Energy Consumption Evaluation of LoRa Sensor Nodes in Wireless Sensor Network

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***Abstract*—The battery life of sensor nodes in a wireless sensor network (WSN) is usually limited. In most Internet of Things (IoT) applications, sensor nodes must operate reliably for a longer duration. Energy efficiency is crucial for extending the lifetime of sensor nodes. In addition, the radio settings should withstand a better data rate transmission while maintaining energy efficiency. LoRa/LoRaWAN is a low-power wide-area network (LPWAN) technology that has recently received a lot of interest. This work proposes a LoRa-based energy consumption model that can be used to estimate the amount of energy each sensor node element in a WSN consumes. The effect of sensing interval and spreading factor on battery lifetime is discussed to determine its effects, when used for field application.**

***Keywords*—LoRa, LoRaWAN, Energy consumption, Battery lifetime.**

I. Introduction

Long Range (LoRa) is a LPWAN technology used for the Internet of Things (IoT) application. It has gathered a lot of traction in the industry and research world in the last few years. LoRa, a patented technology developed by Semtech, uses chirp spread spectrum modulation to transport data, promising extended battery life, large communication distances, and a high node density at the expense of transmission throughput. The IoT, is a group of Internet-connected devices that are typically characterised by their minimal complexity and low power consumption, such as battery-powered sensors [1]. Wireless networks face additional requirements and constraints as a result of these IoT devices. Depending on the region of operation, most LPWAN works in the unlicensed Industrial, Scientific, and Medical radio bands of 433, 868/915 MHz, and 2.4 GHz. SigFox, LoRa, Weightless, and Ingenu are some of the most prominent LPWAN technologies.

The success of LoRa can be attributed to a variety of features and performance guarantees. First, LoRa makes use of the unlicensed ISM frequencies, promising kilometres of communication range and years of battery life. Second, LoRa uses a variant of Chirp Spread Spectrum (CSS) [2] technology that, according to Semtech, is resistant to multi-path and Doppler effects, as well as a high degree of interference. The data is passed through a chirp modulator for binary chirp modulation, which translates each bit chunk to one of two waveforms. The data signal $m(t)$ is defined as,

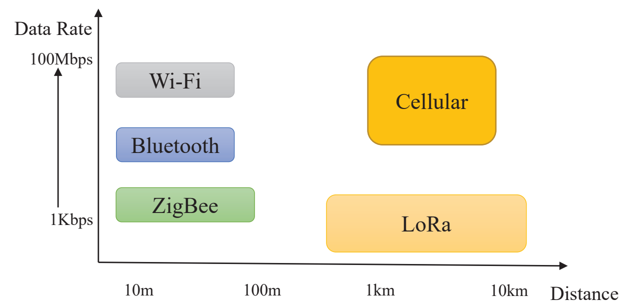

Fig. 1: The comparison of conventional technologies with LoRa.

$$m(t) = \sqrt{\frac{2E_m}{T_m}}\cos[2\pi f_c t \pm \pi(u(\frac{t}{T_m}) - w(\frac{t}{T_m})^2)]. \quad (1)$$

where E_m denotes the energy of $m(t)$ in the symbol time T_m and f_c is the carrier frequency. u and w denotes the peak-to-peak frequency variation and sweep width.

$$T_m = \frac{2^{SF}}{BW}. \quad (2)$$

where SF is the spreading factor and BW is the bandwidth.

