APPLICATION TLBO ALGORITHM FOR LORAWAN OF SMART METER FOR RESIDENTIAL ELECTRICITY

ỨNG DỤNG THUẬT TOÁN TLBO CHO MẠNG CÔNG TƠ ĐIỆN THÔNG MINH DÂN DỤNG LORAWAN

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Abstract:

In this paper, the main objective is to design a smart meter to measure electricity consumption in households with communications based on LoRaWAN (Long Range Wide Area Network) wireless technology. Two devices have been designed, a Smart Meter for Electrical Energy in Households (SMEEH) and a LoRaWAN Network Supervisor (LNS), which optimises the LoRAWAN parameters using the teaching learning base optimisation (TLBO) algorithm. This algorithm allows obtaining the parameters' spreading factor (SF), bandwidth (BW), and code rate (CR) so that the minimum value of the packet loss rate (PLR) is reached, and the load profiles of the households are modelled in real time using cloud data storage. The algorithm implemented in the LNS determines the most appropriate parameters of the LoRaWAN by checking data traffic in real time. The data obtained by the household electrical energy measuring system are acquired through sensors. Load profiles of households obtained by measuring the voltage, current, and active power with LoRaWAN using algorithm TLBO are more accurate.

Keywords:

LoRa network, LoRaWAN, Smart Meter, Teaching-learning-based optimization algorithm (TLBO), Residential electricity.

Tóm tắt:

Trong bài báo này, mục tiêu chính là thiết kế một hệ thống công tơ điện thông minh để đo mức tiêu thụ điện trong các hộ gia đình với khả năng truyền thông dựa trên công nghệ không dây LoRaWAN (mạng không dây tầm xa). Hệ thống được thiết kế gồm hai thiết bị, một công tơ thông minh đo năng lượng điện trong hộ gia đình (SMEEH) và một thiết bị giám sát mạng LoRaWAN (LNS) giúp tối ưu hóa các thông số LoRAWAN bằng cách sử dụng thuật toán tối ưu TLBO. Thuật toán này cho phép lấy hệ số trải rộng (SF), băng thông (BW) và tốc độ mã (CR) của các tham số để đạt được giá trị tối thiểu của tỷ lệ mất gói (PLR) và dữ liệu tải của các hộ gia đình được mô hình hóa trong thời gian thực bằng cách sử dụng lưu trữ dữ liệu đám mây. Thuật toán được thực hiện trong LNS xác định các tham số thích hợp nhất của LoRaWAN bằng cách kiểm tra lưu lượng dữ liệu trong thời gian thực. Dữ liệu do hệ thống đo năng lượng điện gia dụng thu được thông qua các cảm biến. Dữ liệu tải của các hộ gia đình thu được bằng cách đo điện áp, dòng điện và công suất hoạt động với mạng LoRaWan sử dụng thuật toán TLBO là chính xác hơn.

Từ khóa:

Mạng LoRa, LoRaWAN, công tơ điện thông minh, TLBO.

1. INTRODUCTION

Nowadays, the measurement of electricity consumption in households using smart meters (SMs) via Internet of Things (IoT) in real time with data uploading to the cloud is essential. SMs measure and increase the information users receive from electricity companies. With this information, the homeowner can adapt consumption profiles to reduce their electricity bill. Adjusting energy consumption to off-peak hours helps to reduce overall consumption and the homeowner's carbon footprint. Smart technological solutions allow obtaining not only electricity consumption profiles, but also managing consumer's decisions and demand response (DR). Low Power Wide Area Network (LPWAN) is a specification that defines the requirements that devices have to comply with to operate in low energy Wide Area Network (WAN) in [1,2]. Long Range (LoRa) is a technology that makes a LPWAN private network with low-cost devices [3]. In recent times, there has been a wide diffusion of new LPWAN technologies, which has allowed the advancement of the IoT [4]. Most LoRaWANs (Long Range Wide Area Network) perform with fixed parameters that do not allow an optimal functioning of the network. The use of a sufficiently fast algorithm would allow the best solution. Using a Teaching-Learning-Based Optimization (TLBO) algorithm, this type of problem can be optimised This research designed two devices, the first one was the Smart Meter for Electrical Energy in Households (SMEEH), which was placed in the households to measure and send the data obtained in an adjustable time according to Duty Cycle (DC). The second device was the LoRa Network Supervisor (LNS); it receives the electrical data measured by the installed SMEEH and sends them to the cloud. The LNS optimises the LoRa network using a TLBO algorithm to obtain the lowest optimal value of the Packet Loss Rate (PLR). One of the main factors in the SM design was to obtain the Load Profiles (LP) of households. The wireless network was developed by sending the data collected for real-time processing and reducing the PLR, which would improve the efficiency by minimizing data loss to obtain the LPs in real time.

