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# Optimization of IoT Sensor Node Power in LoRaWAN Networks

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**Abstract.** LoRaWAN is becoming popular for IoT deployments worldwide and it is deployed in 143 countries by 133 network operators as of now. LoRa technology uses Chirp Spread Spectrum (CSS) with different Spreading Factors (SF), which makes it possible to achieve a range of several kilometers. However, the recent IoT applications require frequent transmission of data which, leads to long transmission times by the nodes and increases energy requirement. Power consumption is a critical factor for sensor nodes to last long in the filed. There are many LoRa parameters that can be fine-tuned to provide optimum performance with less energy consumption. In this paper, we analyzed several key parameters that affect power consumption and provide a methodological approach to optimize the sensor node power.

**Keywords:** LoRa, LoRaWAN, IoT, Sensor Power Optimization.

## 1 Introduction

LoRaWAN is a popular LPWAN (Low Power Wide Area Network) technology because of its long-range communication coverage, longer battery lifetime and low cost of deployment. LoRaWAN uses proprietary physical layer technology called LoRa (short for Long Range). LoRa nodes have the capability to last longer even up to 10 years in the LoRaWAN network with few messages per day [1, 2]. Because of the rapid growth of the IoT technologies in recent years, more IoT applications and various sensor nodes are introduced every day by researchers and industries for various needs. However, in many emerging applications, the sensor nodes are required to transmit data very frequently [3] to meet the current market demand, and these frequent transmissions and higher data requirements lead to reduced battery life.

Number of papers are published to estimate the power consumption in LoRa nodes [4 - 7] and some researchers are proposed methods to optimize power consumption [8 - 9]. However, none of the researchers considered non-linearity in the LoRa transceiver's current consumption at various RF power levels into their studies to optimize the node power consumption. In addition, LoRa gateway receiver sensitivity also plays a vital role in determining the node transmit power thus affecting power consumption. The receiver sensitivity is associated with the spread factor (SF) settings.

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In this paper, propose an approach to improve the LoRa node battery life by optimizing Spread Factors (SF) and node transmits power level assignments. We also take account of the non-linearity of the LoRa transceiver module and the receiver sensitivity to optimize power consumption.

## 2 Modeling LoRaWAN Sensor Node Current Consumption Profile

In order to calculate and optimize the node's battery life, first the current consumption needs to be mathematically modeled because the node goes through several stages of activities which determine the power consumption. These stages are shown in Fig. 1 for a typical LoRaWAN transmission [4]. States and variables of nodes are shown in Table I.

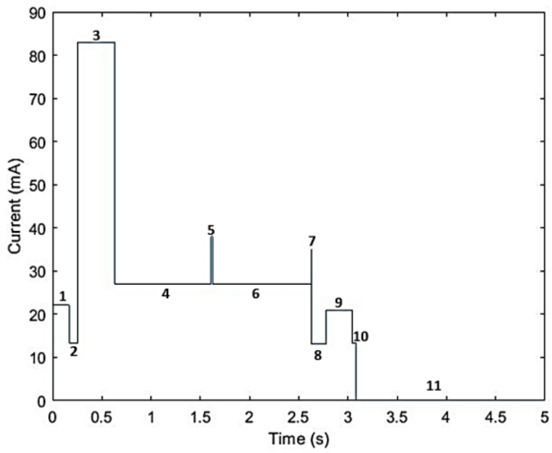


**Fig. 1.** Current consumption profile of a LoRa node[3].

As shown in Table 1, it can be seen that the node is active for all states except the sleep interval. Let $T_{active}$ denotes node active time. Then from [4]:

$$T_{active} = T_{wu} + T_{pre} + T_{pkt} + T_{w1w} + T_{rx1w} + T_{w2w} + T_{rx2w} + T_{off} + T_{post} + T_{seq} \quad (1)$$

It should be noted here that, for an unacknowledged LoRaWAN transmission, packet transmission time ($T_{pkt}$) is the key variable that changes the $T_{active}$ duration significantly.

The parameter $T_{pkt}$ can be calculated using the following equation [10]:

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$$T_{pkt} = \left(N_{pre} + 4.25 + (8 + max[ceil[TEMP](CR + 4), 0])\right)\left(\frac{2^{SF}}{BW}\right) \quad (2)$$

where, $TEMP$ is a temporary variable that is given by:

$$TEMP = \frac{(28 + 8PL + 16CRC - 4SF - 20IH)}{4(SF - 2DE)}$$

Here *PL* is the payload size (bytes) and *SF* is the LoRa spreading factor (7-12). *CRC* takes the value of '1' if used and '0' otherwise. Implicit Header value *IH* is '1' in implicit header mode and '0' otherwise. *DE* is '1' if the data rate optimization value is used and '0' otherwise. The *CR* is the coding rate from 1 to 4. $N_{pre}$ is the number of programmed preamble symbols. *BW* is the bandwidth of the channel.

