Joint Channel and Spreading Factor Selection Algorithm for LoRaWAN Based Networks

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***Abstract*—Remote wireless sensing technologies utilizing low-power wide-area network (LPWAN) protocols such as Long Range (LoRa) and Long Range Wide Area (LoRaWAN), are recently widely deployed as the main backbone for long range based Internet of Things (IoT) applications. These technologies allow low- power and long-range communications thus being ideal candidates for IoT applications and scenarios. In this paper, we present a Joint Channel and Spreading Factor Selection Mode algorithm (JCSFSM) that supports assigning best channel and selecting the spreading factor that achieve rate demand of end-devices. The algorithm improves throughput, reduces power consumption and guarantees link reliability. It is simulated under various network parameters using Matlab. Further, it aims at maximizing the overall network throughput, reducing collisions, extending communication ranges, thus meeting the requirements of several IoT based applications. The experimental results are compared with Random Channel Spreading Factor Selection Mode (RCSFSM) and showed a superior performance at different scenarios.**

I. Introduction

In the past decade, the Internet of Things (IoT) has been highlighted as a hopeful technology that enables any device to communicate with the Internet. In IoT based networks and applications, large number of devices are spatially distributed over the Area of Interests (AoI) to perform remote sensing and monitoring [1], [2], [3], [4]. The power of IoT is to provide reliable communication to the devices that are communicating with each other for exchanging information, sensing and collecting data [5] while preserving the precious energy source of these IoT based devices [6], [7], [8], [9]. Therefore, IoT can support various applications in human life and add smartness to them. Some of these applications are: smart cities and homes, agriculture, transportation, monitoring, security, etc. [10], [11], [12]. The nature of these applications requires communications over large distances, transfers small amounts of data with low energy consumption and low interference , [13] thus extending the battery life time [10]. To achieve the aforementioned characteristics, Low Power Wide Area Network (LPWAN) protocols such as, Long Range (LoRa) and Long Range Wide Area Network (LoRaWAN) protocols are widely used. [10], [14] Recently, several wide-range wireless communication technologies have been deployed to meet many IoT applications characteristics. LoRa and LoRaWAN are actively presented in the area of Device-to-Device (D2D) communications. In the literature, the authors in [15] presented an overview and a comparison between different LPWAN technologies. Their limitations are presented in [16]. Moreover, the experimental performance evaluations by field tests are presented in [17], [18]. It is commonly in LoRa networks where the Spreading Factors (SFs) are considered quasi-orthogonal [19], [20]. In [21], the authors proposed a heuristic SF-allocation algorithm which allows users to be assigned to the same channel if they have similar path losses. Further, it allocates different SFs depending on the distances between them and the gateway. In this work, the authors ignored inter-SF interference. While, co-SF interference in LoRa system is considered in [22]. Particularly, the authors analyzed the outage probability and demonstrated that the successful capturing for the signal can be guaranteed if the Signal to Noise Ratio (SNR) was more than $6dB$. Correct receptions of different SFs transmissions are affected by collisions that result from inter-SF interference [23]. The paper in [24] analyzed LoRa network throughput with imperfect spreading factor orthogonality. The authors studied the harmful effect of both interference in overall up-link network throughput. The implemented network is centered with a single gateway and considered single channel with $125kHz$ bandwidth. The paper results paved the way toward designing mechanisms for allocating SFs while maintaining throughput enhancements. Despite of many advantages that make LoRa efficient for IoT applications. Duty-cycle constraint limits the available time of channel to be used by a device, which is essential for ensuring channel access fairness between IoT devices. The authors in [25] proposed a duty cycle real time scheduling for wireless link algorithm in LPWAN. The algorithm considered the idle duration of the channel and packet loss. They deployed five nodes in a city and performed test-beds in many scenarios, where the case of multiple channels and a single spreading factor is addressed. It can be noted that the previous works discussed the co-SF and inter-SF interference in single channel and gateway LoRa networks. In addition, the published work showed scheduling of multiple channels depending on duty cycle limitations. In the literature, several papers studied networks with multiple channels and gateways. However, the focus was on scenarios of single spreading factor. Our literature review showed that there is a compelling need for considering both the interference with duty cycle constraints and bit rate requirements of users. This paper presents an algorithm to schedule multiple channels and allocate different spreading factors among end-devices, where the spreading factor that meets rate demand of each user is selected. It assumes perfect orthogonal SFs and considers co-SF interference, which occurs when multiple nodes try to access the channel at the same time using the same SF. The proposed algorithm aims at maximizing the overall network throughput, reducing collisions, extending communication ranges, thus meeting the requirements of several IoT based applications.

