



DeRa: Deep-Range Low-Power Wide Area IoT via Ultra-sensitive Signal Detection

A physics-driven receiver for farther-reaching, low-power IoT.

Jialuo Du · Jingkai Lin · Zhichao Cao

Michigan State University



daibaoxuwu.github.io

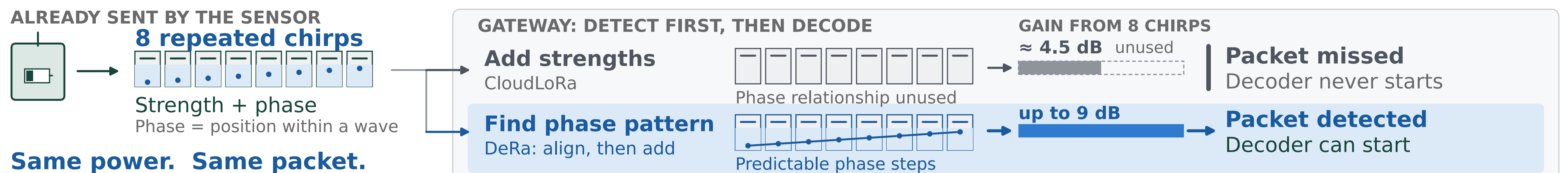
SNR NEEDED TO DETECT 90% OF PACKETS
4.3–4.8 dB lower than LoRaTrimmer

FIELD, 8 INDOOR/OUTDOOR SITES
95.3–100 % detected

COST, LIKE A STANDARD DETECTOR
 $O(N \log N)$ per symbol

1 Why: more reach from the sensors already deployed

A sensor's reach ends where the gateway stops detecting its packets, and a missed packet never reaches the decoder. Rather than change every sensor (precise clocks, longer preambles) or add gateways, DeRa makes the detector itself more sensitive.



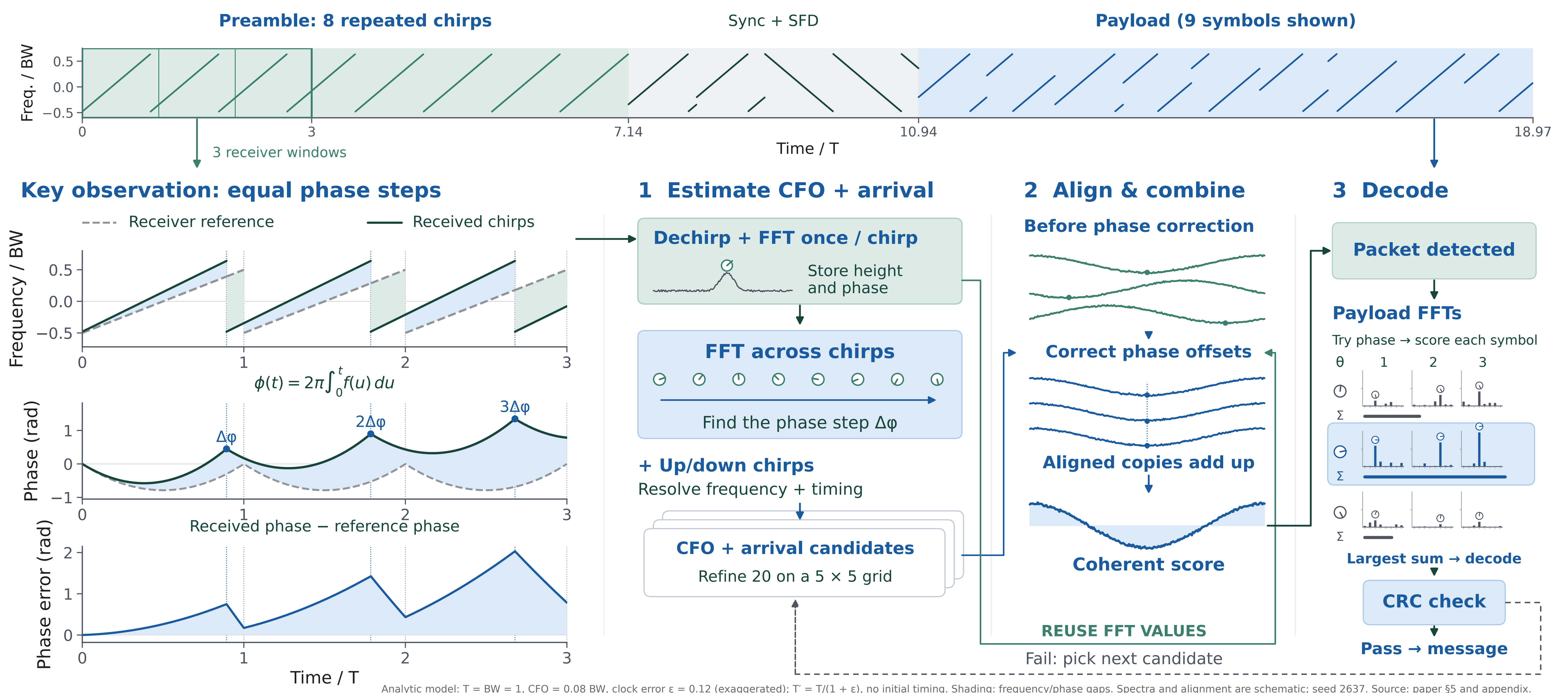
Illustrative weak-packet case: line = strength, dot = phase. Bars: ideal gain from adding 8 chirps, magnitudes $\approx 5 \log_{10} 8$ dB vs. aligned phases $10 \log_{10} 8$ dB (paper §2.3), one dB scale; not measurements.

Why existing detectors fall short: an unknown carrier frequency offset (CFO) scrambles each chirp's phase, so they add strengths (CloudLoRa) or align phases only partly (LoRaTrimmer), and cheap oscillators' offsets of up to 40 kHz make it worse. **DeRa's key idea:** CFO is not noise. It advances every chirp's phase by the same step, so finding that step aligns the chirps and detects the packet in one search.

2 How: find the packet by finding its phase step

Problem. A packet arrives at unknown time τ_0 with unknown CFO f_{CFO} . For each candidate (f_{CFO}, τ_0) , a signal model predicts every preamble chirp's FFT bin and phase P_i ; with V_i the FFT value there, the coherent score $S = |\sum_i V_i e^{-jP_i}|$ peaks at the true pair. Detection means finding that peak, accurately enough to decode. **The catch:** alignment needs f_{CFO} , estimating f_{CFO} needs alignment, and one chirp's phase is too noisy to break the loop.

Key observation: CFO advances every chirp's phase by the same step, $\Delta\phi = 2\pi f_{\text{CFO}} T' \approx 2\pi T(f_{\text{CFO}} - f_{\text{CFO}}^2/f_c)$ (T' : received chirp duration; f_c : carrier). So $V_0, \dots, V_7$ form one sinusoid across chirps, and a second FFT across them tests every step at once.



3 How much weaker a packet can DeRa detect?

PDR (packet detection rate): share of sent packets detected with CFO error $< \text{one FFT bin } (BW/2^{SF})$ and timing error $< 1/BW$, accurate enough to start decoding. **Threshold SNR:** the lowest SNR with $\text{PDR} \geq 90\%$, i.e. the weakest packet reliably detected (negative: LoRa works below the noise floor). **Sensitivity gain:** the threshold of LoRaTrimmer, the strongest baseline, minus DeRa's; 4.3 dB means a packet $2.7\times$ weaker is still detected. Both plots measure detection, not payload decoding.

