

Jakub MAJ, Przemysław ZIELONY, Krzysztof PIOTROWSKI
Leibniz Institute for High Performance Microelectronics

RANGE–ENERGY TRADE-OFF ANALYSIS OF SIMPLELINK LONG RANGE MODE (LRM) CODING TECHNIQUE IN THE PHYSICAL LAYER

This work presents an analysis of the SimpleLink Long Range Mode (LRM) coding technique used in the physical layer, focusing on the impact of transmission configurations on communication range and energy consumption. The study included various coding configurations and transmit power levels, for which the maximum communication range was determined, and the corresponding energy consumption was evaluated for each configuration. The results provide a comparative assessment of the trade-offs between range extension and energy efficiency, highlighting how specific parameter choices influence overall system performance.

ANALIZA KOMPROMISU ZASIĘG–ZUŻYCIE ENERGII DLA TECHNIKI KODOWANIA SIMPLELINK LONG RANGE MODE (LRM) W WARSTWIE FIZYCZNEJ

Niniejsza praca przedstawia analizę techniki kodowania SimpleLink Long Range Mode (LRM) stosowanej w warstwie fizycznej, ze szczególnym uwzględnieniem wpływu konfiguracji transmisji na zasięg komunikacji i zużycie energii. W badaniu uwzględniono różne konfiguracje kodowania i poziomy mocy transmisji, dla których określono maksymalny zasięg komunikacji i oszacowano odpowiadające mu zużycie energii dla każdej konfiguracji. Wyniki stanowią porównawczą ocenę kompromisów między rozszerzeniem zasięgu a efektywnością energetyczną, podkreślając, jak dobór konkretnych parametrów wpływa na ogólną wydajność systemu.

1. INTRODUCTION

Low-Power Wide-Area Networks (LPWANs) [1], [2] are widely used in Internet of Things applications that require long-range communication with limited energy resources. Such systems operate with low data rates, constrained power budgets, and extended communication distances. As a result, achieving an extended communication range while maintaining low energy consumption remains a key challenge in such systems.

One approach to extending communication range is the use of coding and spreading techniques that reduce data rate in exchange for improved sensitivity. SimpleLink Long Range [3] is an example of such a solution, based on Direct Sequence Spread Spectrum (DSSS) and coding mechanisms, where the data rate depends on both the symbol rate and the spreading factor. As a result, increasing the DSSS level decreases the available data rate while improving link robustness. This increases transmission time and, consequently, energy consumption, making optimization of the range–energy trade-off non-trivial.

The main contributions of this paper include an experimental evaluation of DSSS configurations without higher-layer mechanisms, an analysis of the impact of DSSS and transmission power on communication range and energy consumption, and measurement-based results obtained outdoors.

2. RELATED WORKS

The performance of low-power wireless systems strongly depends on PHY (physical layer) parameters such as transmission power, data rate, and spreading techniques such as DSSS. Spörk et al. [4] evaluate the four BLE 5 PHY modes and compare them in terms of throughput, reliability, and power consumption.

Bor and Roedig [5] study the impact of LoRa parameters, including spreading factor, bandwidth, coding rate, and transmission power, on energy consumption and communication reliability. In [6], the *This work was supported by the European Regional Development Fund within the INTERREG VI A BB-PL 2021-2027 Programme, project MobiRobAI, grant number BBPL0100046, and project SmartRiver2, grant number BBPL0100056. The funding institution had no role in the design of the study, the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.*

authors analyze the reliability of LoRa-based LP-WAN communication as a function of the number of nodes, spreading factor, distance, and environment type, demonstrating that transmission performance depends not only on PHY configuration, but also on deployment conditions. Bindel [7] analyzes the influence of LoRa transmission parameters such as spreading factor, transmission power, and coding rate on transmission time, current consumption, signal-to-noise level, and packet reception rate.

Energy aspects are addressed more directly in [8], which analyzes the energy consumption of LPWA-based IoT devices operating in LoRaWAN, Sigfox, NB-IoT, and EC-GSM-IoT networks, with IEEE 802.15.4 used for comparison.

Wunsch et al. [9] investigate the implementation and performance aspects of IEEE 802.15.4 LECIM DSSS PHY, addressing DSSS-based low-data-rate PHY and large spreading factors.

Existing studies focus on standardized technologies and rarely address proprietary DSSS-based PHY schemes such as SimpleLink Long Range.