The rest of the paper is organized as follows: Section II provides a technical overview about LoRa technology. Section III discusses the theoretical foundation and aim of the Joint Channel and Spreading Factor Selection Mode algorithm. Section IV presents the simulation results and discussion. Finally, section V concludes the paper and proposes future direction of research.

II. Technical Background

Semtech developed a network physical layer technology called LoRa, for long-range and low-power communications [26]. LoRa uses Chirp Spread Spectrum modulation (CSS) to produce a chirp signal of frequency that increases or decreases with time interval [14]. LoRa performs error detection and correction through Forward Error Correction (FEC) codes to increase system robustness against noise, interference and Doppler Effect. Code rates (CRs) range from $4/5$ to $4/8$ according to $4/(CR+4)$, with $CR \in \{1, 2, 3, 4\}$. Also, There are four parameters used to characterize Lora: Carrier Frequency (CF), channel bandwidth (BW), transmission power (P_{tx}), and spreading factor. According to them, several features are affected and changed, such as, data rates, transmission range and energy consumption. LoRa physical layer operates in 1G band, e.g. 433, 868 or 915 MHz bands, these ranges are employed depending on the region or frequency plan. In Europe, only 868-870MHz license-free Industrial Scientific Medial (ISM) band is used. In this band, there are nine different channels, the first three channels are implemented in each end device, and the additional five channels are optionally used by end-devices. All of them have the bandwidth of 125 kHz, the ninth channel is centered at 868.3 MHz with bandwidth 250 kHz, for Frequency Shift Keying (FSK) modulation, channel ten is used with 250 kHz bandwidth. In Europe, only 125 kHz and 250 kHz are used. The spreading factor represents the ratio between the symbol and chip rates, its values range from 7 to 12. A higher value improves the signal to noise ratio, robustness to interference, sensitivity, and thus improves the communication range. However, the data rate and the airtime are decreases, increased, respectively. Different SFs tune the chirp rate which determines the number of chips used to encode each symbol [22]. The network consists of end devices and gateways; each node has a specific rate demand requirement. In this paper, the proposed algorithm considers duty cycle constraints, which limit the available time of the channel and the bit rate for the available spreading factors. Further, it selects the available channel, which insures link reliability and a spreading factor that guarantees the bit rate demand of the end device.

III. Joint Channel and Spreading Factor Selection Mode Algorithm

In this section, the theoretical assumptions and main objectives of the Joint Channel and Spreading Factor Selection Mode algorithm are described. In this work, a LoRa cell that is centered with a single gateway and has a radius of $R\ Km$ is considered. It consists of N end-devices or nodes such as sensors and actuators also called motes, distributed in a fixed and/or random way, and located in the range of each other at different distances from the gateway. The motes are connected to the gateway via a single hop LoRa wireless links, and the gateway is connected to a remote server via the IP network [27]. In this work, the available band in the cell utilizes the European Union (EU) 863-870 MHz ISM band, which is divided into non-overlapping frequency channels. Let C denotes the set of all up-link channels as $C \in \{1, 2, ..., \mathrm{N}_c\}$,where N_c is the number of up-link channels that may have $125kHz$ and $250kHz$ bandwidth. Moreover, define the set of spreading factors as M, where $M \in \{7, 8, ..., 12\}$. In this scheme, several up-link transmission channels are available for each device at any time, where each end-device can access only one available channel and spreading factor. Further, the different SFs are assumed to be orthogonal; and thus parallel transmission can be received at the gateway on different SFs simultaneously [28]. The data bit rate (R_m), where $m \in M$ that can be supported by each SF_m is denoted by (Eq.1) [24] :

