Battery Optimal Configuration of Transmission Settings in LoRa Moving Nodes

Ashirwad Gupta, Makoto Fujinami
System Platform Research Laboratories
NEC Corporation
Kanagawa, Japan
{a-gupta@cp, m-fujinami@ab}.jp.nec.com

***Abstract*—This paper proposes a novel method of selecting battery-optimal transmission settings for moving nodes in Long Range (LoRa) system. In LoRa communication, transmission setting plays an important role as it affects coverage range, data rate, and battery consumption. Therefore, its optimal configuration is required to ensure successful communication with long battery life. However, with small data rate and resource-limited LoRa nodes, configuration of optimal settings becomes challenging. Current solutions require multiple transmissions for fixed distance between nodes and gateways to achieve the optimal settings. The existing methods become unsuitable for moving nodes because of continuous change in distance between the nodes and the gateways. Thus, each transmission would require different optimal setting. Due to lack of such configuration method, conventional method uses same fixed high energy setting for all transmissions to ensure high reliability, which results in shorter battery life. To minimize energy consumption without affecting reliability, the proposed method dynamically configures the optimal setting for each transmission depending on the distance between current location of the moving node and the nearest gateway, using path loss estimation. The simulation result shows that, for 95% reliability, the proposed method achieves 47% reduction in energy consumption as compared with conventional method.**

***Index Terms*—LoRa, Battery Optimization, Moving Nodes, Transmission Parameters Selection**

I. Introduction

Low Power Wide Area (LPWA) communication has emerged as an important enabling technology for connecting inexpensive ubiquitous sensors in Internet of Things (IoT) [1]–[4]. LPWA networks are able to provide wide area connectivity at low energy consumption for resource-limited sensors and actuators, hereinafter referred to as nodes. There are several LPWA technologies such as Sigfox, LoRa, NB-IoT, LTE-M, Wi-SUN, etc. Among them, LoRa has gained large popularity in the IoT community and has been widely used in various applications [5]–[12] owing to its several additional benefits. First, LoRa operates in unlicensed spectrum band which saves users from expensive spectrum usage fees. Second, users can quickly setup private network at low cost, without involving third party. Third, LoRa uses simple star network topology of direct connection of nodes with gateways, which keeps the system free of complex routing protocols and easy to use. Fourth, higher robustness against noise and interference, where LoRa receivers can decode a signal even at 19.5 dB below the noise floor [13].

In addition, LoRa provides high flexibility in choosing transmission settings to meet users requirements of communication range, data rate, and battery consumption. LoRa can have multiple possible settings with varying parameters including Spreading Factor (SF), Bandwidth (BW), Coding Rate (CR), Transmitted Power (TP), etc. which can be set independently. These parameters can be configured to achieve longer range by using higher energy or higher throughput in exchange for smaller communication range. Therefore, their optimal configuration is required to achieve successful communication with long battery life. A battery-optimal transmission setting, also referred as optimal setting, is the transmission setting that requires minimum battery consumption for transmitting a message with probability of successful communication greater than or equal to the given reliability. Naive choices such as high energy setting can consume as much as 100 times more battery than the optimal setting, resulting in shorter battery life, thus increased cost of the system [14].

However, configuration method of optimal settings for moving nodes is missing in LoRa Wide Area Network (LoRaWAN) specification [15]. The existing state of the art works related to energy optimization in LoRa are applicable only to static nodes. The authors in [14] use trial and error method, whereas feedback based on previous communications is used in [15] and [16]. The described methods require multiple transmissions at fixed distance between gateways and nodes to achieve optimal settings by convergence, which becomes unsuitable in moving node scenarios. Other works involving LoRa moving nodes [7]–[12] do not optimize for battery consumption and use same fixed high energy setting throughout the movement to achieve high reliability.

In this paper, we propose a novel method to configure optimal transmission settings in moving nodes to achieve a given reliability of the communication. The proposed method selects optimal setting dynamically for each transmission, depending on distance between the current location of the moving node and the nearest gateway. To achieve the given reliability, the proposed method describes a way to countermeasure unpredictable attenuation caused by varying wireless conditions. Thereafter, via simulation, we evaluate the performance of the proposed method for real-time logistics monitoring use-case. To the best of our knowledge, this paper is the first work to propose battery optimization method for moving LoRa nodes.