3. METHODOLOGY

The experiments were conducted using the SimpleLink Long Range physical layer, operating in the 868 MHz band and employing DSSS-based coding combined with GFSK (Gaussian Frequency-Shift Keying) modulation. In this work, three DSSS configurations were evaluated: 2, 4, and 8. The symbol rate was fixed at 20 ksps (kilosymbols per second), resulting in effective data rates of 5 kbps (kilobits per second), 2.5 kbps, and 1.25 kbps, respectively. Increasing DSSS improves sensitivity at the cost of reduced data rate and longer transmission time. The transmission power was varied across five levels: –10 dBm, 0 dBm, 5 dBm, 10 dBm, and 14 dBm. All other PHY parameters remained constant.

The experiments were performed using a custom board based on the CC1352R device. The node was powered with a constant supply voltage of 3.3 V. Energy consumption was measured using the WISDOM platform [10], which enables current and voltage measurements. The sampling rate was set to 1950 samples per second. For each transmission, the measurement window was aligned with the transmission event and covered the entire transmission duration.

Measurements were conducted in an outdoor rural environment with near line-of-sight (quasi-LOS) conditions. The test area consisted of flat terrain with partial obstructions. Both transmitter and receiver antennas were placed at an approximate height of 2 m above ground level.

For each PHY configuration and transmission power level, packets with a fixed payload size of 50 bytes were transmitted without MAC-layer mechanisms or retransmissions. The maximum communication distance was defined as the largest distance at which at least one packet was successfully received. This metric was included as an additional reference representing the absolute connectivity limit of the evaluated PHY configuration. Since such communication conditions are not suitable for reliable IoT operation, the optimal communication distance corresponding to a PDR exceeding 95% was additionally introduced to represent a practically usable communication range. The PDR was calculated based on 1000 transmitted packets at each distance. Energy consumption was measured for a single packet transmission event. The time duration of the transmission was determined based on the number of recorded samples and the sampling rate.

The consumed energy during the transmission event was calculated based on the recorded samples. The measured transmission energy corresponds to the complete packet transmission, including protocol overhead, while normalization was performed relative to the useful payload of 50 bytes, resulting in metrics such as energy per useful bit. Additionally, the energy per meter was calculated by dividing the transmission energy by the corresponding communication distance for both distance metrics.

4. EVALUATION

4.1. Communication Distance

Table 1 presents the measured maximum and optimal communication distances. The measured distances vary depending on both the DSSS configuration and the transmission power level.

Table 1. Maximum and optimal communication distance [m] for different DSSS and Tx Power configurations

DSSS	TX [dBm]	Max Dist. [m]	Opt. Dist. [m]
2	-10	950	850
	0	2240	2180
	5	2255	2227
	10	2604	2458
	14	2884	2727
4	-10	750	650
	0	1986	1795
	5	2262	1985
	10	2737	2728
	14	3085	2812
8	-10	750	650
	0	2144	2085
	5	2300	2255
	10	2945	2881
	14	3264	3018

Increasing the transmission power consistently improves the communication range for all DSSS configurations. In contrast, the influence of the DSSS parameter is limited and inconsistent across configurations. At higher transmission powers (10–14 dBm), increasing DSSS from 2 to 8 results in a moderate increase in maximum distance on the order of 10–15%. However, at lower transmission powers, the differences between DSSS configurations are smaller and are inconsistent.

A similar trend is observed for the optimal communication distance. While higher DSSS values may provide slight improvements under favorable conditions, the observed gains are relatively small and depend on specific transmission power and propagation conditions. In several cases, increasing DSSS does not improve the optimal distance.

4.2. Energy Efficiency

The energy-related metrics are presented in Table 2. In contrast to the distance results, the impact of DSSS on energy consumption is clear and consistent.

Table 2. Energy consumption per useful bit and per meter

DSSS	TX [dBm]	Energy/bit [μ J]	Energy/m [μ J/m]
2	-10	7.16	3.37
	0	10.41	1.91
	5	12.59	2.26
	10	15.25	2.48
	14	18.29	2.68
4	-10	13.61	8.38
	0	20.10	4.48
	5	23.96	4.83
	10	29.58	4.34
	14	35.15	5.00
8	-10	26.05	16.03
	0	38.86	7.46
	5	47.33	8.39
	10	58.20	8.08
	14	67.89	9.00

For all transmission power levels, increasing DSSS leads to a substantial increase in energy per useful bit. The observed increase is approximately proportional to the spreading factor, resulting in roughly a twofold increase when moving from DSSS=2 to DSSS=4, and up to a fourfold increase for DSSS=8.