Different authors have investigated LoRa technology. Ali et al. [3] analysed the performance of the LoRaWAN on an indoor test-bank, considering data rates, communication range, energy consumption, and packet losses indoors. Juha et al. [4] developed the features of the LoRa's technology and the extension of the LoRaWAN. LoRa measurement data was collected throughout the city to characterize LoRa performance and coverage in reference [2]. In this respect, Hoeller et al. [6] presented the use of gateways and message replication with numerous receiving antennas to reach temporal and spatial ranges.

The efficiency of the LoRaWAN technology has been optimised in reference [6]. In this sense, Cano-Ortega [5] used an algorithm deduced from the ABC to optimize the performance of the LoRa network. Taha et al. [10] analysed the LoRaWAN, covering its functionality, integration, architecture, future challenges, current market, and the main development of the LoRaWAN transceiver. Moreover, Sánchez et al. [7] designed an intelligent public lighting system using a LoRaWAN that increases the energy efficiency of street lights. Sandoval et al. [14] developed a mathematical model of the LoRa network nodes that allows a full description of the operation of long-range IoT units. Lastly, Cano et al. [12] analysed the monitoring of the operation and efficiency of induction motors operating LoRa. Sánchez et al. [11] develop a device to control all of a power analyser and integrate the device into the LoRaWAN. The design of SMs to measure electrical energy consumption is fundamental, although most of the authors used devices already on the market. Benzi et al. [13] proposed the definition of a local interface for SMs, proposing solutions for the market by considering international and Viet Nam regulations. Other authors have also designed SMs. Minchala-Avila et al. [11] presented the design of SMs with DR capabilities, which provides communication between the SM installed in the households and the distribution management system and vice versa. Different methods have also been analysed to obtain the active power measured in real time. Kumar et al. [14] analysed a method that measures active power with traditional meters in real time, when recording less than 10 W.

2. SMART METER METHODOLOGY AND DESIGN

2.1. Proposed LoRaWAN Architecture

The proposed LoRaWAN architecture consists of the following: (i) The SMEEH exchanges information with the LNS with LoRa protocol; (ii) LNS uploads the data sent by SMEEHs to the cloud using TTN [12]; (iii) The TTN sends the received data to the MQTT (Message Queue Telemetry Transport) [15] and If This, Then That (IFTTT) [19] also a web hosting server, Google Sheets etc. TTN offers free versions that allow users to adapt the best profile for them. It is designed to operate with the LoRaWAN system and provides access to MQTT, IFFT, web hosting server, etc. These services allow the development of visualization interfaces according to the needs of each system. This device continuously monitors data traffic on the LoRaWAN looking for the best network configuration parameters for minimal data loss. SMEEHs located in different households measured and sent data to the LNS. Fig. 1 shows the LoRaWAN architecture of the system.

The configuration parameters of the LoRaWAN (bandwidth (BW), spread factor (SF), and code rate (CR)) have a decisive influence on the speed and modulation of data traffic. Noreen et al. tested the effect of configuration factors on speed and time transmission, and Phung et al. [17] developed an evaluation of their capacities versus their efficiency of the LoRaWAN. Several researchers, such as [16-17], tested different configuration parameters of a LoRaWAN. These parameters combined to provide various energy and transmission levels:

- BW: shows the frequency interval in the transmission range.
- SF: is the number of chips per symbol.
- CR: is the coding rate.

