Cognitive Radio to enable communication infrastructure in Smart Grids

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***Abstract*— Smart grids (SG) arise from the need to modernize the current electrical network and there are projected like an advanced digital two-way power flow power system. A medullar component for SG to be a reality is having a reliable communication infrastructure where this two-way communication can take place. In this sense, an emerging technology that can enable SC is Cognitive Radio (CR). In this paper, a literature review on the state of the art of CR in SG is made and, derived from this, the use of the IEEE 802.22 standard is proposed to enable a Home Area Network (HAN).**

***Keywords*—Smart Grid, Cognitive Radio, HAN, WRAN**

I. Introduction

Smart Grids emerge in response to modernize the current power grid, integrate the control and monitoring process of green technologies, and also allow distributed energy resources (DERs) to be securely connected. The grids are autonomous, effective, and efficient in the management of electrical energy, allowing the utility companies to continue using existing infrastructure, avoiding or reducing the construction of new power plants [1].

The advances in communication systems, mainly those driven by the spread of the Internet, offer to the new power grid the possibility of performing flexible and effective operations of control and monitoring at a low cost. Smart grids are an opportunity to use communication and information technologies to the adaptation the current electric power systems of the new grid [2].

For the Smart Grid to become a reality, solid, reliable, and efficient communication infrastructure is needed to ensure the exchange of information. In these networks, the interconnection of many communication systems is expected. However, the current communication systems are not designed to support the new demands of the Smart grid. For this reason, several research works are oriented to search for solutions regarding communication technology to enable the network.

Cognitive Radio is a promising technology for the SG environment as it can increase spectral efficiency, transmission capacity responding to spectrum scarcity where licensed and unlicensed users coexist [3].

The remainder of this paper is structured as follows: Section II describes related work. The communications network architectures for SG are described in Section III. The advantages of using CR in SG communication infrastructure are presented in Section IV. In Section V, IEEE 802.22 is described. Section VI proposes a HAN base on CR. Finally, Section VII concludes the paper.

II. Related Work

In the literature, proposals are registered for using existing communications technologies to consolidate the smart grid [4]. As far as wireless communications are concerned, their progress makes them suitable for many of the SG applications. However, a disadvantage is that a fixed policy for spectrum allocation regulates these networks.

This allocation can be inefficient, therefore a proposal to address this challenge is the use of Cognitive Radio (CR) which uses the existing spectrum through timely access to licensed bands without interfering with the users of these bands (primary users). Another factor for the use of CR is that, according to SG's vision, many devices will be connected, which will cause congestion of the existing communication network. Therefore, CR is a suitable option to mitigate the spectrum scarcity derived from this machine-to-machine (M2M) communications. CR-based networks can help to efficiently collect and transport large volumes of data by making better use of spectrum. The use of spectrum gaps can provide low latency communication links.

There are four key functions in CR: spectrum sensing which is the finding of spectrum gaps, spectrum management which is the selection of the best available channel, spectrum mobility which is the movement from one channel to another and finally spectrum sharing which is the coordination of access to shared channels by the SUs.

Several authors propose in their works CR to provide a solution to this "spectrum crisis" in [5] a detailed description of each of the network layers and propose the use of a Genetic

Algorithm (GA) to configure the network using CR. The authors of [6] propose a new paradigm for spectrum access "Hybrid Spectrum Access", where licensed and unlicensed spectrum bands are dispatched. The authors investigate the optimal number of primary and secondary users through the use of Markov chains. In [7], they develop the mathematical model for an AMI network based on CR. The authors of [8] propose solutions to problems in SG networks using CR in three different scenarios. In [9] they propose using CR to improve the reliability of communication between SG network layers by proposing ISM and licensed bands as a backup and propose a rule to decide when to stop spectrum sensing.

III. Communications network architecture for Smart Grid

The communication layer is one of the critical elements to enable Smart grid application. In the context of SG, the communication network can be represented as a multilayer hierarchical architecture. According to the data rates it handles, coverage range, this can be classified into [10]:

- Network for local area users, for example, Home Area Network (HAN), Building Area Network (BAN), Industrial Area Network (INS).
- Neighborhood Area Network (NAN) o Field Area Network (FAN).
- Wide Area Network (WAN).

These layers of the network have many applications and diverse requirements of quality of service, and therefore it is considered a network of heterogeneous characteristics.

The communication infrastructure for the SG must fulfill three functions: sensing, transmission, and control. The embedded sensing system is in charge of many smart meters or sensors that detect at various points the state of the network in real-time. Two-way transmission links are needed to establish data communication between sensors and control centers. Therefore, the SG's communication network infrastructure has to integrate new technologies to achieve the new functions to achieve these purposes. The deployment of the SG will be geographically broad connecting a large set of nodes. Therefore, the communication infrastructure must foresee that it will be a multi-layered structure that extends across the entire SG [11].