A. Parameters of LoRa

The four crucial parameters of LoRa are channel, bandwidth, spreading factor, and transmission power. LoRa uses the ISM band, with bandwidth options such as 125 KHz, 250 KHz, and 500 KHz. The spreading factor (SF), or angle of chirps, remains constant throughout the packet. The spreading factor determines the actual data rate for a system with fixed frequency bandwidth. LoRa modulation supported six different spreading factors at the time, extending from SF7 to SF12. The transmission power can take values from 2 dBm to 20 dBm as shown in Table I. The network server controls the LoRa MAC layer, which is essentially an ALOHA protocol. Due to the orthogonality of transmission sub-bands and quasi-orthogonality of spreading factor, the gateways can receive signals from numerous end-devices at the same time [3]. In LoRaWAN, the static node have an Adaptive Data Rate (ADR) mode that is responsible of radio resource management and runtime link modification for individual end nodes. If

TABLE I: Key parameters of LoRa

Sl.No	Parameters	Values
1	Spreading factor	7-12
2	Coding rate	4/5,4/6,4/7,4/8
3	Frequency	433, 868, 915 MHz
4	Bandwidth	125, 250, 500 KHz
5	Transmit power	2-20 dBm

an end node detects a large number of consecutive uplink broadcasts without a downlink response from the network, it assumes that the network is down and fixes the problem by gradually increasing its transmit power and spreading factor. The values of these parameters affect the network size, deploying environment, and the amount of link variation, as well as the time, it takes for the end node to converge to a state in which it can successfully reinstate a reliable link to the network.

II. Related Works

Supply chain management, logistics, fleet management, animal tracking, structural health monitoring [4] and other dynamic IoT-based applications are becoming more prevalent in daily life [5], [6], [7]. The innovative and integrated notion of IoT technology necessitates the development of networks and systems that are both sustainable and energy efficient [8]. As a result of this demand, IoT is looking for green solutions, and Green IoT has transformed the industry. Several energy efficient strategies are employed in applications to make them self-sufficient and sustainable [9], [10]. To build a reliable connection in LoRaWAN, an adaptive data rate approach [3], [11] is employed, which changes the transmit power and SF according on the network conditions. When the end nodes do not get a downlink response for the next uplink, the connection is assumed to be lost. As a result, the transmit power and spreading factor will be increased. This algorithm minimises the end node's power usage by adjusting transmit power according to the link situation. In [12], a battery-free deployment of LoRa devices using capacitors rather than batteries is addressed. The energy collected from the environment is stored in small capacitors, which eliminates the battery's negative environmental effects. Another technique used in this study is energy-aware sensing, in which the device shuts down when the collected power is low and resumes detecting once the power requirement is reached. The device can sense even at low power because LoRa technology is low power and long range. A deep neural network and LoRa communication are proposed in [13] for an energy efficient river water pollution monitoring system. In [14], an adaptive transmission power control algorithm is proposed for an energy aware transmission. In [15], the energy profiling of IoT node reveals that transmission power contributes a major share in the energy drain. These studies shows that energy consumption and battery lifetime has significant relevance in IoT applications.

III. Analysis of energy consumption

The choice of transmit power has a significant impact on the end node's energy usage. The LoRa nodes' transmit power can be adjusted from 2 dBm to 20 dBm. Usually, 14 dBm is the default power used for the majority of practical applications [16]. One of the most difficult design and implementation challenges for communicating sensors is energy consumption.

Another thing to consider when calculating energy is the time on air (ToA), also known as transmission time. The time it takes for a signal from the sender to reach the receiver, indicated as t, is known as ToA. The LoRa packet's ToA is the sum of the preamble and payload durations.

$$t = t_{pr} + t_{pd}. \tag{3}$$

The preamble duration is expressed as:

$$t_{pr} = (4.25 + N_p) * (2^{SF})/BW. \tag{4}$$

The duration of the payload is defined as:

$$t_{pd} = P_{sy} * (2^{SF})/BW. \tag{5}$$

$$P_{sy} = 8 + \max(ceil(\tfrac{8PL-4SF+44-20H}{4*(SF-2DE)})* (CR+4), 0). \tag{6}$$

The number of preamble symbols is indicated by N_p, which is set to 8 by default. The length of the payload (in bytes) is indicated by PL, with SF indicating the spreading factor, BW indicating bandwidth, and CR indicating coding rate. The presence of a physical header is indicated by H, while the usage of low data rate optimization is indicated by DE.

