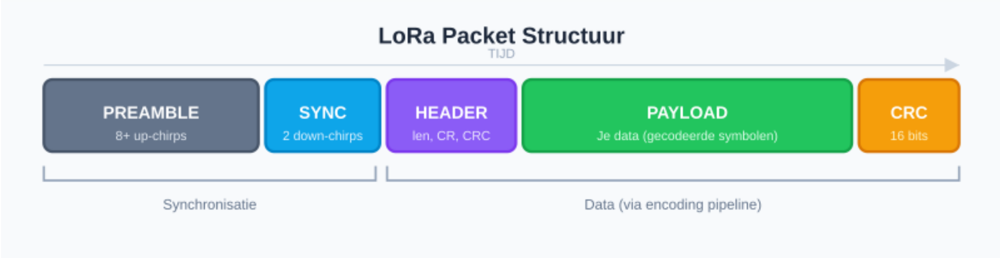

Figure 2: LoRa packet structure with preamble, sync word, header, payload and CRC

2.1 What the Receiver Learns from the Preamble

Information	How
Timing	Chirps arrive at regular intervals
Frequency offset	Preamble chirps are symbol 0, deviation = drift
SF confirmation	Chirp length matches expected SF
Network ID	Sync word must match

2.2 Synchronization Steps

1. Listen to noise...
2. Detect: "hey, this looks like a chirp"
3. Detect: "another chirp, same timing"
4. Count 8 chirps → "I am synchronized"
5. Wait for sync word (2 down-chirps)
6. Sync word matches → "this packet is for my network"
7. Now the data symbols arrive → decode

3. Demodulation: Down-chirp Mixing

The receiver multiplies the received signal with a locally generated down-chirp (reverse sweep). When you multiply a rising frequency with a falling frequency of the same rate, the changes cancel out. What remains is a constant tone.

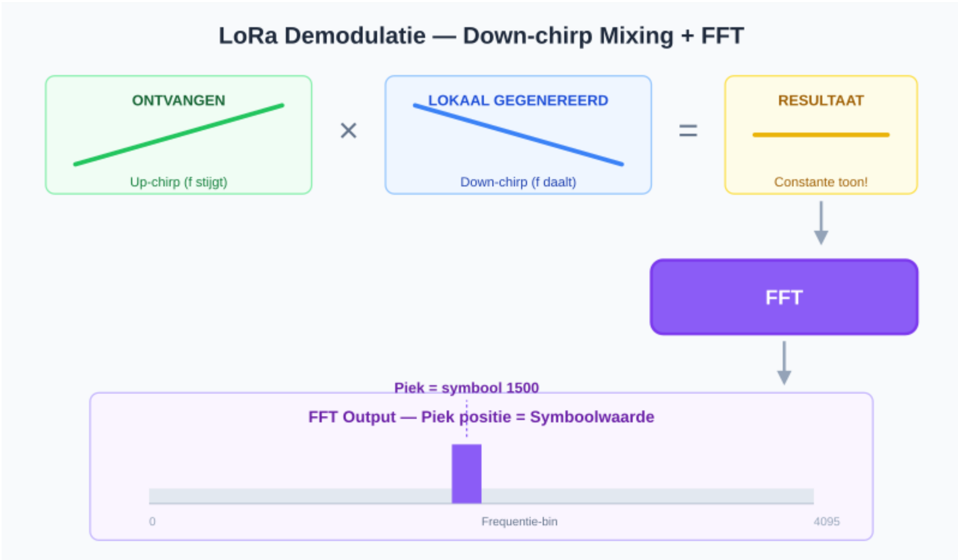

Figure 3: Demodulation via down-chirp mixing and FFT

The frequency of the resulting tone depends on the starting position of the chirp. The receiver performs a Fast Fourier Transform (FFT) on that result. The position of the peak in the spectrum is the symbol value.

3.1 Demodulation Steps

8. Receive up-chirp
9. Multiply with local down-chirp
10. Result = constant tone
11. FFT → find the frequency
12. Frequency bin = symbol value

3.2 Symbol Value from Frequency

After the FFT, each frequency bin corresponds to a symbol value:

Symbol	Resulting Tone
Symbol 0	0 Hz (DC)
Symbol 1000	~244 Hz
Symbol 2048	~500 Hz
Symbol 4095	~999 Hz

4. SF Orthogonality

Different Spreading Factors (SF7, SF9, SF12) can exist simultaneously on the same frequency without interfering with each other. They are orthogonal — they don't "see" each other.

