Towards Cognitive Radio in Low Power Wide Area Network for Industrial IoT Applications

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***Abstract*—In this paper, we have discussed the integration of Cognitive Radio (CR) in Low Power Wide Area Network (LPWAN) based on a generic network architecture and a PHY layer front-end model. Essentially, since most existing LPWAN technologies are proprietary in nature, it is necessary to present insights that may spur newer developments to enhance many Internet of Things (IoT)-based applications, including Industrial IoT (IIoT) applications such as smart factories, smart metering, and smart city architectures. Generally, this paper will benefit researchers who may be seeking to develop CR-LPWAN systems towards enhancing IoT-based applications.**

***Index Terms*—Cognitive Radio, Industrial, IoT, LPWAN, Survey**

I. Introduction

Many Internet of Things (IoT)-based applications such as smart industries, smart metering, smart homes, and smart city architectures, are mostly required to transmit data over long distances, consume low energy, be cheap to purchase, and be highly scalable [1]. However, these design requirements are typically unmet by existing cellular communication technologies (such as 3G and 4G technologies) because cellular technologies are designed mainly to service multimedia applications that consume more power, need more bandwidth, and are more expensive to deploy [2]. Thus, there has been a recent drive to satisfy the above requirements concerning IoT-based applications, which has led to the birth of newer and more suitable communication technologies such as the Low Power Wide Area Network (LPWAN).

LPWAN is widely used in many Industrial IoT (IIoT)-based applications because it offers long transmission range, low power consumption rates, simplified network topology (often single hop and star topology), low cost, simple and scalable deployment, thin infrastructure, small data frame sizes, albeit low data rates [3], [4]. In fact, because of these qualities, it has been forecasted according to [5] that 700 million IoT devices may be connected over LPWAN standards by 2021. Nevertheless, it has also been observed that most LPWAN technologies will typically suffer from spectra congestion since they are deployed mostly in the unlicensed Industrial, Scientific, and Medical (ISM) band. This may lead to increased interference, reduced transmission range, limited scalability, and spectra inefficiency to LPWAN systems [6].

Consequently, the need to alleviate the above limitations has motivated the recent paradigm shift towards the integration of Cognitive Radio (CR) in LPWAN. The study of CR has matured in recent times with the aim to improve spectral utilization and efficiency in wireless communication systems. CR is a new radio technology that can automatically detect available channels in a wireless spectrum and change its transmission parameters in order to guarantee improved communication and radio operating behavior [7]. Because CR solves some wireless communication problems such as interference, spectral efficiency, and delayed network deployment, hence, it has gained wider consideration under new IEEE standards such as IEEE 802.22, IEEE 802.15.2, IEEE Standards Coordinating Committee (SCC) 41 [8]. In fact, CR has been used in many IIoT-based applications, for example, it has been used to improve the Quality of Service (QoS) in Wireless Sensor Network (WSN)-based smart grid applications [9], [10]. CR has been used to minimize interference in industrial WSNs (IWSNs) with benefits such as timely transmission, reduced latency and lower frame losses [7]. Recent reports indicate further that CR may improve dynamic spectrum allocation in industrial CR networks [11], minimize delay routing in time-critical industrial applications [12], provide fast convergence for dynamic spectrum access in IWSNs [13], and achieve effective spectrum hand-off in IIoT [14]. Other potential IIoT areas where CR may be investigated may include to safeguard endpoints in cyberphysical systems (CPS) [15] probably through the introduction of agile frequency hopping schemes in endpoints. Furthermore, future industrial systems characterized by Industrial CPS as discussed in [16] may also benefit from CR technologies particularly to enhance spectral access to cloud-based big data infrastructures.