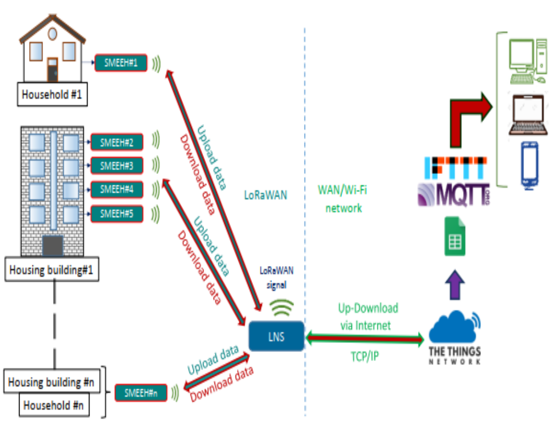

Figure 1. LoRaWAN architecture

The parameters used to calculate the nominal bit rate (in bits per second) is expressed in (1).

$$R_b = SF \times \frac{BW}{2^{SF}} \times CR \qquad (1)$$

Table 1. LoRaWAN Frequency Bands

Region	Uplink	Downlink
VN868	SF7BW125 to SF12BW125 and SF7BW250	SF7BW125 to SF12BW125 and SF7BW250 (RX1) SF9BW125 (RX2)
VN433	No frequency plan yet	
VN915	SF7BW125 to SF10BW125 and SF8BW500	SF7BW500 to SF12BW500 (RX1) SF12BW500 (RX2)
VN470	SF7BW125 to SF12BW125	SF7BW125 to SF12BW125 (RX1) SF12BW125 (RX2)

The Time on Air tToA for packets in a LoRaWAN using the LoRa modulation can be determined by Eq. (2):

$$t_{ToA} = \frac{2^{SF}}{BW}\left[(NP + 4{,}25) + \left(8 + \max\left[\left(\frac{28+8PL+16CRC-4SF}{4\times(SF-2DE)}\right) x(CR+4)\right]\right)\right] \qquad (2)$$

where, CRC denotes the existence 1, of the CRC field in the physical message, NP is the number of symbols, PL is the payload size and DE indicates the use of data rate optimisation. Sensitivity S is the inherent property of a system’s ability to extract information from signals.

It can also be quantified as the lowest possible signal strength that can trigger the system to its packet resolution.

where, S is receiver sensitivity in dBm, NF is the noise figure of a receiver in dBm, and SNR is the signal to noise ratio in dBm.

LoRaWAN devices in Viet Nam force a per channel DC limitation to cope with the regulations issued by the Viet Nam Telecommunications Standards. Table 1 shows the LoRaWAN frequency bands.

2.2. Hardware-Software Design

This section describes each of the devices used in this research. In addition, block diagrams are presented, which allow the connections between the components used in each device to be understood.

2.2.1. SMEEH Design

In this research, the SMEEH was designed and developed to measure the consumption of electricity in households using a LoRaWAN and store data in the cloud. The SMEEH is supported by the Arduino Nano [12] together with the Dragino LoRa Bee (DLB) [18] for accessing the LoRaWAN. The objective was to design a prototype that measures electrical variables with sensors to provide LPs from households using LoRaWAN communication. The designed SMEEH is modular, allowing the easy replacement of system components and expansion. Fig. 2 displays the SMEEH block diagram, including the components and the connection with the AN microprocessor. To determine the electrical parameters (v, i, and p), the SMEEH works with the PZEM-004t meter (PZEM) [7]. PZEM communicates with the AN board using digital input/output #11 and #12. The power supply voltage of the Arduino AN is 5V DC. An external power supply unit is used to supply the AN within the voltage limits.

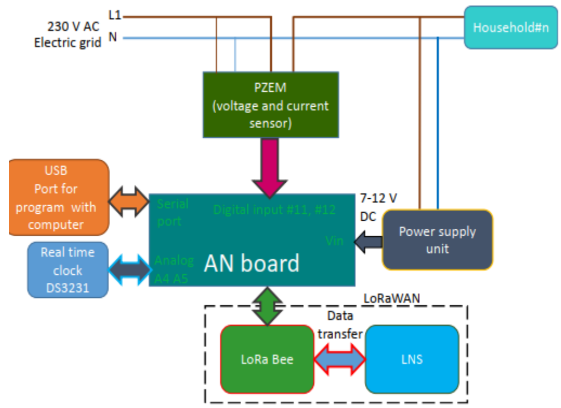

Figure 2. Hardware block diagram of SMEEH

2.2.2. SMEEH Program

To run the program that measures the electrical variables and sends the information to the LoRaWAN, the microcontroller AN is used. Fig. 3 shows the flow chart for the SMEEH. The process has several routines:

(i) It initializes the system.

