Successive Interference Cancellation Prototype for BLE and IEEE 802.15.4 in the Physical Layer

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***Abstract*—Bluetooth Low Energy (BLE) and IEEE 802.15.4 are two widely adopted wireless communication protocols in Internet of Things (IoT) applications. Both operate in the 2.4 GHz ISM band, where their coexistence can cause mutual interference. In this demo, we present a proof-of-concept post-processing prototype that recovers colliding packets by employing an effective algorithm based on a coarse-to-fine exhaustive search and cross-correlation for Successive Interference Cancellation (SIC). First, the stronger signal is demodulated, then its reconstructed waveform is subtracted from the captured interfered signal in order to demodulate the weaker signal. This approach allows the demodulation of both protocols despite overlaps in frequency and time. The experimental setup includes three software-defined radios (two transmitters, one per protocol, and one receiver), all connected to the same host computer. This solution is most suitable for gateways, where power consumption and computational resources are less constrained. Its main limitation is that it assumes direct line of sight between transmitters and receiver, so a dominant high-power signal exceeds any multipath reflections. It further requires a sufficiently high SNR to recover the low-power signal after subtraction, and the ADC's quantisation limits the power difference between the two protocols. It demonstrates the potential to increase coexistence throughput in dense IoT deployments.**

***Index Terms*—IEEE 802.15.4, BLE, Physical layer, IoT**

I. Technical Details

We present a demo of a software-defined radio (SDR) prototype implementing Successive Interference Cancellation (SIC). By capturing and storing the I/Q samples during packet collisions for post-processing, we show that we can recover overlapping packets at the receiver.

We will show a live capture of colliding packets on a receiver SDR tuned to the same frequency as two SDR transmitters (one for BLE, one for IEEE 802.15.4), both connected to a single computer with a GNU Radio installation (Fig. 1). By comparing the payloads recovered via SIC post-processing with the original transmitted data, we show the technique's effectiveness and highlight its limitations, including the required power disparity between signals and the necessary sampling rate needed for reliable packet recovery.

Specifically, the receiver is configured to demodulate the higher-power protocol first, assuming we know in advance which protocol arrives at higher power, employing an FSK-based demodulator for both BLE and IEEE 802.15.4 [1]. Upon successful detection and CRC verification of a packet, the baseband I/Q samples spanning the collision interval are

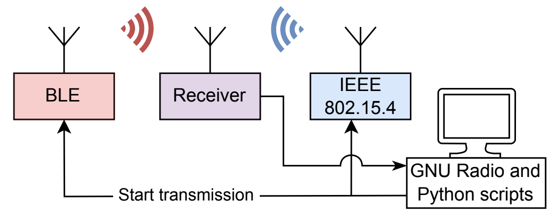


Fig. 1: Physical and over-the-air connections between transmitters and receiver.

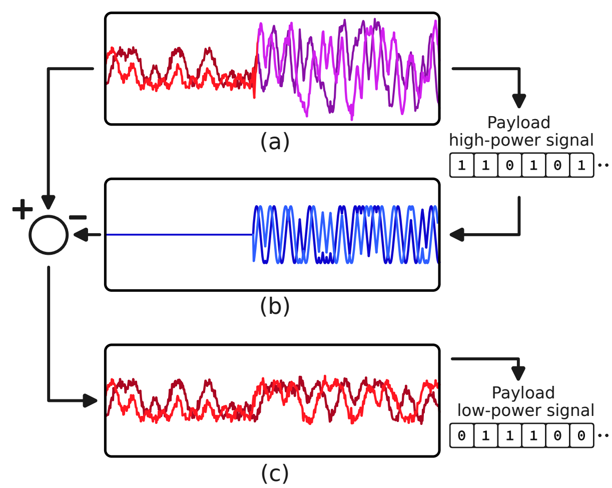


Fig. 2: Schematic of the algorithm: (a) received interfered signal; (b) high-power signal waveform reconstruction and alignment; (c) resulting signal after subtraction. Dark and light hues represent I and Q components, respectively.

stored. A Python script then post-processes these samples to recover the weaker signal's payload.

The post-processing algorithm assumes a direct line-of-sight channel between the transmitters and receiver so that the received baseband signal $s_{\mathrm{rx}}[t]$ can be modelled as the sum of the two transmitted waveforms plus noise:

$$s_{\mathrm{rx}}[t] = A_h\, s_{\mathrm{tx},h}[t - t_h]\, e^{j(2\pi f_h t + \phi_h)} + A_\ell\, s_{\mathrm{tx},\ell}[t - t_\ell]\, e^{j(2\pi f_\ell t + \phi_\ell)} + n[t].$$

where subscripts h and ℓ refer to the high- and low-power signals, respectively.

The post-processing stage takes as input the recorded baseband I/Q signal $s_{\mathrm{rx}}[t]$ and the decoded high-power payload (Fig. 2a, where the purple interval represents a collision). First, the band-limited I/Q sequence is upsampled to enable fine time-alignment when subtracting the reconstructed high-power waveform. Then, a unit-amplitude replica of the high-power waveform $s_{\mathrm{tx},h}[t]$ is generated at this increased sampling rate by remodulating the decoded symbols with the appropriate protocol-specific pulse-shaping filter. To estimate the alignment parameters—amplitude A_h, delay t_h, phase offset ϕ_h, and frequency offset f_h (on the order of kHz due to local-oscillator mismatches between transmitters and receiver), a coarse-to-fine search over candidate frequency offsets is performed. For each candidate, the corresponding frequency shift is applied, and the cross-correlation with the stored I/Q waveform $s_{\mathrm{rx}}[t]$ is computed. The parameter set that maximises this metric is used for alignment (Fig. 2b). Finally, the aligned reconstructed waveform is subtracted from $s_{\mathrm{rx}}[t]$ (Fig. 2c) and the low-power protocol's demodulator is run on the residual signal to recover its payload.