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The rest of the paper is organized as follows. Section II discusses the related work. Section III provides the overview of LoRa technology. Section IV explains the key parameters and system model used in the paper. Section V describes the proposed method. Section VI explains the simulation setup and the obtained results, and Section VII concludes the paper.

II. Related Work

As LoRa is considerably new technology, only limited work has been done in the area of battery optimization. In [15] and [16], adaptive data rate (ADR) method is specified for energy optimization in static nodes. ADR involves adaptation of LoRa transmission parameters to save transmission energy using feedback mechanism based on previous communications. Similarly, a probing algorithm using trial and error method for selecting the optimal settings is illustrated in [14] These described methods converge to an optimal setting step by step after multiple transmissions for the fixed distance between the node and the gateways. However, such methods become unsuitable in moving node scenarios.

The research involving LoRa moving nodes include several works. LoRa is used for obtaining battery status in moving Electric Vehicles in [10], tracking system for moving vehicles in [7]–[9], [12], and human monitoring in [11] and [17]. However, none of the aforementioned works account for energy optimization in transmission settings for moving nodes. All of them use conventional method of using a fixed pre-configured setting for transmissions throughout the movement. This conventional mechanism is highly energy inefficient as it uses high power settings even when the node is close to a gateway. Besides, battery optimization techniques [18], [19] for moving nodes used in other wireless communications such as LTE, Wi-Fi, 5G, require frequent exchanges of information about channel conditions, previous communication history, user traffic, etc. However, such methods become inapplicable for LoRa due to its duty-cycle restriction, in which each LoRa node is allowed to only send a few messages a day to avoid interference.

III. LoRa Overview

A LoRa network constitutes of two components, LoRa and LoRaWAN. LoRa corresponds to the proprietary physical layer developed by Semtech. On the other hand, LoRaWAN corresponds to the Medium Access Control (MAC) and network layers, which is open and described in a specification developed by the non-profit LoRa Alliance [15]. In this paper, we use the word LoRa to describe LoRa network including both LoRa and LoRaWAN for simplicity.

There are several transmission parameters that affect LoRa communication. The important parameters are as follows:

- **Spreading Factor (SF)**: Under CSS modulation, for a given SF ranging from 7 to 12, LoRa spreads each symbol over 2^{SF} chirps. This spreading of one symbol onto many chirps results in very low data rate for LoRa but increases the Signal to Noise Ratio (SNR) and sensitivity of LoRa transceivers. Thus, higher spreading factor increases the range at the expense of low data rate and higher power consumption.
- **Transmission Power (TP)**: TP defines the power of transmission used by LoRa transceiver. Higher transmission power increase the transmission range but also increases the energy consumption. Although, it can be set in range from 4 dBm to 20 dBm, but general LoRa transceivers powers are set starting from 2dBm to maximum of 14dBm in steps of 3 dBm as mentioned in specification sheet [20].
- **Bandwidth (BW)**: BW refers to the width of the frequency in the transmission band. Higher bandwidth results in higher data rate but due to added noise in higher BW, sensitivity decreases resulting to lower transmission range. Although BW range can vary from 7.8 kHz to 500 kHz, but generally LoRa network operates at either 125 kHz, 250 kHz or 500 kHz.
- **Coding Rate (CR)**: CR is a Forward Error Correction (FEC) rate that is used to further increase the receiver sensitivity in presence of interference. Smaller coding rates increase robustness against interference but decrease the data rate. In LoRa, CR can be set to either: 4/5, 4/6, 4/7 or 4/8 . In the paper, as interference is not considered, thus we set CR fixed as 4/5.
- **Carrier Frequency (CF)**: CF is the central frequency of the transmission band. LoRa transceivers available today operate in frequency bands between 137MHz to 1020 MHz varying with each country regulations.

IV. System Model

In this section, we describe parameters and system model that are used in the paper.

A. Radio Propagation Model

In this paper, we use the Okumura-Hata propagation model [21] to estimate the path loss of wireless transmission in physical layer for urban area.

$$PL = \alpha + \beta log_{10}(d) \tag{1}$$

where d is the distance between the node and the gateway in kilometer (km) and PL is path loss in decibel (dB). α and β are functions of effective base antenna height (h_B), mobile antenna height (h_M) and carrier frequency (f), which is CF in this paper.

$$\alpha = 69.55 + 26.16log_{10}(f) - 13.82log_{10}(h_B) - C_H \tag{2}$$

$$\beta = 44.9 - 6.55log_{10}(h_B) \tag{3}$$

For large city environment, C_H is given by:

$$C_H = 3.2(log_{10}(11.75h_M))^2 - 4.97 \tag{4}$$

where f is in MHz, h_B and h_M are in meter (m). For this paper, we considered h_B as 2 m and h_M as 30 m.