(ii) Measure electrical variables with PZEM, if data received are correct, it is submitted to the cloud. After the measurement, waits for confirmation; if the message is not received, the reading process is repeated.

(iii) Examine LoRaWAN and obtain transmission data to confirm the received measurement data.

(iv) If the maximum time is exceeded, examine the LoraWAN and the device

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must submit a message to the LNS to execute the TLBO algorithm and look for the optimal configuration parameters of the LoRaWAN.

(v) If it is not correct, the LoRaWAN is scanned again until the confirmation message is received.

(vi) Look at the new parameter, change the message, and modify the network parameters.

This allows the system to adapt dynamically to always obtain the best performance in packet loss in a continuous manne.

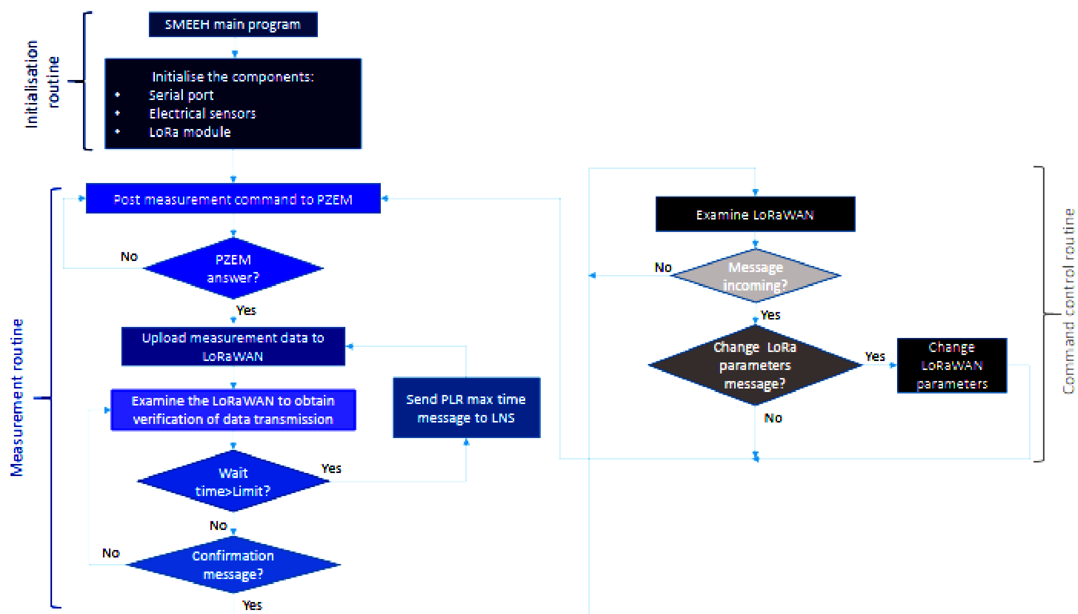

Figure 3. Flow chart of the SMEEH principal program

2.3. LNS Program

The LNS receives the messages of the measured electrical variables. It sends confirmation messages to the SMEEHs. If any SMEEH does not receive a confirmation message, it sends the LNS a message to run the TLBO algorithm to obtain new optimal network parameters. Once the TLBO is executed, the LNS sends the new parameters to all the SMEEHs. Fig. 4 shows the flowchart for the LNS. The device performs the following tasks cyclically:

(i) Initialization

(ii) Explore the Wi-Fi network

(iii) If a change message is received, it executes the TLBO algorithm to obtain optimal parameters LoRaWAN, changes LoRaWAN parameters and submits a new configuration to the connected SMEEHs.

(iv) Scan LoRaWAN to check for a message with SMEEH measurements.

(v) If there is a new message, identify SMEEH.