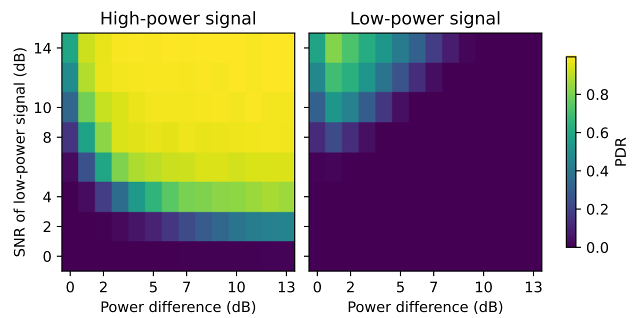
II. Relevance

Our demo falls under the EUPSICO tracks on "Signal Processing for the Internet of Things" and "Signal Processing for Communications". We show a very visual demonstration of our approach in which we use signal processing concepts to apply Successive Interference Cancellation to BLE and IEEE 802.15.4 coexistence. This is particularly relevant for dense IoT deployments, as increasing throughput by preventing retransmissions can be achieved solely through signal processing at the PHY layer, recovering colliding packets that would be otherwise discarded.

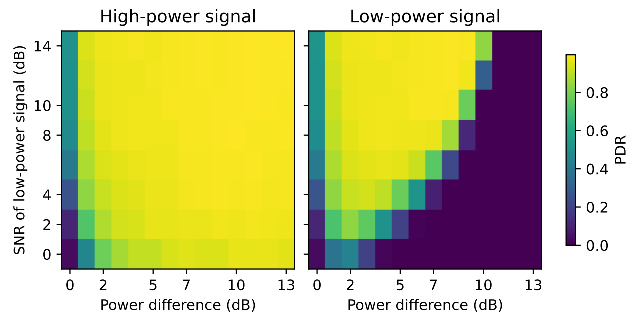
Throughput gains are dependent on the BLE rate and on whether they are measured relative to BLE-only or IEEE 802.15.4-only operation. Combining BLE at 2 Mbit/s with IEEE 802.15.4 (250 kbit/s, code rate 1/8), a 12.5% increase in total throughput is achieved compared to BLE alone (and a 25% increase when BLE is at 1 Mbit/s). Conversely, relative to IEEE 802.15.4 alone, up to an 8× improvement is observed with BLE at 2 Mbit/s (4× at 1 Mbit/s).

While more complex PHY schemes (e.g. 16–1024 QAM) can also raise throughput, a SIC approach preserves node simplicity by shifting all complexity to gateways. This aligns with IoT scenarios where off-the-shelf chips (e.g. nRF52) already support BLE and IEEE 802.15.4 PHYs, making reuse of existing hardware a potential application.

Although SIC is an existing concept [2], [3], its application to BLE and IEEE 802.15.4 at the physical layer has not, to our knowledge, been documented. To validate its effectiveness in terms of packet delivery ratio, and to demonstrate its potential in interference-prone networks, we conducted Monte Carlo simulations (1000 trials per power-difference level) under varying SNRs, random phase offsets, fractional delays and frequency mismatches (Fig. 3).



(a) Simulation with 4 MS/s.



(b) Simulation with 30 MS/s.

Fig. 3: Monte Carlo simulation results for two sampling rates, with 1000 trials per PDR value. IEEE 802.15.4 is the high-power signal with 30-Byte payload, and BLE at 1 Mb/s is the low-power signal with a 200-Byte payloads.

III. Logistics

The demo consists of a laptop connected to two ADALM Pluto SDRs used as transmitters (small box), and one USRP SDR used as the receiver (shoebox sized), over USB. All equipment comfortably fits on a table. The only requirement for showing the demo is a table, ideally an external screen and a power strip to power the laptop, the USRP and the screen. No internet connection is needed.

Acknowledgment

This work was partially funded by the French National Research Agency (ANR-22-PEFT-0007) as part of France 2030 and the NF-FITNESS project, and by the European Union's Horizon Europe Framework Programme under Grant Agreement No. 101093046 (project"OpenSwarm"). Views and opinions expressed are however those of the author(s) only and the European Commission is not responsible for any use that may be made of the information it contains

References

[1] T. Schmid, "GNU Radio 802.15.4 en-and decoding," 2006.
[2] S. Sen, N. Santhapuri, R. R. Choudhury, and S. Nelakuditi, "Successive interference cancellation: Carving out mac layer opportunities," *IEEE Transactions on Mobile Computing*, vol. 12, no. 2, pp. 346–357, 2012.
[3] X. Zhang and M. Haenggi, "The performance of successive interference cancellation in random wireless networks," *IEEE Transactions on Information Theory*, vol. 60, no. 10, pp. 6368–6388, 2014.