B. Maximum Coupling Loss

In wireless communications, range of the communication is dependent on Maximum Coupling Loss (MCL) of the system. MCL is defined as the maximum total channel loss between transmitter and receiver antenna ports at which the packets can still be delivered. For successful transmission:

$$MCL > PL \tag{5}$$

where MCL for message transmission from the node to the gateway is determined based on sensitivity of the gateway and TP used by the node [22] as follows:

$$\text{MCL} = \text{TP} - \text{Gateway sensitivity} \tag{6}$$

Gateway sensitivity is the lowest power level at which the gateway can detect a signal and demodulate message. Using sensitivity data from [20], MCL (in dB) of LoRa transceivers for TP at 0 dBm, is as follows:

TABLE I
MCL [dB] OF LORA FOR DIFFERENT SF AND BW AT TP = 0 dBm [20]

BW/SF	7	8	9	10	11	12
125 kHz	123	126	129	132	133	136
250 kHz	120	123	125	128	130	133
500 kHz	116	119	122	125	128	130

C. Reliability

In this paper, we define reliability as the ratio of number of packets successfully delivered at the gateways to the total number of transmitted packets from the node during the movement for a given time duration.

$$\text{Reliability} = \frac{\text{Number of packets successfully delivered}}{\text{Total number of packets sent}} \tag{7}$$

The packets transmitted from the node fail to deliver if they could not satisfy the condition mentioned in (5). The PL defined in (1) refers to the average statistical path loss in the city environment. However, in real-life scenarios, path loss fluctuates and exact path loss is hard to estimate. This happens because wireless communication is effected by several unpredictable factors [23]–[25] such as the blocking of signals caused by large obstacles (also known as shadowing effect), fluctuation caused by weather conditions, human traffic, and other factors. Thus, real path loss can be mathematically defined as:

$$PL_{real} = PL + X_\sigma \tag{8}$$

where X_σ is a zero-mean Gaussian distributed random variable with standard deviation σ. For urban environment, the value of σ generally varies from 1.7 to 3.6 for urban environment [23]. In this paper, we consider σ value to be 2 which corresponds to moderate variations in weather conditions. As interference is not considered, packet error at MAC layer is not examined in this paper.

D. Energy Consumption

Generally, the gateways are connected to power grid, thus we only evaluate the energy consumption of the nodes in this paper. Energy consumption of the battery of a node for one transmission depends on supply voltage V and supply current I_s drawn for the given setting s and is calculated by:

$$\begin{aligned} E &= \text{Time on Air} \times \text{Voltage} \times \text{Current} \\ &= \frac{L_{packet}}{R_s} \times V \times I_s \end{aligned} \tag{9}$$

where L_{packet} is the transmitted data packet size in bits. R_s is transmission data rate in bits per second (bps) for a given setting s with corresponding SF_s, BW_s, CR_s. It is calculated as follows [15] :

$$R_s = SF_s * \frac{CR_s}{2^{SF_s}} * BW_s * 1000 \tag{10}$$

LoRa transmitter draws different I_s for different TP. For voltage of 3.3 V, 25 °C and 868 MHz band, I_s is as follows:

TABLE II
SUPPLY CURRENT USED BY TRANSMITTER [26]

TP	2 dBm	5 dBm	8 dBm	11 dBm	14 dBm
I_s	24 mA	25 mA	25 mA	32 mA	44 mA

V. PROPOSED SOLUTION

In this section, we explain the proposed method in detail. First, we specify the mechanism of dynamic selection of optimal settings for each transmission. Following it, we describe a way to ensure high reliability against varying channel conditions. The overall network topology with moving node scenario is described in Fig. 1. The gateways are connected to the internet through backhaul network via 3G/4G/Ethernet.