Nevertheless, there are still some issues that must be addressed in order to deploy CR-LPWAN systems successfully. One of these issues concerns the standardization of CR-LPWAN systems particularly as it pertains to the network architecture and Physical (PHY) layer front-end model that may support CR-LPWAN systems. The adoption of common models for CR-LPWAN systems may yet remain an early research issue since most LPWAN technologies are generally proprietary with little information available in the research

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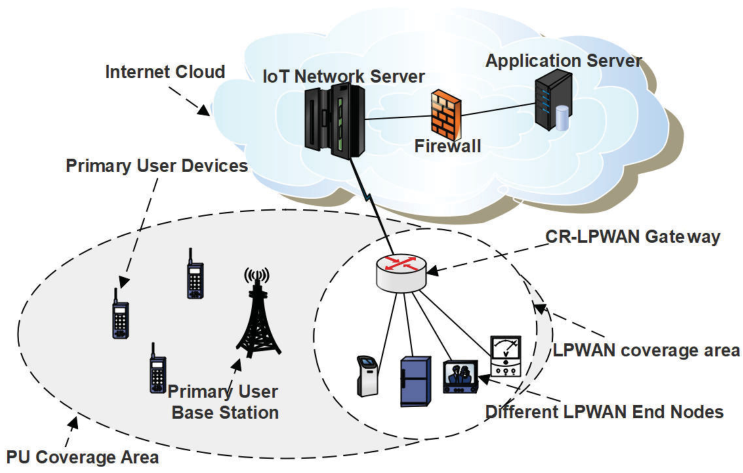

Fig. 1. A generic network architecture depicting a CR-LPWAN Gateway

community. Consequently, in this paper, we have presented a generic CR-LPWAN network architecture and a corresponding PHY layer CR-LPWAN frontend that may be used by researchers who are seeking to develop CR-LPWAN systems to enhance IIoT and other general IoT-based applications.

To this end, we have highlighted in Section II some recent research efforts concerned with developing CR-LPWAN systems. In Section III, we discuss a generic network architecture to support CR-LPWAN, while Section IV presents a PHY layer front-end for CR-LPWAN systems. We conclude in Section V.

II. Related Work

In this section, we have highlighted some recent efforts pertaining to the development of CR-LPWAN systems. We have mentioned only a few works in this section since at the time of this writing the literature may be young in this regard. Concerning the development of CR-LPWAN systems, Saifullah *et al.,* presented a pioneering effort in [17] that pertains to the concept of sensor network over white spaces (SNOW). In particular, they extended SNOW to LPWAN over white spaces in [18] using an innovative PHY layer design that involves distributed orthogonal frequency-division multiplexing (D-OFDM). At the moment, SNOW supports only the use of geolocation database technology for the discovery of TVWS (Television White-Space). The designs such as in [18] may benefit from a more detailed PHY front-end model that supports spectrum sensing as proposed here in this paper.

Chen *et al.,* in [19] proposed cognitive-LPWAN (C-LPWAN) based on an Artificial Intelligence (AI)-enabled cognitive engine. They presented a robust C-LPWAN architecture that achieved better performance over some known LPWAN technologies such as LoRa, NB-IoT, and LTE-M in terms of its reduced delay and minimal energy consumption rate. Essentially, the C-LPWAN architecture integrates different LPWAN technologies in order to use the best option per time and per application. Thus, the cognitive engine in the C-LPWAN architecture uses high precision calculations, in-depth data analysis, and distributed Cloud support to select the best LPWAN technology to be used per time. In a different paper, Dongare *et al.,* proposed a LPWAN architecture termed OpenChirp to leverage different IoT-based applications [20]. Though based on LoRaWAN (Long Range Wide Area Network), OpenChirp provides a gateway that is designed with software-defined radio capabilities for the future exploration of white-spaces. Moon in [21] proposed dynamic spectrum access strategy for CR-LPWAN to maximize spectrum capacity. Moon showed via numerical analytics that CR-LPWAN systems may achieve good blocking probability than typical LPWAN technologies.

A pending issue with the above discussed works is the lack of a well elucidated network architecture and PHY layer front-end that supports the widespread development of CR-LPWAN systems. Consequently, in this paper, we have addressed this gap by presenting an overview of a generic network architecture and PHY layer front-end that supports CR-LPWAN systems with the aim to enhance IoT-based applications.

III. CR-LPWAN: A Generic Network Architecture

A typical generic network architecture is illustrated in Fig. 1 that supports CR-LPWAN systems based on the deployment of some basic network elements required by most LPWAN networks. The CR-LPWAN system is deployed at the LPWAN Gateway (GW) in order to minimize the design complexities that may be incurred at the LPWAN end nodes, which typically are resource constrained. It is convenient to deploy CR technologies at the LPWAN GW since most GW infrastructures usually possess more computational and physical resources than the end nodes.