(vi) The data received from SMEEH are

sent to TTN service and then send a confirmation message to SMEEH.

The LNS is used to access the cloud, which communicates LNS devices with LoRa technology. There are different communication protocols to configure the LNS. In addition, the LNS for data transmitted with Internet access was designed in this research. In this paper, the TTN was chosen because it allows data integration with many possibilities at the programming level and access to many devices (tablet, PC, smartphone, etc.).

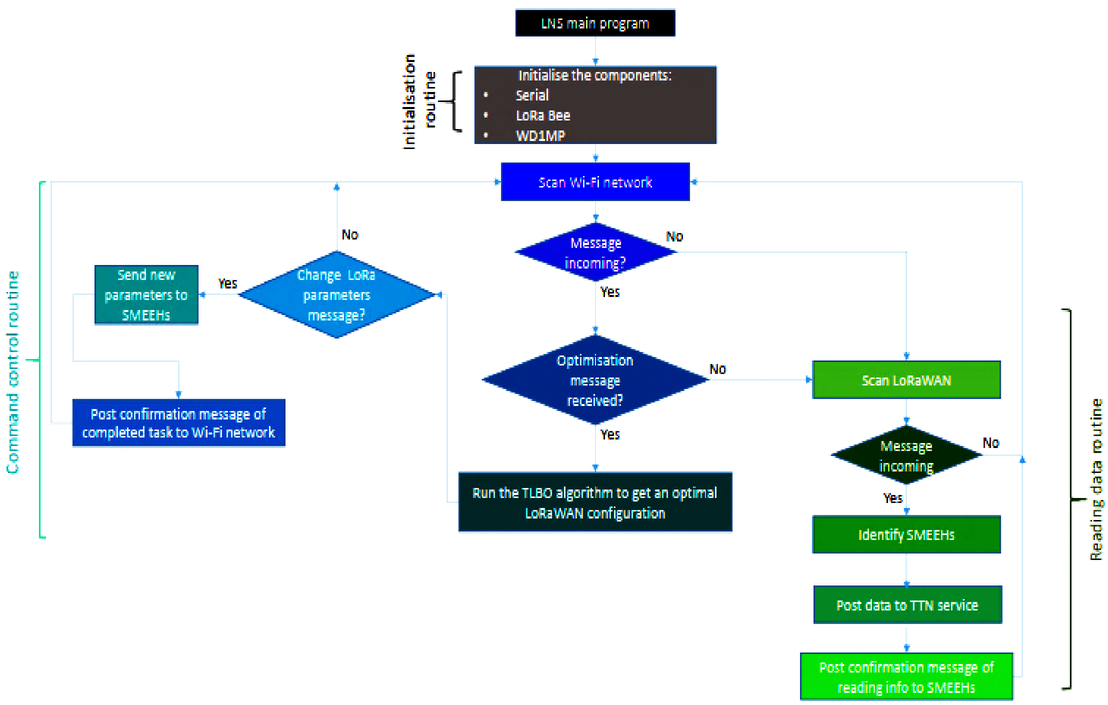

Figure 4. Flow chart of the LNS principal program

3. APPLICATION TLBO ALGORITHM FOR LORAWAN OF SMART METER

TLBO algorithm is used to solve high-level problems with an overall stochastic optimization algorithm supported by populations. By studying a group of students who offer several solutions along with the one indicated by the teacher, the optimal solution to the problem is obtained in reference [16]. The optimal solution is obtained by simulating the teaching process that exists between the students and the teacher. The most important properties of the TLBO algorithm are to indicate the limits of the population and the number of repetitions, but no specific search variables or performance are necessary. In order to do this, the TLBO is based on to main stages, the student stage (learning phase) and the teacher stage (teaching phase).

