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Algorithm for ensuring the minimum power consumption of the end node in the LoRaWAN network

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ABSTRACT

The paper approves the relevance of the development of theoretically justified tools aimed at power consumption minimization in the data transmission network of the LoRa WAN standard. Such a network is used to monitor various objects in a distributed system of the Internet of things. LoRa WAN end nodes have autonomous power supplies, for which energy costs saving is important. The paper presents expressions for estimating the power consumption of a LoRa WAN end node. Based on the results of computational experiments, a database was formed containing signal attenuation values and their corresponding recommended values of transmitter power and spectrum spreading factor. This database is used in the algorithm for ensuring the minimum power consumption of the end node.

Keywords: LoRa WAN, power consumption, network end node, signal attenuation, signal-to-noise ratio, spreading factor, transmitter power.

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1. Introduction

In recent years, much attention has been paid to the improvement of wireless communication systems, especially self-organizing networks[1]–[6], radio networks based on unmanned aerial vehicles[7]–[11], networks for monitoring territories and specific objects[12]–[14]. Based on wireless technologies, the Internet of Things (IoT) [15]–[18], smart city [19], [20], and precision agriculture [21]–[25] systems are being created, which are designed to collect, process and analyze data obtained from numerous low-power sensor transmitting devices.
IoT systems are built on data networks with low power consumption. A common standard for such networks is LoRa WAN [26]. LoRa WAN nodes are designed for low-speed data exchange. They have autonomous power supplies that operate for a long time without replacement or recharging [27]. In this regard, the task of minimizing power consumption during the operation of LoRa WAN network nodes is relevant.
The analysis showed that the methods proposed by the developers that are used in practice to reduce the energy costs of sensor nodes have a number of disadvantages. Some of them are based on the use of heuristic algorithms that have insufficient theoretical justification, others require the formation of massive training data and the implementation of cumbersome neural network tuning procedures[28]–[30].

2. Research method

The paper aims to develop an algorithm for ensuring the minimum power consumption of the end node in the LoRa WAN network. This algorithm should be based on the use of adequate computational models.
Estimating the power consumption of the end node of the LoRa WAN network
During the operation of the LoRa WAN network, messages are delivered at a specified frequency by means of frame transmission from the end node to the gateway node. In this case, the delivery of each message is accompanied by the power consumption of the end node. You can calculate this value, measured in watt per hour, using the following expression:

$$EC = ANF \cdot TFRM \cdot TP_{mW} \cdot 10^{-3} \qquad (1)$$

where ANF – average number of frames required to deliver a message;

$TFRM$ – frame transmission duration, H;

TP_{mW} – end node output power, mW.

The information contained in the message is transmitted from the end node to the gateway node in the form of a frame. On a correctly received frame, the gateway node sends an confirmation frame to the end node. Upon receipt of such a confirmation, the message is considered successfully delivered. If, within the specified time, the end node does not receive an confirmation for the previously sent frame, then the end node retransmits this frame. To avoid congestion, the number of retransmissions should not exceed some allowable value . The average number of frames required to deliver a message can be calculated using the formula:

$$ANF = d_1^n + 2 \cdot d_2^n + 3 \cdot d_3^n + ... + (n+1) \cdot d_{n+1}^n \qquad (2)$$

where n – natural number;

d_1^n , d_2^n, …, d_{n+1}^n – the probability of delivering a message using 1, 2, …, $(n+1)$ frames respectively at $NRT = n$

The probability of delivering a message with 1 frame with can be calculated using the formula:

$$d_1^n = p \cdot a \qquad (3)$$

where p – frame delivery probability;

a – confirmation delivery probability.

The probability of delivering a message with 2 frames with can be calculated using the formula:

$$d_2^n = p \cdot a \cdot \left[p \cdot (1-a) + (1-p) \right] \qquad (4)$$

To calculate the probability of message delivery in the sensor network using ($n+1$) frames, the following expression can be used:

$$d_{n+1}^n = p \cdot a \cdot \left[p \cdot (1-a) + (1-p) \right]^n \qquad (5)$$

Calculation of quantities and , used in (3) – (5), should be done with expressions:

$$p = (1-BER)^{LFRM} \qquad (6)$$

$$a = (1-BER)^{LACK} \qquad (7)$$

where BER – bit error probability in data transmission.

$LFRM$ – frame bit length.