$$R_m = m.CR/(2^m/BW), \tag{1}$$

where CR is the coding rate that corresponds to a specific error correction rate, which is equal to $4/5$,$4/6$, $4/7$ or $4/8$, [26], and BW is the channel bandwidth. End devices communicate with a gateway over a single-hop link. For a successful signal reception at the gateway from end-device i, the following two conditions must be satisfied:

1) The up-link received Signal-to-Noise Ratio value, specifically, SNR_m^i for end-device i at SF_m is above a threshold q_{SF_m}. The SNR_m^i is evaluated as follows [24]:

$$SNR_m^i = P_{tmax} \cdot |h_i|^2 . A(f_c)/(d_i^{\alpha} . \sigma_c^2), \tag{2}$$

For LoRaWAN, there are five different power values: 2, 5, 8, 11 and 14 dB_m [29], where P_{tmax}=14dB_m is the maximum transmit power, h_i represents the channel gain between end device i and the gateway. $A(f_c) = (f_c^2 . 10^{-2.8})^{-1}$ is the deterministic loss, f_c is the carrier frequency, d_i is the distance between end-device and the gateway, α is the path loss exponent and σ_c^2 is the Additive White Gaussian Noise (AWGN). In this work, the value of the path loss exponent α is selected as 4, which represents the lossy urban environment [27].

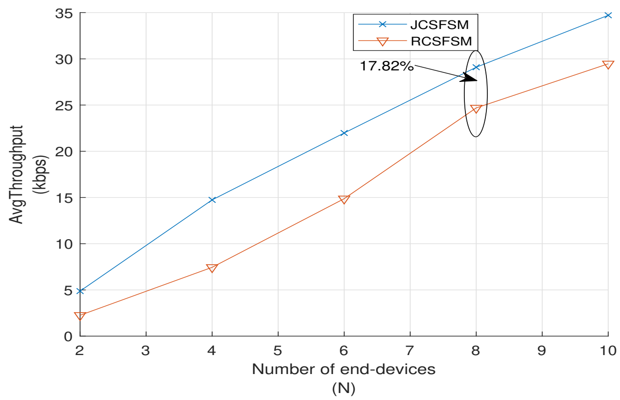

Fig. 1. Network average throughput vs. number of end-devices.

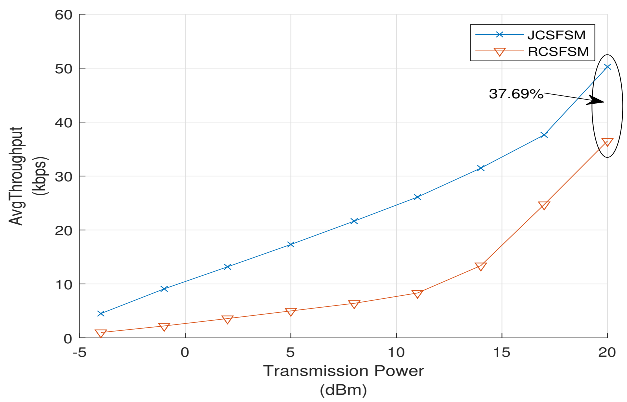

Fig. 2. Network average throughput vs. transmission power.