A similar behavior is observed for the energy per meter calculated at the optimal communication distance. Across all transmission power levels, higher DSSS configurations require significantly more energy to achieve the same communication distance, typically by a factor of two to four compared to DSSS=2.

The observed increase in energy consumption is primarily associated with the longer transmission duration resulting from the reduced effective data rate of higher DSSS configurations. In the evaluated

platform, DSSS processing is handled within the radio subsystem, while no additional software-side signal processing was introduced during the experiments. Therefore, the contribution of CPU computational overhead to the measured energy consumption is expected to be limited compared to the impact of prolonged radio activity.

Combining these observations with the relatively small and inconsistent improvements in communication distance, increasing DSSS significantly increases energy consumption while providing only limited gains in communication range. Consequently, higher DSSS configurations are less energy-efficient under the considered experimental conditions.

5. CONCLUSIONS

This paper presents an experimental evaluation of the SimpleLink Long Range physical layer, focusing on the impact of DSSS-based configurations on communication distance and energy efficiency.

The obtained results show that increasing the DSSS parameter leads to a significant and consistent increase in transmission energy. The energy per useful bit grows approximately proportionally to the spreading factor, resulting in up to a fourfold increase when comparing DSSS=2 and DSSS=8.

In contrast, the improvement in communication distance is limited and not consistent across configurations. While higher DSSS values can provide moderate range gains at higher transmission power levels, the observed improvements remain relatively small and depend on the specific operating conditions. In several cases, increasing DSSS does not improve the achievable communication range.

Future work may include extending the analysis to different environments, such as urban or interference-prone scenarios, as well as investigating the impact of higher-layer mechanisms, including retransmissions and MAC-layer protocols, on the overall system performance.

REFERENCES

1. Raza U., Kulkarni P., Sooriyabandara M.: Low Power Wide Area Networks: An Overview, *IEEE Commun. Surveys Tuts.*, vol. 19, no. 2, pp. 855–873, 2017.
2. Centenaro M., Vangelista L., Zanella A., Zorzi M.: Long-Range Communications in Unlicensed Bands: The Rising Stars in the IoT and Smart City Scenarios, *IEEE Wireless Commun.*, vol. 23, no. 5, pp. 60–67, 2016.
3. Hellan S.: CC13xx Long Range Modes, Texas Instruments, Tech. Rep. SWRA642, Dec. 2018.
4. Spörk M., Boano C.A., Römer K.: Performance and Trade-offs of the New PHY Modes of BLE 5, in *Proc. ACM MobiHoc Workshop on Pervasive Systems in the IoT Era (PERSIST-IoT)*, New York, NY, USA, 2019, pp. 7–12.
5. Bor M., Roedig U.: LoRa Transmission Parameter Selection, in *Proc. 13th Int. Conf. on Distributed Computing in Sensor Systems (DCOSS)*, 2017, pp. 27–34.
6. Maj J., Eljasz D., Piotrowski K.: Analysis of Communication Parameters for Chosen LP-WAN Standards, in *Proc. 13th Conf. on Measurement Systems in Research and in Industry (MS)*, Zielona Góra, Poland: University of Zielona Góra, Institute of Metrology, Electronics and Computer Science, 2020, pp. 57–60.
7. Bindel S.: Study of Transmission Parameters in LoRa, 2020. [Online]. Available: <https://hal.science/hal-05489747v1/file/main.pdf>. [Accessed: Apr. 22, 2026].
8. Finnegan J., Brown S.: An Analysis of the Energy Consumption of LPWA-based IoT Devices, in *Proc. IEEE Int. Symp. on Networks, Computers and Communications (ISNCC)*, Rome, Italy, 2018, pp. 1–6.
9. Wunsch F., Maier K., Jäkel H., Jondral F.K.: Implementation and Performance Evaluation of IEEE 802.15.4 LECIM DSSS PHY at 2.4 GHz, in *Proc. GNU Radio Conf. (GRCon)*, San Diego, CA, USA, 2017.
10. Froberg M, Langendörfer P.: Demonstration of WISDOM - a Wireless in Field Measurement and Debugging Platform for Wireless Sensor Networks and Devices, *MEConet Journal: Works in Progress in Embedded Computing (WiPiEC)*, vol. 6, no. 1, p. 2, Jul. 2021.