To determine the distance interval that the teacher obtains in each subject and the average result of each subject, the following equation is defined:

$$X_{neu} = X_i + r \text{ x } (X_{teacher} - T_F \text{ x } X_{mean}) \quad (4)$$

Where *Xteacher* is the best subject, X_i is the current solution, *Xmean* is the current average subject, T_F is the teaching factor has the value 1 or 2, which sets the value of the average, and X_{neu} is the impact on the student. X_i is the difference between the qualities of all students and the knowledge of the teacher, *r* random vector uniformly distributed within [0,1]. There are two possible solutions in the learner phase; the individual in the previous stage *i* joins itself different from himself or herself, *j*. Then, individual *i* tries to move his or her current position, which is associated to the relative value with respect to *j* in a certain direction. Then, the position of individual *i* is changed if his or her value improves.

$$X_{neu} = X_i + r \text{ x } (X_i - X_j) \quad (5)$$

$$X_{neu} = X_i + r \text{ x } (X_j - X_i) \quad (6)$$

At the end of the learning phase, the accepted values of the function will become the input to the teaching phase in the next iteration. The procedure of the teaching and learning phase continues until the desired final conditions are achieved.

Application TLBO Algorithm for LoRaWAN of Smart meter.

The LoRaWAN consists of combination of three values (BW, SF, and CR) that enable the PLR to be reduced. The LoRaWAN is optimised by calculating the optimum parameters that minimise the PLR. Furthermore, these parameters define the limitations of the process.

$BW \in$ {125,250,500}

$SF \in$ {7,8,9,10,11,12}

$CR \in$ {4/5, 4/6, 4/7, 4/8}

Depending on the region, only the allowed values of BW and SF can be used (Table). The PLR is minimised by using the real-time optimisation function provided by:

$$min \text{ PLR } [\text{BW}(t), \text{SF}(t), \text{CR}(t)] \quad (7)$$

There are several possible solutions; the highest BW value is chosen to achieve a higher transmission speed using the optimization algorithm, as can be seen in Eq. (8):

$$BW(t) = BWop \quad (8)$$

where, BW*op* is the highest BW value. In this research, located in Viet Nam, the initial value for BW would be 125 kHz.

Once the BW has been set, considering the possible solutions with the minimum PLR, the algorithm looks for the best SF, as shown in Eq. (9):

$$\text{SF}(t)=\text{SF}op \quad (9)$$

where, SF*op* is the optimal SF value. The lower value of SF results in a higher transmission rate and lower tToA. Once the BW and SF have been selected, if there is more than a minimum, the value of CR is sought through the algorithm, which allows a higher transmission speed

$$\text{CR}(t)=\text{CR}op \quad (10)$$

where, CR*op* is the highest CR value. The initial CR is 4/5 to start the algorithm.

The population (pop) is defined with the n possible states. Where the number of possible variations is *P*, and the number of variables is D, in our case, 72 and 3, respectively. BW, SF, and CR are combined for each state.

$$pop = \begin{bmatrix} x_{1,1} & \cdots & x_{1,D} \\ \cdots & \cdots & \cdots \\ x_{P1} & \cdots & x_{P,D} \end{bmatrix} \quad (11)$$

The research is located in Viet Nam according to (Table 1), there would be 28 possible combinations. Fig. 5 shows the TLBO flow chart to achieve the optimal BW, SF, and CR values of the LoRaWAN.