In order to operate, the CR-LPWAN GW (see Fig. 1) scans its surrounding local spectra to detect free channels (white-spaces) for opportunistic use. Geo-location database technology may be used to supplement spectrum sensing at

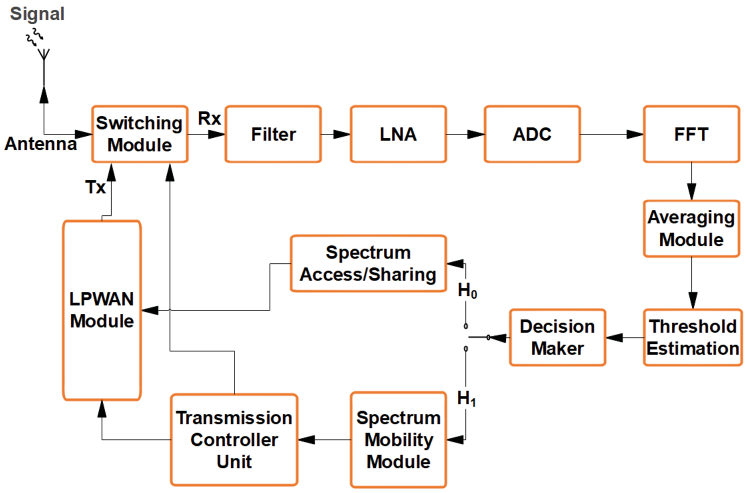

Fig. 2. A generic PHY Layer model of a CR-LPWAN frontend

the GW as discussed in [18]. However, we have considered only spectrum sensing in our generic architecture since it is fully motivated by the IEEE 802.22 standard [22]. In most cases, the LPWAN coverage may exist within the coverage area of a primary user (PU) transmitter as in Fig. 1. Typical PU transmitters work in the TV white-space (TVWS) i.e. in the VHF - UHF band. Essentially, in cases where a free channel is identified, the CR-LPWAN GW initiates communication by broadcasting this free channel to participating LPWAN end nodes in the network (see Fig. 1). These end nodes may include sensors (such as in smart factories/industries) and these diverse LPWAN nodes may communicate to the CR-LPWAN GW via the identified white-space. Then, the GW may be linked to an IoT network server connected to different application servers based on the application area through a firewall. This generic CR-LPWAN network (see Fig. 1) will facilitate different IoT and IIoT-based applications since it confines the inclusion of the CR design and its operational complexities to the GW instead of the end nodes.

IV. A Generic PHY Layer Model for CR-LPWAN Systems

We present in Fig. 2 a generic PHY layer model for CR-LPWAN systems. Recall in Section III that the CR-LPWAN GW decides whether PU signals are present (H_1) or absent (H_0) in the sensed band based on adaptive threshold values [23]. If the H_0 case is true, the GW activates the spectrum access/sharing module (see Fig. 2) to prepare for LPWAN communication via the LPWAN module. However, if the H_1 case is true, the spectrum mobility module (see Fig. 2) is activated to expedite withdrawal from the band. This command is fed to the transmission controller in order to disengage any on-going transmission process in the LPWAN module. The GW then simultaneously activates the switching module to begin sensing again (receiving mode) instead of transmitting. However, if the H_0 case persists, then the LPWAN module is kept active for continuous transmission. The individual blocks in Fig. 2 are well known and details about each block can be found in [24]. However, we have introduced the LPWAN module to carter for other specific LPWAN PHY layer technologies, which are exclusively determined by each LPWAN developer. This may include the modulation type, band of operation, number of channels, link symmetry, adaptive data rates, payload length, and MAC layer operations such as forward error correction, handover, authentication and encryption. However, we do not discuss these LPWAN functions in this paper since they have been covered extensively in other documents such as [4], [25].

V. Conclusion

In this paper, we have presented a generic network architecture and a PHY layer front-end model that support the development of CR-LPWAN systems. The generic network architecture discussed here suggests that CR services in a LPWAN network should be deployed at the gateway (GW) instead of at the LPWAN end-nodes, since most GWs are usually equipped with better computing and memory resources, and with more robust power supply units. The PHY layer front-end model proposed in this paper incorporates basic sensing units along with other LPWAN functions in order to support existing diversity among different LPWAN developers. Essentially, our paper serves to spur the further development of CR-LPWAN systems with the aim to enhance IIoT and other IoT-based applications.

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