Orthogonal means "perpendicular" — two things that don't influence each other, even though they exist in the same space. Just like the X-axis and Y-axis in a graph: moving along X doesn't change anything about Y.

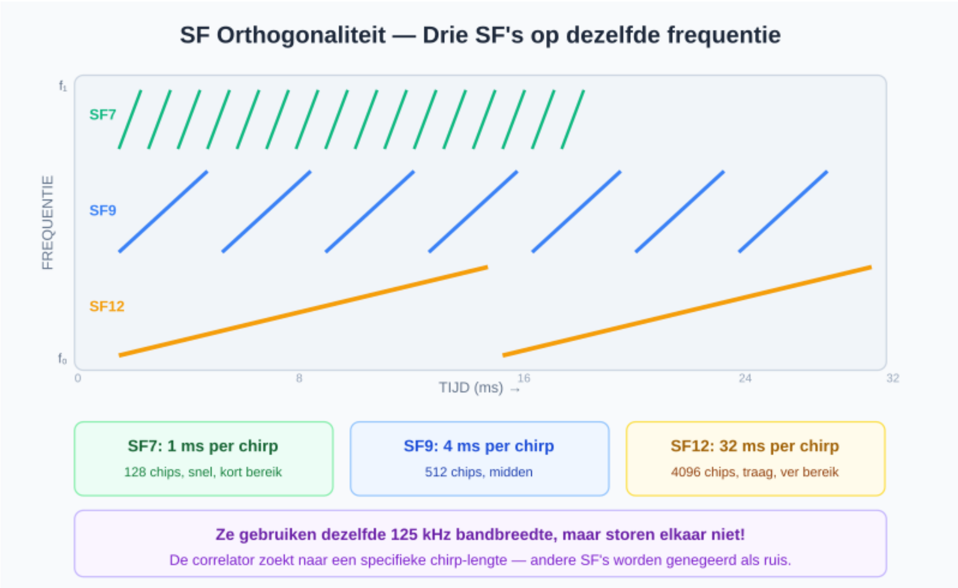

Figure 4: SF7, SF9 and SF12 simultaneously on the same 125 kHz bandwidth

4.1 Chirp Duration per Spreading Factor

SF	Chirp Duration (125 kHz BW)	Chips per Symbol
SF7	~1 ms	128
SF9	~4 ms	512
SF12	~32 ms	4096

The correlator in the receiver searches for a specific chirp length. An SF7 receiver looks for fast chirps of 1 ms. An SF12 chirp of 32 ms looks like slow noise to it — the mathematical correlation is virtually zero.

Important: For MeshCore this means that all nodes in your mesh must use the same SF. Anyone choosing a different SF is invisible to the network.

5. Chirp Spread Spectrum (CSS)

LoRa doesn't use AM or classic FM, but CSS modulation — Chirp Spread Spectrum. With LoRa, the amplitude is constant, the frequency always sweeps from low to high, and only where the sweep begins is data.

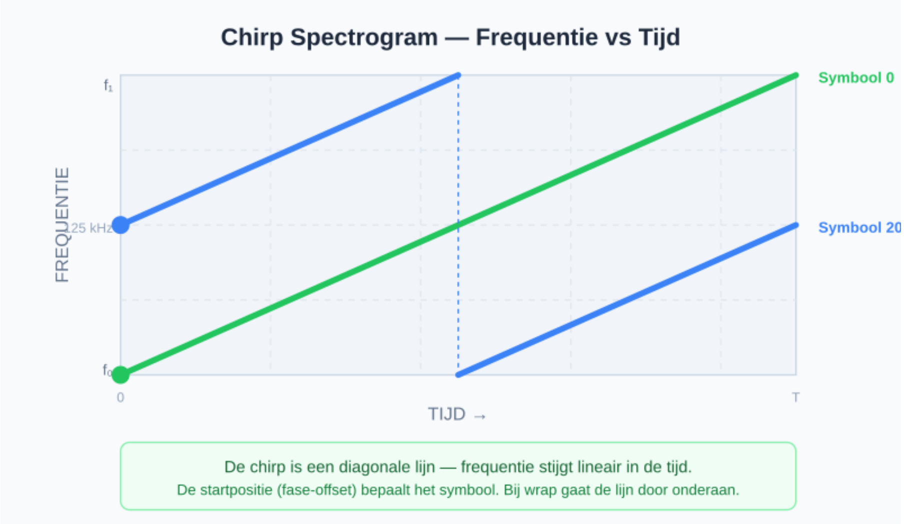

Figure 5: Spectrogram — the chirp as a diagonal line, phase offset determines the symbol

5.1 The Diagonal Line

In a spectrogram (frequency vs time), a chirp is a diagonal line. The symbol value determines where the diagonal begins. With a different starting position, the chirp "wraps" — it continues at the bottom when it reaches the top.