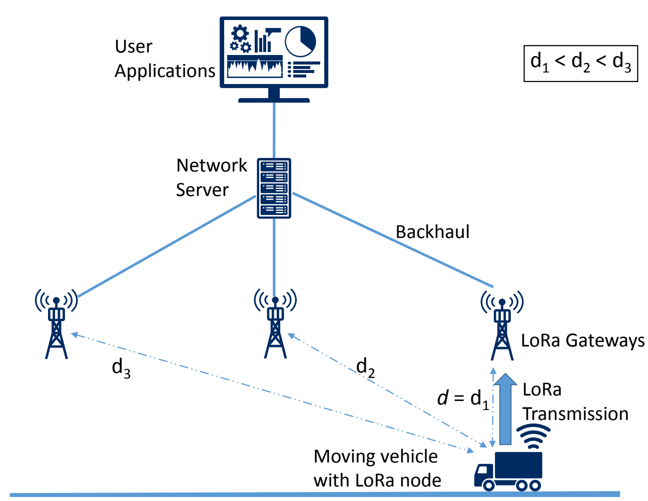

Fig. 1. Network Topology of LoRa for the proposed method with a moving node transmitting to the nearest gateway located at distance d = d_1 from the current location of the node.

Algorithm 1: Dynamic selection algorithm

function OPTIMALSETTING(d)
  S = {SF × BW × TP}
  $Connection \leftarrow FALSE$
  $s_{opt} \leftarrow s_{max}$
  $E_{min} \leftarrow E_{max}$
  Calculate PL for given d from (1)
  while s *in* S **do**
    Calculate MCL_s from (6)
    if $MCL_s > PL$ **then**
      $Connection \leftarrow TRUE$
      $R_s = SF_s * \frac{CR_s}{2^{SF_s}} * BW_s * 1000$
      $E_s = \frac{L_{packet}}{R_s} * V * I_s$
      if $E_{min} > E_s$ **then**
        $E_{min} \leftarrow E_s$
        $s_{opt} \leftarrow s$
  if $Connection \neq TRUE$ **then**
    return NULL
  else
    return s_{opt}

A. Dynamic Selection

The proposed algorithm uses dynamic selection of optimal setting s_{opt} based on estimated path loss, depending on the distance d between current location of the node and the nearest gateway, as per (1). The distance between the node and each gateway is calculated using the respective location coordinates. The algorithm is executed at the node where location coordinates of the gateways are stored in advance and current location of the nodes is obtained using attached Global Navigation Satellite System (GNSS) / Global Positioning System (GPS) device. In this paper, each setting s is a combination of independently varying SF, BW, and TP and thus is a subset of S = {SF×BW×TP}

At the beginning, the proposed method initializes s_{opt} with s_{max} corresponding to the setting {SF12, BW125, TP14} with SF = 12, BW = 125 kHz, TP = 14 dBm, as it uses maximum energy E_{max} among all possible settings in LoRa transmission, as illustrated in Fig. 2. The method then iterates over all possible setting and chooses the s_{opt} which consumes minimum energy for successful communication at the given d. The algorithm returns null value for s_{opt} when value of *Connection* is set to be *FALSE*. This implies that the transmission is only attempted when the nearest gateway is within the maximum communication range of LoRa transmission. This saves battery when the gateways are sparsely located and node could not connect to them.

Fig. 2 illustrates the communication range of different settings for varying SF and TP at fixed BW = 125kHz. It is observed that for each distance, there are multiple settings that can enable the communication. Out of these settings, the proposed method chooses the setting with lowest energy consumption, marked with red diamond, for a given d.

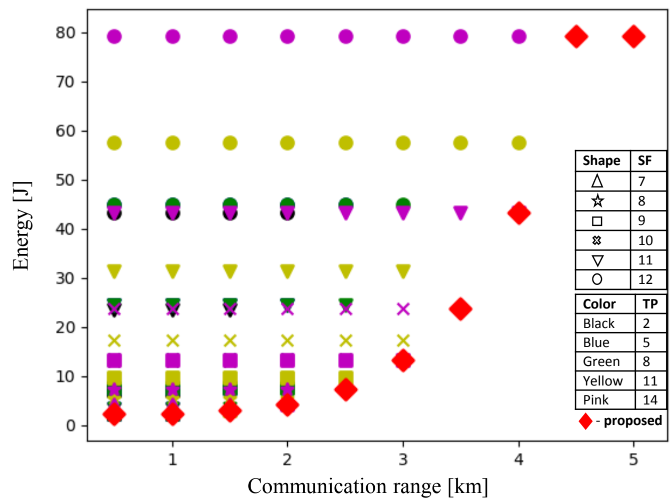

Fig. 2. Communication range and energy consumption of each LoRa transmission of 20-byte data for varying SF, TP settings at BW = 125kHz.