**Table 1.** States and variables for LoRaWAN unacknowledged transmission.

| State | Description | Duration | Current |
|---|---|---|---|
| 1 | Wake Up | $T_{wu}$ | $I_{wu}$ |
| 2 | Radio Preparation | $T_{pre}$ | $I_{pre}$ |
| 3 | Packet Transmission | $T_{pkt}$ | $I_{pkt}$ |
| 4 | Wait First Receive Window | $T_{w1w}$ | $I_{w1w}$ |
| 5 | First Receive Window | $T_{rx1w}$ | $I_{rx1w}$ |
| 6 | Wait Second Receive Window | $T_{w2w}$ | $I_{w2w}$ |
| | Second Receive Window | $T_{rx2w}$ | $I_{rx2w}$ |
| 8 | Radio Turn Off | $T_{off}$ | $I_{off}$ |
| 9 | Post Processing | $T_{post}$ | $I_{post}$ |
| 10 | Turn Off Sequence | $T_{seq}$ | $I_{seq}$ |
| 11 | Sleep | $T_{sleep}$ | $I_{sleep}$ |

Packet transmission time, $T_{pkt}$, for various payloads ($PL$) is shown in Fig. 2. It can be seen that packet transmission time increases with increasing spread factors as well as the $PL$ sizes.

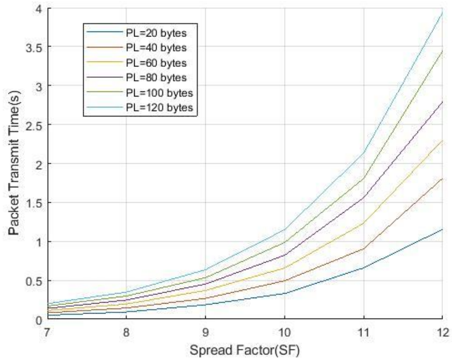


**Fig.2.** Packet transmission time, $T_{pkt}$, for various payloads (PL).

Node's sleep duration is denoted as $T_{sleep}$. This duration will vary depending on the node transmission interval (duty cycle) settings. So one cycle time of the node, $T_{cycle}$ is given by:

$$T_{cycle} = T_{active} + T_{sleep} \tag{3}$$

Nevertheless, as shown in Fig. 1, each state consumes different current levels. Therefore, the average current consumption, $I_{ave}$, for unacknowledged LoRaWAN transmission can be calculated as follow:

$$I_{ave} = \frac{1}{T_{active}+T_{sleep}} \sum_{i=1}^{N_{states}} T_i . I_i \tag{4}$$

where, $N_{states}$ is the 11 states in the transmission sequence.

Fig. 3 shows the calculated average current consumption comparison for various payloads and SF parameters at $T_{cycle} = 60\ sec$s with $I_{pkt} = 80\ mA$. It can be observed that the node's average current consumption doesn't vary much with the PL sizes at lower SFs (i.e *SF 7 and 8*). However, the node's average current consumption varies significantly with PL sizes at higher SFs (i.e *SF 12*). Therefore, SF and PL parameters significantly affect the battery life of the node. For a longer node's battery life, these parameters should be carefully chosen.

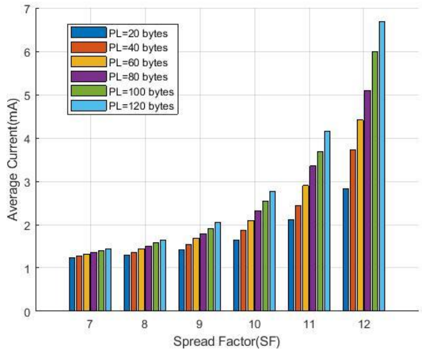


**Fig.3.** Average current consumption comparison for various payloads at *60 secs* node transmission intervals with *80 mA* transmit current.

## 3 LoRa Transceiver RF Power Level and Current Consumption Relationship

RF output power of LoRa modules can also be changed to a desired level. For example, LoRa transceiver module SX1272 from Semtech supports 0 dBm to 20 dBm RF outputs. Fig. 4 shows the relationship between the RF power level and the current consumption of the SX1272 LoRa transceiver module. It can be seen from Fig. 4, that the transmission current, $I_{pkt}$ increases with the RF power setting in a nonlinear manner. It is interesting to note that the transmission current is almost constant when the power level setting is less than 13 dBm level. After the 13 dBm level, the current consumption increases 4 times, from 30 mA to 120 mA. Therefore, we can define a desired operating region as shown in Fig. 4 for longer battery life.