5.2 Modulation Comparison

Modulation	What Varies
AM	Amplitude
FM	Instantaneous frequency
PM	Phase
CSS/LoRa	Phase of a chirp (starting position in the sweep)

6. The Encoding Pipeline

From text to radio signal, the data passes through seven steps. Each step adds redundancy for robustness.

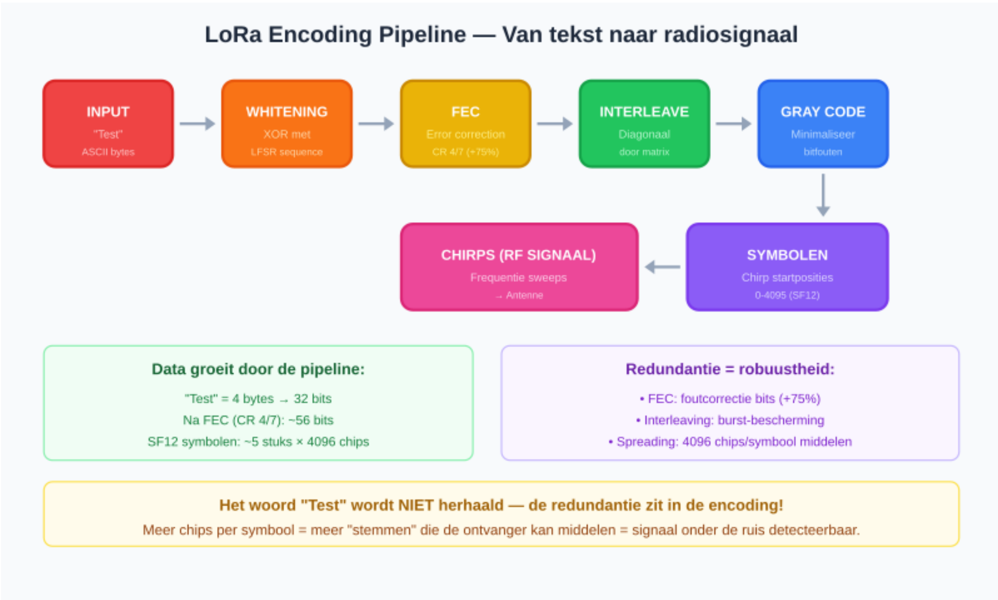

Figure 6: The complete encoding pipeline from "Test" to radio signal

6.1 The Seven Encoding Steps

13. **Input** — raw ASCII bytes ("Test" → 0x54, 0x65, 0x73, 0x74)
14. **Whitening** — XOR with pseudo-random sequence
15. **FEC** — Forward Error Correction (CR 4/7 = 75% overhead)
16. **Interleaving** — bits diagonally through matrix
17. **Gray coding** — minimize bit errors
18. **Symbols** — chirp starting positions (0-4095 at SF12)
19. **Chirps** — the radio signal to the antenna

7. Bits, Symbols and Chips

- **Bit**: what you want to send (your data)
- **Symbol**: a group of bits that are encoded together
- **Chip**: the smallest time unit of the radio signal

7.1 Spreading Factor and Chips

SF	Chips per Symbol	Bits per Symbol
SF7	128 (2^7)	7
SF8	256 (2^8)	8
SF10	1024 (2^{10})	10
SF12	4096 (2^{12})	12

More chips per symbol means more redundancy. The receiver correlates all chips together and can therefore extract signals from the noise — up to 20 dB below the noise floor.

8. Emergency Networks and SF Selection

All nodes in a mesh must use the same SF. This is comparable to analog radio where you also agree on FM vs AM beforehand.

8.1 Regional Presets

Region	Preset	SF	BW
EU868	LongFast	SF11	125 kHz
EU868	VLongSlow	SF12	125 kHz
US915	MedFast	SF9	250 kHz

An emergency network defines in advance: frequency, preset (which sets SF/BW/CR), and optionally a sync word for separation between groups.

8.2 Example Emergency Network Configuration

EMERGENCY NET EUROPE

```
Frequency: 869.525 MHz
SF: 12
BW: 125 kHz
CR: 4/7
Sync Word: 0x12
```

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