B. Offset

In Algorithm 1, the dynamic selection calculates optimal setting based on estimated PL. However, as described in (8), the path loss fluctuates in real-life scenarios and cannot be exactly predicted in advance. This reduces the probability of message being transmitted to the gateways due to unpredictable attenuation. Thus, to ensure high reliability against multiple fading factors, we introduce a factor of *offset*. It adjusts the new estimated path loss PL_{eff} as follows:

$$PL_{eff} = PL + offset \tag{11}$$

where *offset* can be regarded as the buffer kept for the channel loss that can be caused by wireless channel variations. Thus, PL_{eff} signifies that path loss is estimated intentionally high to prevent any possible message communication failure to the gateway due to aforementioned situations. However, while using higher *offset*, higher power settings are used for each transmission, which increases the battery consumption. As there is a trade-off between reliability and battery consumption for varying *offset*, the value of *offset* is decided as per battery and reliability requirements of the use-case. When *offset* is considered, PL_{eff} is used instead of PL in Algorithm 1.

VI. EVALUATION

In this section, a real-time logistics monitoring use-case is evaluated to transmit messages from a moving node to nearby static gateways using LoRa. We analyze the energy consumption and reliability of sending 20-byte packet containing temperature and humidity information, every one minute for 24-hour time duration, by varying transmission settings consisting SF, BW, and TP. The moving node moves randomly and freely anywhere within the area of square size 10×10 sq. km with random varying speed between 0-100 km/h. Four gateways are distributed uniformly in the area.

TABLE III
SIMULATION PARAMETERS

Fixed Parameter	Value	Variable Parameter	Value
CF	868 MHz	BW	{125, 250, 500} kHz
CR	4/5	SF	{7, 8, 9, 10, 11, 12}
σ	2	TP	{2, 5, 8, 11, 14} dBm
L_{packet}	20 $\times$ 8 bits	*Offset*	0 - 3 dB

In our settings, we evaluate one way communication and do not consider protocols and scheduling. The other parameters are listed in Table III.

Fig. 3 shows the effect of varying *offset* on reliability and corresponding energy consumption. It is illustrated that by using higher *offset* values, higher reliability is achieved at the expense of higher energy. Without *offset*, the dynamic selection achieves reliability of 69%. This reliability is observed to be increased to 96% on increasing the *offset* value from 0 to 3 dB, which corresponds to 83% increase in energy consumption. Thus, for example, use-cases with reliability requirements $\geq$80% can set *offset* value to 1 to ensure needed reliability while achieving low battery consumption. In the Fig. 3, the effect of offset values are shown up to 3 dB, but it can be further extended to obtain higher reliability.

Fig. 4 illustrates the comparison between the conventional method and the proposed method in terms of the energy consumption and the reliability achieved for a 24-hour movement of the node. As each setting have three parameters, each point is shown with three characteristics: color, shape and size. The points depicting proposed method, including different offsets, are marked same with red diamond, for easy comparison. For conventional method, as any setting can be used, we compare for all different possible settings. It is observed that multiple settings can achieve a given reliability requirement. For example, the best conventional setting for satisfying reliability requirement of $\geq$80% is {SF9, BW250, TP14} as

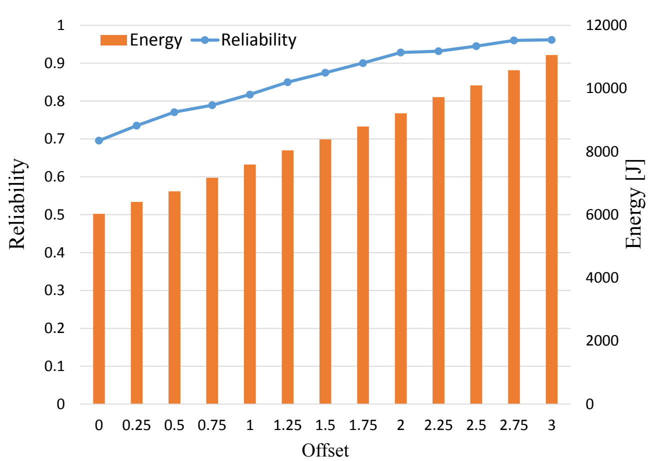

Fig. 3. Effect of offset on energy consumption and reliability of the communication for 24-hour movement.