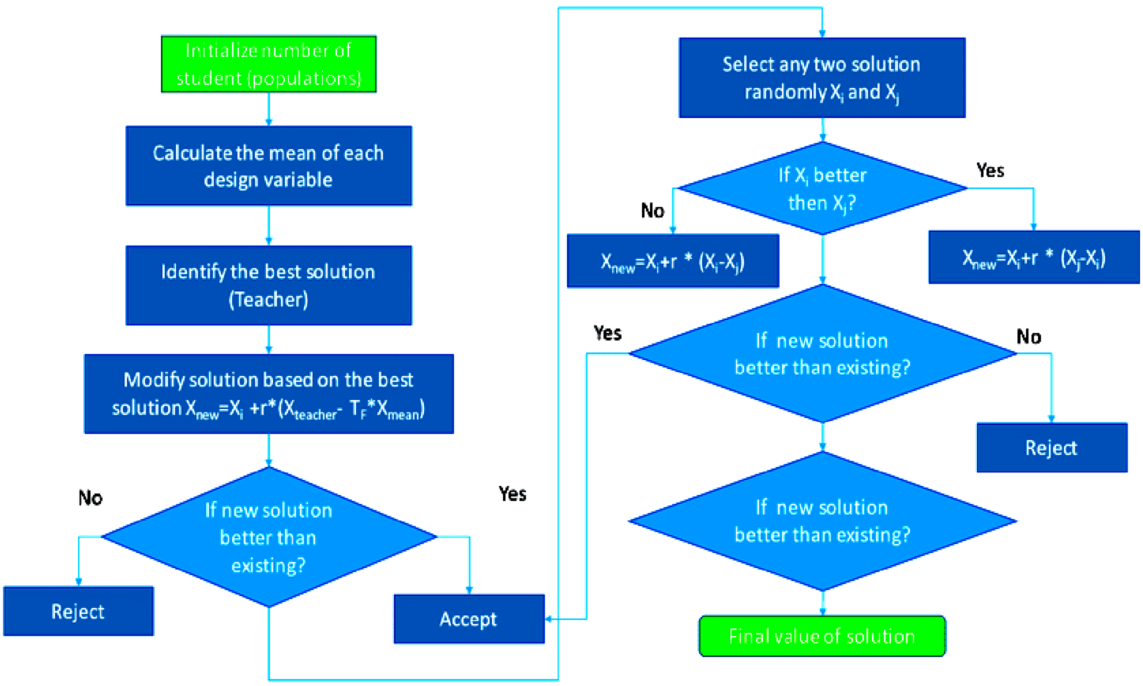

Figure 5. TLBO flow chart

4. TEST - RESULTS AND DISCUSION

4.1. Case study

To perform the tests, three houses with different sizes and occupation profiles were used. The houses are located in Ho Chi Minh, Viet Nam. The consumption in each household is very different, giving rise to different LPs, which is why these households were chosen for the study.

The features of the households are shown in Table 2 to define the LPs that were obtained with the measurements made by the SMEEH installed in the houses, located in the general electrical panels of each house.

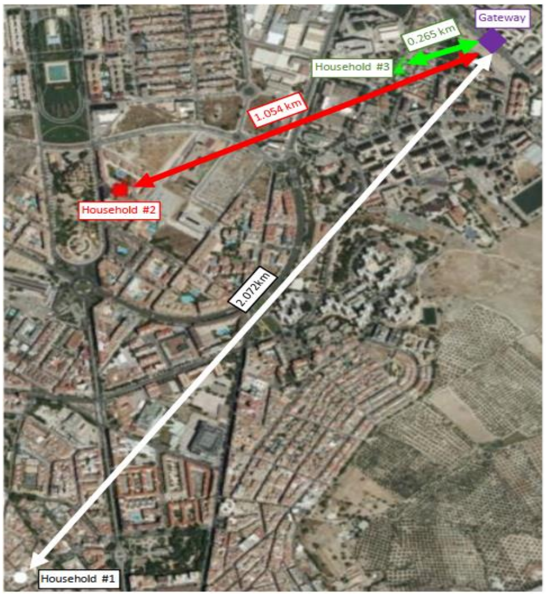

Figure 6. Households and LNS location

Table 2. Key features of the households

Features	Household #1	Household #2	Household #3
Building type Family members	Apartment 2	Town home 4	Terraced home 4
sTotal surface (m2) Device X UTM (m) Y UTM (m)	70 SMEEH #1 432083 4180822	102 SMEEH #2 430537 4182016	360 SMEEH #3 431250 4182392

4.2. Results obtained applying TLBO algorithm

Once the influence of the configuration parameters was analysed, the conclusions obtained should serve as a basis for the implementation of the TLBO algorithm set out in point 3.3.1. The tests were performed for each household for 1.5 hours. Table 3 shows the summary and comparison of the results obtained. The results obtained concerning the PLR and runtime support the application of the TLBO algorithm in the optimisation of the LoRaWAN.