$LACK$ – confirmation bit length.

The value of the bit error probability during data transmission can be calculated using the Q-function according to the empirical formula [31]:

$$BER = 0{,}5 \cdot Q\left[\sqrt{SNR \cdot 2^{SF+1}} - \sqrt{1{,}386 \cdot SF + 1{,}154} \right] \qquad (8)$$

where SNR – signal-to-noise ratio at the input of the receiving device of the gateway node.

Value , which shows how many times the signal level exceeds the noise level at the input of the receiving device of the gateway node, can be calculated by the formula:

$$SNR = \frac{RP \cdot 10^{-3}}{k \cdot TEMP \cdot W \cdot NF} \qquad (9)$$

Where RP – signal power at the input of the receiving device of the gateway node, mW;

$k = 1,38 \times 10^{-23}$ – Boltzmann constant, J/K.
$TEMP$ – temperature.
W – channel bandwidth.
NF – receiver noise ratio.

The strength of the signal received by the gateway node can be calculated using the following expression:

$$RP = 10^{\frac{TP+A}{10}} \quad (10)$$

where A – signal attenuation during its transmission from the end node to the gateway node, dB;
TP – end node output power, measured in dBm.

To convert output power values measured in dBm to values measured in mW, use the expression:

$$TP_{mW} = 10^{TP/10} \quad (11)$$

The value of the Q-function can be calculated using the following expression:

$$Q(x) = \frac{1}{\pi} \cdot \int_0^{\frac{\pi}{2}} e^{\left(\frac{-x^2}{2 \cdot \sin^2 t}\right)} dt \quad (12)$$

where x – Q-function argument.
t – integration parameter.

The frame transmission duration in hours is calculated by the formula:

$$TFRM = \frac{T_{ms} \cdot 10^{-3}}{3600} \quad (13)$$

where T_{ms} – frame transmission duration, measured in ms.

T_{ms} takes the values presented in Table 1 and depends on the spectrum spreading factor set during signal transmission SF [32]:

Table 1 – Frame transmission duration values depending on the spectrum spreading factor

SF	T_{ms}, ms
7	53
8	88
9	177
10	313
11	627
12	1187

To ensure a high probability of message delivery and minimize the power consumption of end nodes, it is necessary to choose the right values for the output power of the end node and the spreading factor of the transmitted signals.

3. Results and discussion

Expressions (1) - (13) are used to conduct computational experiments to estimate the energy consumed by the end node in the process of message transmission. As a result, we have the values that EC takes depending on the values A, TP and SF. An example of such data is presented in Table 2. Cells with dashes in this table correspond to cases in which the signal level at the input of the gateway node is lower than the sensitivity of the receiving device. The remaining cells in the tables correspond to such values of the quantities A, TP and SF, under which the probability of delivering a message is higher than 0,95.

Table 2 - Values × 10-7 (W/h) at dB

TP, dBm	*SF*					
	7	8	9	10	11	12
2	-	-	-	-	3,05	5,23
5	-	-	-	2,95	5,51	10,43
8	-	-	3,24	5,49	10,99	20,80
11	-	3,15	6,19	10,95	21,93	41,51
14	3,74	6,14	12,35	21,84	43,75	82,82

The results obtained are recommended to be used in the process of selecting signal parameters in the LoRaWAN network. So, for example, if $A = -137$ dB, then the final node should be set $TP = 5$ dBm and $SF = 10$, because in this case, the power consumption of the node will be minimal ($EC = 2,95 \times 10^{-7}$ W/h).

Following this logic, the database “Signal attenuation A – transmitter power TP – spreading factor SF ”, the structure of which corresponds to table 3.

Table 3 – Database structure

Database line number	Signal attenuation	Transmitter power	Spreading factor
1	A_1	TP_1	SF_1
2	A_2	TP_2	SF_2
…	…	…	…
n	A_n	TP_n	SF_n
…	…	…	…
N	A_N	TP_N	SF_N

This database contains the following transmitter power values TP_n and spreading factor of the transmitted signal SF_n, the installation of which ensures the minimum power consumption of the end node during signal attenuation A_n.

3.1. Algorithm development

An algorithm has been developed to ensure the minimum power consumption of the end node in the LoRaWAN network. The block diagram of the algorithm is shown in Figure 1. The algorithm prescribes the following steps.