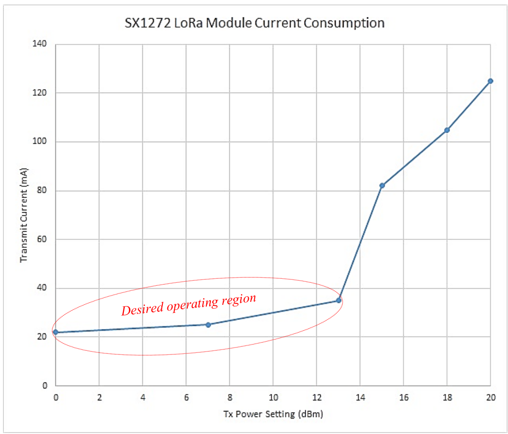


**Fig. 4.** Current consumption of the SX1272 LoRa Module [Obtained from SX1272 LoRa Modem Calculator].

Next, the average current consumption was calculated for various power levels with $PL = 40\ bytes$ and $T_{cycle} = 60\ secs$ to visualize the effect of transceiver nonlinearity. Fig. 5 shows the average current consumption variation with RF power level setting for different SFs.

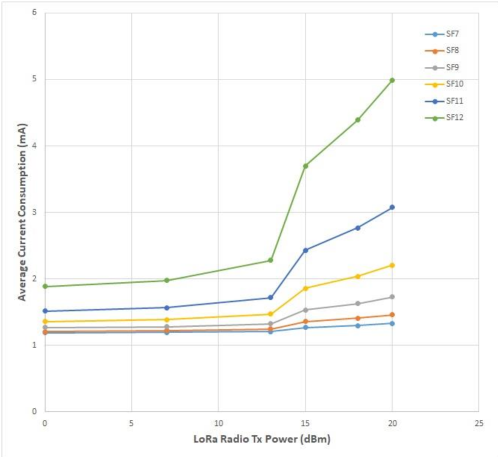


**Fig. 5.** Average current consumption comparison for various LoRa radio transceiver power level settings with PL = 40 bytes.

## 4 Optimal LoRa Transceiver Power Level and SF Selection

From Fig. 5, it is clearly visible that LoRa transmission with *SF=7* will consume less battery power compared to other SF settings with the same PL conditions. Battery current consumption increases with SF. On the other hand, higher SF transmission (eg. *SF=12*) requires less receive power at the receiver (higher receiver sensitivity). So, receiver sensitivity is also be taken into consideration when determining the power level and SF for a node.

A LoRa signal can be decoded at the gateway when the received power is higher than the LoRa receiver sensitivity. The LoRa receiver sensitivity is dependent on the SF and BW combination [10] and the receiver sensitivity values are shown in Table 2 [Calculated using Semtech LoRa Modem Calculator Tool].

**Table 2.** LoRa Reciever Sensitivities.

| | Receiver Sensitivity (dBm) | | |
|---|---|---|---|
| SF | BW = 125 kHz | BW = 125 kHz | BW = 125 kHz |
| 7 | -123 | -120 | -117 |
| 8 | -126 | -123 | -120 |
| 9 | -129 | -126 | -123 |
| 10 | -132 | -129 | -126 |
| 11 | -134.5 | -131.5 | -128.5 |
| 12 | -137 | -134 | -131 |

Based on the above analysis and RF link budget calculation, the optimum transmitter parameter selection graph was generated for a fixed PL size of 40 bytes. It is shown in Fig. 6. The graph shows the average power consumption variation with the power margin at the receiver for different SFs. Note that different SFs have different sensitivity as per Table 2. For example, to get a 16 dB RF margin, $SF = 8$ will be the optimized spread factor with the lowest power consumption as indicated with the red arrow in Fig. 6. Based on this graph, optimal SF and the transceiver RF power level can be chosen depending on the power margin requirement of the wireless channel for 40 bytes of PL.

## 5 Conclusion

This study provides a methodical approach to optimize the LoRa sensor node power consumption considering various spreading factors, transceiver current profile, RF power levels, and receiver sensitivities. Optimum transmission parameter selection graph was obtained for fixed PL and duty cycle (DC) conditions. The graph will help us to choose the optimum LoRa transmitter parameters for a given wireless channel condition between the sensor node and the receiver. A similar approach can be applied for various PLs, duty cycles (DC) and bandwidth (BW) parameters to obtain the optimum power setting.

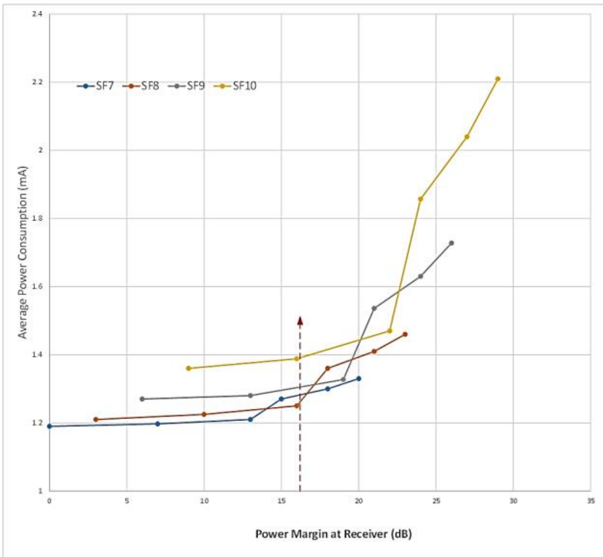


**Fig. 6.** Optimum transmission parameter selection graph.

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