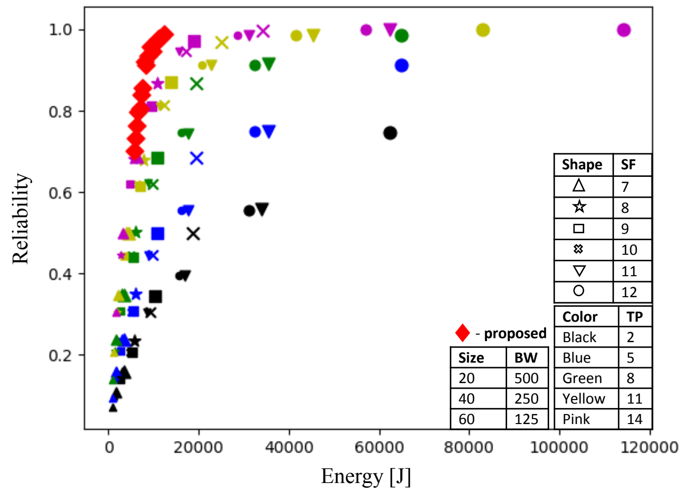

Fig. 4. Reliability and energy consumption comparison between the proposed and conventional methods for 24-hour movement.

it consumes lowest energy among all conventional settings, whereas {SF12, BW125, TP14} consumes the highest energy. However, due to unknown node movement, prediction of such best conventional setting with minimum energy consumption for the given reliability is not feasible in advance. However, to compare the effectiveness of the proposed algorithm, we compare its performance with the best possible conventional method. Fig. 4 illustrates that proposed method not only achieves lowest energy for a given reliability but also for a given energy, it achieves the highest reliability than other settings.

Fig. 5 illustrates the reduction in energy consumption achieved by the proposed method for different reliability, as compared with the best conventional setting, on average of 1000 iterations, each of 24-hour movement of the node. It is observed that the proposed method achieves 47% reduction in battery consumption for 95% reliability. Besides, with the proposed method, reliability can be increased from 70% to 95%, for only 48% increase in battery consumption. In contrast, conventional method would require 128% increased

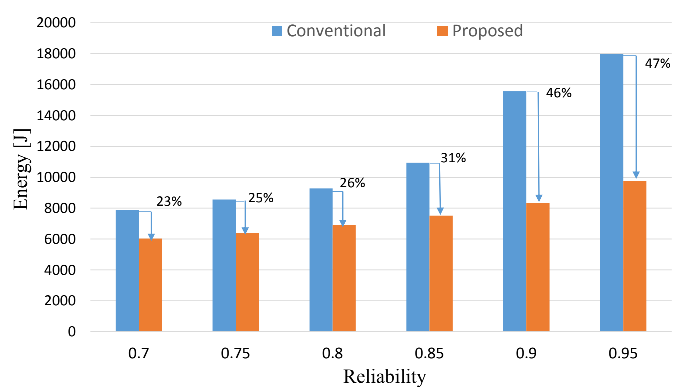

Fig. 5. Energy consumption comparison between the conventional and proposed method for different reliability for 24-hour movement on average over 1000 iterations.

energy consumption for the similar improvement. Thus, using the proposed method, reliability achieved in the use-case can be improved significantly for only marginal increase in the battery consumption.

VII. Conclusion

In this work, we propose a novel configuration method of selecting optimal settings for transmissions in moving LoRa nodes. The proposed method dynamically configures the optimal setting for each transmission depending on the distance between the current location of the moving node and the nearest gateway. For each transmission, the optimal setting is calculated based on path loss estimation and sensitivity of the LoRa gateways. This way the node uses low energy settings when close to the gateways and adapts to higher energy settings when it moves away from the gateways, without affecting the reliability. Thereafter, we introduce a factor of offset to ensure high reliability against unpredictable attenuation caused by multiple fading factors. The simulation result illustrates that for 95% reliability, the proposed method achieves 47% reduction in energy consumption, as compared with conventional methods. Evaluation of the proposed method under interference from nearby nodes and multiple transmission is left for future work.

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