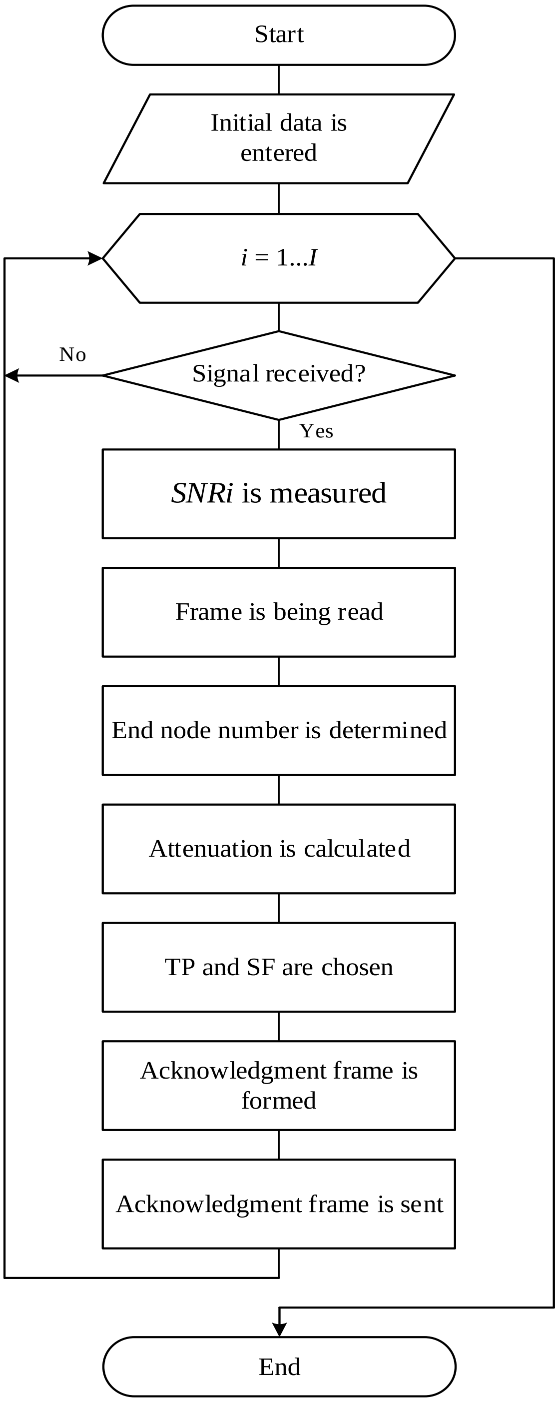

Figure 1 - Algorithm for ensuring the minimum power consumption of the end node in the LoRa WAN network.

Step 1. Input of initial data. Value T is entered – that is the maximum number of time slots. Number of the current time interval t is set as 0. Initial values of TP and SF are entered. The pre-formed database "Signal attenuation - transmitter power - spreading factor" is loaded.

Step 2. Time interval number t increases by 1. If the number of the current time interval exceeds the value T, then go to step 9.

Step 3. If the signal is accepted by the gateway node, go to step 4. Otherwise, return to step 2.

Step 4. At the input of the receiving device of the gateway node, the power of the received signal RP and value SNR is measured.

Step 5. The data frame received by the gateway node is read.

Step 6. The number of the end node from which the data frame arrived is determined.

Step 7. The current level of signal attenuation during frame transmission is calculated using the formula:

$$A = RP - TP \tag{14}$$

Step 8. From the previously formed database, the transmitter power and spreading factor values are selected that correspond to the current level of signal attenuation and are recommended for installation at the end node.

Step 9. An acknowledgment frame is formed in the gateway node, in which data on the recommended values TP and SF are entered.

Step 10. The generated acknowledgment frame is transmitted to the end node from which the data frame arrived. End of the algorithm.

4. Conclusions

LoRa WAN end nodes have autonomous power supplies, for which saving energy costs is important. The algorithm presented in the article makes it possible to ensure the minimum power consumption of the end node in such a network. The algorithm uses a database containing signal attenuation values and their corresponding recommended transmitter power and spreading factor values. This database was formed based on the results of computational experiments carried out on the basis of theoretically substantiated mathematical models.

Further development of the stated study results will be the development of software for the implementation of the algorithm proposed in the paper.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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