2) Link reliability; where the up-link signal can be decoded at the gateway when P_r is higher than the receiver sensitivity $S^{(SF,BW)}$ as shown in (Eq.3) [30]:

$$P_r > S^{SF,BW}, \tag{3}$$

Now, let P_r denotes the received power at the gateway, consider the following Equation [23]:

$$P_r = P_{tmax} + G - L - L_{pl}, \tag{4}$$

Where G is the antenna power gains, L is the power loss at the end-device i. Also, we consider log-distance path loss model in which the attenuation of the signal in terms of distance d_i, L_{pl} is given by (Eq.5) [29]:

$$L_{pl} = L_{pl}^{d_0} + 10\alpha \ln d_i/d_0 - X_\sigma, \tag{5}$$

where the received power at reference distance d_0 is $L_{pl}^{d_0}$, and the variance is X_σ. LoRa network consists of nodes, gateways exist in the range of each other, since there are many devices that could be assigned to the same SF, both the co-SF, and inter-SF interference may occur. However, as mentioned in [31], the inter-SF interference is dominated by co-SF interference. Therefore, we assume that the SFs are perfectly orthogonal which implies low inter-SF interference. In the case of co-SF interference, one of the two received signals on the same channel and the same SF at the gateway can be decoded if the signals difference is above 6 dB. The proposed Joint Channel and Spreading Factor Selection Mode allocates a spreading factor value depending on rate demand of each end-device and considers the availability of frequency channel for each up-link transmission. This scheme improves the overall network throughput, reduces collisions, and minimizes energy consumption and guarantees long-range communication.

IV. Results and Discussion

In this section, for the given aforementioned network model, the simulation experiments are conducted with different metrics to evaluate the performance of the proposed algorithm. Then the proposed scheme is compared with the Random Channel and Spreading Factor Selection Mode algorithm. In this mode, the gateway chooses channel and spreading factor randomly for each up- link. Here, traffic demand for each end-device may vary based on the kind of its offered service. Further, when an end-device transmits packets to the gateway. The main challenge is to find an available set of channels and spreading factors over the up-link path. The proposed scheme considers data rate demand, the distance and link reliability, accordingly, it selects the best channel and spreading factor.

Further, Fig. 1 plots the network average throughput performance as a function of the number of end-devices. This figure shows that the achieved throughput increases as the number of end-devices increases due to the gateway traffic increase. Specifically, for $N = 8$, JCSFSM outperforms RCSFSM by 17.82%. The transmission power is an effective parameter on the network performance. Increasing the transmission power, increases the data rate. Figure 2 depicts the network average throughput performance as a function of the transmission power of the end-device. Specifically, for $P_t = 20\ dB_m$, JCSFSM outperforms RCSFSM by 37.69%. Moreover, the number of successful transmissions per end-device as a function of the number of end-devices is depicted in Fig. 3, which shows an increase number of successful transmissions, wherein JCSFSM outperforms RCSFSM by 23.135%.

V. Conclusion and Future Work

In this paper, we presented an algorithm for channels scheduling between nodes in the network, and allocating spreading factors that provide bit rate requirements. Our proposed algorithm improves network throughput, minimizes collisions, improves link reliability and satisfies rate demand of users. Future work can be done to study transmission power adaptation of the nodes. The nodes located randomly in the region where there are obstacles and conditions that always changed. Therefore, they can change their power accordingly; this will improve the overall energy consumption.

Acknowledgment

This work is supported by the German Jordanian University under the grant No. SEEIT 02/2018

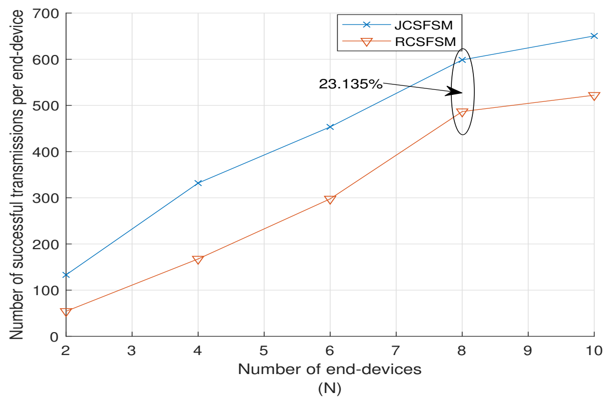

Fig. 3. Number of successful transmissions per end-device vs. number of end-devices.

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