LoRa parameters optimization

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1 Introduction

This section describes the behavior and limitations of an adaptive physical layer (PHY) optimization algorithm for LoRa communication, implemented and tested on the Arduino MKR WAN 1310 platform. The algorithm dynamically adjusts transmission power, spreading factor (SF), bandwidth (BW), and coding rate (CR) based on measured RSSI and SNR values in order to maximize communication range while minimizing energy consumption.

2 Theory under parameters

2.1 Transmit Power

The Received Signal Strength Indicator (RSSI) is directly related to the transmit power of the sender and the path loss between the transmitter and receiver. Under constant channel conditions, increasing the transmit power results in a nearly linear increase in RSSI at the receiver. Therefore, RSSI is an effective metric for estimating link margin with respect to transmit power.

2.2 Spreading factor

The spreading factor in LoRa modulation determines the number of chips per symbol. Increasing the spreading factor increases the symbol duration and processing gain, which improves receiver sensitivity.

Empirically and according to Semtech documentation, increasing SF by one step reduces the minimum required SNR for successful demodulation by approximately:

$$\Delta\mathrm{SNR}_{\mathrm{min}} \approx -2.5, \mathrm{dB} \tag{1}$$

This means that higher SF values allow successful reception at significantly lower SNR levels.

2.3 Bandwidth

Reducing the signal bandwidth decreases the integrated noise power at the receiver.

$$NoiseFloor_{[dBm]} = -174 + 10 \cdot \log_{10}(BW) \tag{2}$$

Since thermal noise power is proportional to bandwidth, lowering BW improves the effective SNR.

A reduction of bandwidth by a factor of two results in an SNR improvement of approximately:

$$\Delta\text{SNR} \approx +3, \text{dB} \tag{3}$$

While this theoretically improves link performance, reduced bandwidth also significantly increases sensitivity to carrier frequency offset (CFO), oscillator drift, and temperature-induced frequency errors.

3 Optimization Strategy and Parameter Ordering

Optimization has two different steps:

1. Checking SNR and RSSI thresholds:
   (a) RSSI under lower threshold(-105) increasing TxPower
   (b) SNR under lower threshold(depends on SF) increasing SF and decreasing BW
   (c) SNR over upper threshold(7) decreasing SF and increasing BW
   (d) RSSI over upper threshold(-60) decreasing TxPower
2. Standard optimization when system is stable:
   (a) Decrease spreading factor (SF)
   (b) Increase bandwidth (BW) when channel conditions improve
   (c) Reduce coding rate (CR)
   (d) Reduce transmit power (TxPower)

To ensure stable adaptation and minimize energy consumption, the following optimization order is applied:

SF and BW adjustments significantly affect time-on-air and receiver sensitivity. Incrementing the SF by one step or halving the BW doubles the symbol duration T_s, thus doubling the total energy consumption per packet. Conversely, increasing the BW or decreasing the SF reduces energy consumption by approximately a factor of two.

In contrast, reducing transmit power does not yield equally large energy savings, as the radio remains active for the same transmission duration. Lower TxPower primarily reduces instantaneous power consumption but does not shorten airtime.

4 Experimental Results and Observation

The algorithm was evaluated in a real-world scenario where the distance between the node and the gateway was incrementally increased up to 700 m. Initially, the system was located in close proximity, allowing the optimization engine to reach the highest data rate (SF7, BW 500 kHz, and minimum TxPower).

As the distance increased, the following transitions were observed:

1. **Phase 1: Power Compensation.** When the RSSI dropped below the threshold of -105 dBm, the algorithm immediately increased the *TxPower*. This successfully maintained the link stability without increasing the Time-on-Air (ToA).

2. **Phase 2: First Modulation Adjustment.** Upon further distance increase, the SNR dropped below the acceptable threshold for SF7. The algorithm responded by increasing the Spreading Factor to SF8 and decreasing BW to 250 kHz. This resulted in a measurable improvement in SNR, effectively extending the functional range.

3. **Phase 3: Critical Failure at 700 m.** At the maximum distance of approximately 700 m, the SNR again fell below the threshold (approx. -4 dB). The algorithm attempted a second aggressive optimization by increasing the Spreading Factor to SF9 and reducing the Bandwidth to index 7 (125 kHz).

Despite the theoretical sensitivity gain of +3 dB from the bandwidth reduction, this final adjustment led to a total loss of communication. The system was unable to receive packets until the config was reverted after timeout.

5 Hardware Limitations and Bandwidth Reduction

The Arduino MKR WAN 1310 is based on the SX1276 transceiver and uses a standard crystal oscillator without temperature compensation (TCXO).

According to the Semtech SX1276 datasheet, the LoRa modem is intolerant to frequency offsets in the region of ±25% of the configured bandwidth, and will accurately report the error over this same range. This implies that frequency error due to oscillator instability may exceed the allowable offset for narrow bandwidths, leading to failed preamble detection and demodulation even if the logical parameters are correctly synchronized and a handshake mechanism is used.

This explains the observed behavior where communication fails at high SF and reduced BW near the maximum tested distance of approximately 700 m, while restoring a higher bandwidth (e.g., 250 kHz) immediately re-establishes the link.

6 Conclusion

The experimental results demonstrate that aggressive bandwidth reduction on hardware without a temperature-compensated oscillator can lead to complete link failure, despite theoretical SNR improvements. A robust adaptive LoRa algorithm must therefore prioritize SF adjustments, use bandwidth reduction cautiously, and account for hardware frequency stability limitations.

References

[1] Semtech, *AN1200.22 LoRa™ Modulation Basics*, 2016.

[2] Semtech, *SX1276/77/78/79 Datasheet*, 2013. https://www.alldatasheet.com/html-pdf/800239/SEMTECH/SX1276/11057/37/SX1276.html