Table 3. Comparison of optimization results of LoRaWAN configuration

Household	Range			Maximum possible	Optiamal solutions	Best solution				TLBO time (ms)
	BW (kHZ)	SF	CR			BW (Khz)	SF	CR	PLR	
#1	7			28	3	125	7	4/5	29	5.8
#2	125	8	4/5	28	2	125	8	4/6	35	6.3
#3	250	9	4/6	28	3	250	7	4/6	31	5.2
		10	4/7	28	3					
		11	4/8	28	3					
		12	4/8	28	3					

The optimal frequency for households #1 and #2 is 125 kHz, but there are changes in the SF and CR. Therefore, for household #1 there is a SF of 7 and CR of 4/5, and for household #2, there is a SF of 8 and CR of 4/6. The optimum for household #3 is produced with a BW of 250 kHz, SF of 7, and CR of 4/6. The application of a TLBO algorithm obtains minimums of 29%, 35%, and 31% with execution times of 5.8, 6.3, and 5.2 ms for households #1, #2, and #3, respectively. Below are the results for the 3 households. Fig. 7 show the test results of PLR for all household by applying the TLBO algorithm. The optimisation of the LoRaWAN network parameters makes it possible to obtain the power consumption measurement in each household with a lower PLR, as shown in Fig. 13, from 1,100 s household #1 and household #3 stabilize with an average PLR of 35% and 30% respectively, and at 450 s in household #2 with an average PLR of 31%. The PLR decreases each time the TLBO algorithm runs in LNS. The highest received signal strengths occur in household #3with an average RSSI value of -75 dBm due to the closer location of the house to the LNS, while household #2 has an average value of -82 dBm and household #3 is in the order of -83 dBm as it is further away from the LNS. By applying the TLBO algorithm, the RSSI values increase and therefore the received signal improves and the PLR decreases.

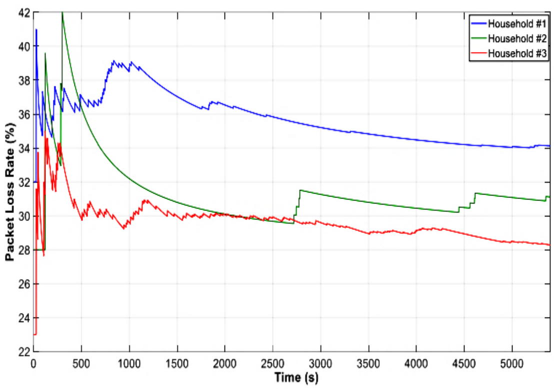

Figure 7. Distribution of the PLR in the three households with 1.5 hours of observation

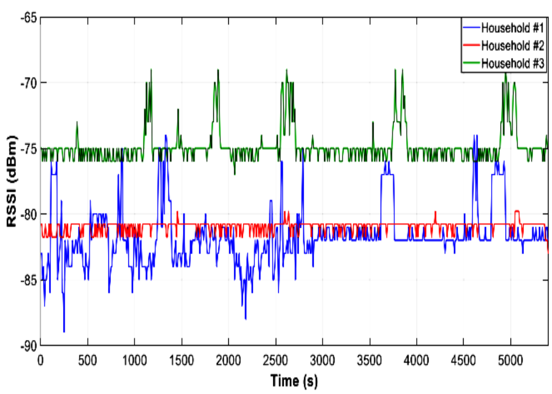

Figure 8. Distribution of the RSSI in the three households with 1.5 hours of observation

Fig.8 show the results of RSSI for all household by applying the TLBO algorithm.

5. CONCLUSIONS

The application of IoT in electrical meters is growing in importance. Therefore, household consumption data in the cloud that is uploaded in real time can provide comprehensive information about the LPs in households. This knowledge can be used in many applications, either in real time or with subsequent analysis. The system developed is composed of the LNS that serves as the communications centre of the LoRaWAN by sending and receiving information from the SMEEHs, optimises the settings of the LoRaWAN, and connects to the IoT by uploading the data obtained in each of the homes to the cloud. The LNS can work with up to 300 SMEEHs. The second device designed was the SMEEH, which is installed in the households where the data are monitored. The SMEEH sends the measurements to the LNS and receives orders from LNS to change the communication parameters with the LoRaWAN.

The tests performed on the LoRaWAN without the application of a TLBO and individually for each of the households studied obtained a PLR close to 20%. PLR and RSSI measurements were made for each of the 72 potential combinations of the BW, SF, and CR parameters.

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Biography:

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