The energy consumption for a transmit power P_t with time on air (ToA) t is defined as,

$$E(t) = P_t * t. \tag{7}$$

Energy per useful bit, E_b for payload size PL is defined as:

$$E_b = \frac{E(t)}{8 * PL}. \tag{8}$$

The data rate R_s, is defined as:

$$R_s = SF * \frac{CR}{2^{SF}} * BW * 1000. \tag{9}$$

Energy consumption in terms of data rate is expressed as:

$$E_s = \frac{PLx}{R_s} * V * I. \tag{10}$$

where PLx is the packet length.

IV. Life time of a sensor node

As LoRa end-devices are battery-powered, it is considered that they would transmit at regular intervals to extend their life. After each transmission period, the monitoring devices are put to sleep until they are measured again [11]. Let the sensing interval, Ts, be the time between two consecutive monitoring slots of a LoRaWAN device.

$$E_{total} = V * I_i * t_i, \quad i \in \{tx, rx_1, rx_2, sleep, s_1, s_2, s_3\} \tag{11}$$

The voltage of the LoRa device is V, and the current and time taken in transmit mode, sleep, first and second receive

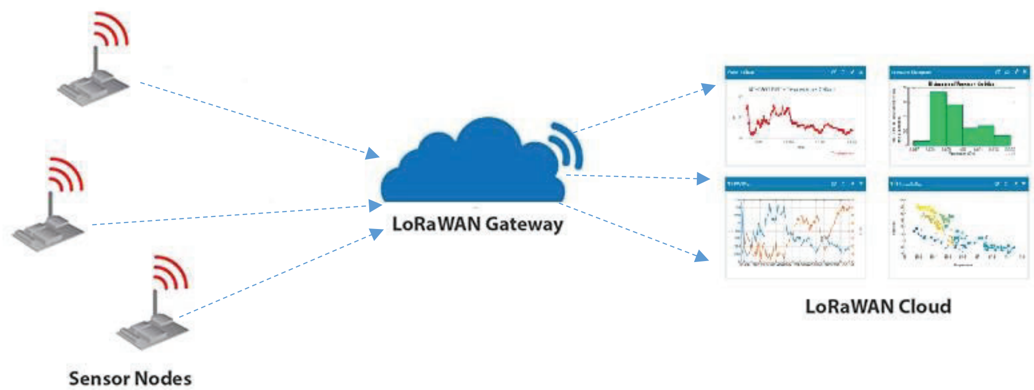

Fig. 2: The architecture of LoRaWAN with sensor node and gateway as in a practical application.

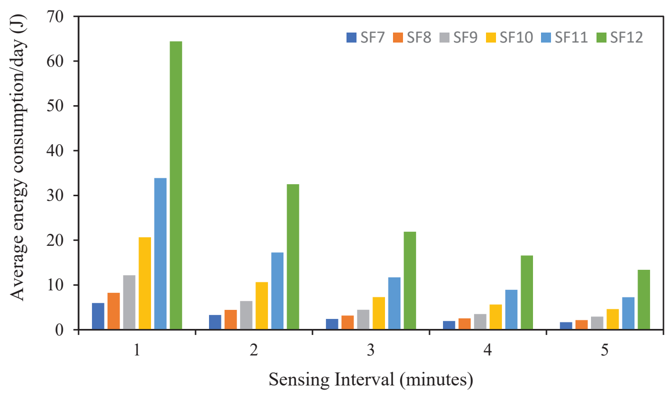

Fig. 3: The average energy consumption in a day with varying sensing interval.

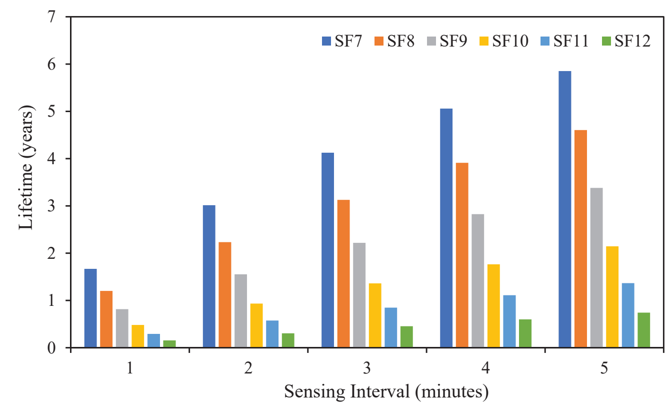

Fig. 4: The battery lifetime for different sensing interval and spreading factor.

windows of the end node are $I_i, t_i \in tx, rx_1, rx_2, sleep$. The current and time corresponding to the sensors utilised for the LoRa monitoring device are $I_i, t_i \in s_1, s_2, s_3$ as shown in Fig.2. Let $E_{average}$ be the average daily energy use, so that the battery life of the system with a 1100 mAh battery is stated as [17]:

$$BL = Capacity_{(bat)}/E_{(average)} \tag{12}$$

V. Result and Discussion

This section discusses the battery life and energy consumption of an IoT enabled sensor system and the various parameters depending on its energy drain. The parameters of LoRa have a significant impact on the battery lifetime of the sensor node. The present study considers spreading factor of LoRa and sensing interval of the device. After each transmission, the monitoring devices are put to sleep until the next sensing and the sensing interval is the period between two successive monitoring slots. In [18], the study the battery life of LoRa on various scenarios is discussed where the variation of spreading factor is considered and the sensing interval is disregarded. The average energy consumption in a day with varying sensing interval is shown in Fig.3. The effect of spreading factor is also estimated that shows that energy consumption increases with an increase in spreading factor. As depicted in Fig.4, the excess amount of energy

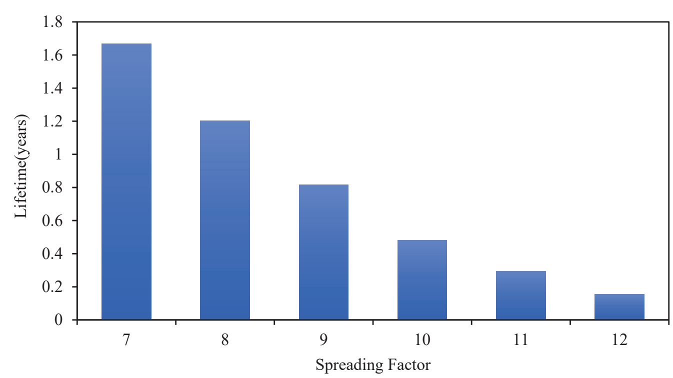

Fig. 5: The battery lifetime for varying spreading factor.

is capable of extending the battery life several times as the sensing interval increases from 1 to 5 minutes. As we increase the sensing interval from 1 to 5 minutes, the system is capable of extending the battery life by a significant margin. The life time calculation of the battery is shown in Fig. 5 for a sensing interval of 60 seconds. For spreading factor of 7, the battery life is 1.7 years which decreases with increase in spreading factor.

VI. Conclusion

The energy saving schemes and techniques are very important in LPWAN technologies as it determines the lifetime of the sensor node when it comes to practical application. The paper discusses about the significance of LoRa based systems in IoT enabled applications. The energy consumption and lifetime of a LoRa sensor node is discussed along with its influence on sensing interval and spreading factor. As the spreading factor increases from 7 to 12, the lifetime of the battery decreases from 1.7 years to 2 months. Also, for a spreading factor of 12, the energy consumption per day decreases with the increase in sensing interval, and battery lifetime improved to a maximum of 6 years. The study shows that the average energy consumption increases and lifetime of the battery decreases with decrease in sensing interval and increase in spreading factor. Future research activities can focus on optimizing these parameters using suitable optimization techniques.

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