A. Description of the communicaation network level

a) Local Networks. HAN/BAN/IAN networks allow communication between household appliances, electric vehicles, and any other electrical equipment of the network users. The HAN enables the communication between appliances and electrical equipment capable of sending and receiving signals to smart meters, in-home displays (IHDs), or Home Energy Management (HEM). These applications include automated homes, intelligent room temperature control, water heater temperature, control, and management of energy consumption. BAN and IAN networks have commercial and industrial purposes related to automation, ventilation, heating and air conditioning (HVAC), and other industrial energy management applications. They also act as gateways between HANs and NANs. These HAN/BAN/IAN networks require secure communication links, data rates from 10 to 100kb/s, and a coverage area of 100 to 200 m^2.

b) Neighborhood Area Network (NAN): This network-level allows communication between HAN and WAN (Wide Area Network); it covers the distribution and transmission domain of the electrical network. It allows collecting the information of the network users to transmit it to the companies that provide the service. This network is also called Field Area Network (FAN) as it also connects field equipment such as intelligent electronic devices (EDs). It enables applications such as smart metering, outage management, power quality monitoring, and distribution automation. It also includes a metering network part of one of the SG applications called AMI (Advanced Metering Infrastructure), allowing remote meter readings, control, and detection of unauthorized use. It allows electricity usage information to be transmitted from energy meters to a utility company or third-party system, allowing field devices to be remotely controlled, for example, in distribution automation applications. NAN/FAN NAN/FAN is connected to WAN via a network, where data from many NAN/FANs is aggregated and transported between NAN/FAN and WAN. Depending on the topology of the power grid (centralized/distributed) and the communication technology used, a NAN cluster can have a few hundred to a few thousand SMs (Smart Meters) covering several square kilometers, and each SM can need from 100 Kb/s to 10 Mb/s. A NAN is a critical section in an SG as it transports a large volume of diverse data and control information between service providers in WAN and smart devices in HAN.

c) WAN. This level is central to the communication of an SG, as it collects information from multiple NANs and forwards it to a control center. It covers transmission and power generation domains that enable long-distance communications between different Data Aggregation Points (DAPs) of power generation plants, control centers, substations, transmission and distribution networks, distributed resources power stations, etc. Therefore, it handles a high volume of data up to thousands of terabytes that is communicated through WAN to the link with the control center, with a required speed of 10 to 100 MB/s, covering hundreds of kilometers.

According to the description of the network layers in the previous section, the SG covers a wide geographical area.

B. Applications for the SG network

The entire operation of SG can be classified into multiple applications. According to the U.S. Department of Energy, in six categories fall, if not all, most of the applications described below [12] [13]:

1) AMI (Advanced Metering Infraestructure): To collect, analyze and measure energy consumption for billing purposes, load management, outage information through two-way communication between the consumer and utility.

2) DRM (Demand Response Management): To reduce energy consumption to users when the cost of electricity is higher.

3) WASA (Wide-Area Situational Awareness): To obtain a real-time network operation status, using advanced monitoring technologies.

4) DER (Distribuited Energy Resources): For large-scale energy storage, uninterruptible power supplies, and hybrid vehicle batteries.

5) Electric Transportatio: Energy storage devices initiate operation when a power outage is detected to balance demand on the grid.

6) DGM (Distribution Grid Management): To provide effective fault detection, with the ability to isolate faults and restore power, allowing service providers to monitor and control grid resources.

C. Challenges at the Communication Levels in a SG.

There are many challenges associated with upgrading to the current communication infrastructure to enable the objectives and applications of a SG. In summary, the key challenges are as follows [10] [3]:

- The SG network has different requirements than the existing communication networks since they were designed under different needs than the current ones, such as data rate, latency, number of users, new applications support. Therefore, it is also challenging to select the existing technologies and topologies to be used in the SG network.
- Lack of standards for interoperability, which are necessary for the effective deployment of communication networks in a SG environment as this network is displayed in a heterogeneous environment (Het-Net).
- Another setback is presented in the current wireless infrastructure, as fixed policies for spectrum allocation regulate conventional wireless networks. This fixed allocation turns out to be inefficient for using the spectrum. In other words, the SG network faces radio spectrum scarcity.
- The integration of other energy sources into the current electricity grid is also a challenge this grid proposal faces.
- Network security is also a critical point; the research is related to the search for security mechanisms to ensure the reliability and integrity of user information.

At [3] and [4], some proposed solutions are presented. This paper will be focus on radio spectrum scarcity.

IV. COGNITIVE RADIO AND THE SG

Cognitive radio has potential to support the demands of SG applications. According to [4], some of the advantages it has over other current wireless technologies are:

- In a HAN that will connect network smart meters and appliances, sensors, actuators; if technologies such as ZigBee, Bluetooth, and Wi-Fi are used, there is likely interference between the meters and the other components of the network that compete for data transfer in the ISM band (Industrial, scientific and medical frequency band) jeopardizing the reliability of communication with the use of CR parameters could be adapted to circumvent interference in the HAN to ensure reliable communication of the SG meter.
- Broadband wireless access, microwave, and cellular networks provide good coverage but only support licensed users. Using CR avoids licensing costs.
- Each layer of the SG architecture has its own environment and bandwidth requirements, and it isn't easy to adopt a single communication technology. Wireless LAN and WiMAX provide good coverage with high data rates and operate in either licensed or unlicensed spectrum or both. However, they cover a limited set of SG layers. On the other hand, SG communication is appropriate for all layers as well as for different applications.
- LTE (Long Term Evolution) is a fourth-generation communication technology (4G). It has extensive coverage, high data rates, and good mobility. LTE uses orthogonal frequency division multiple access (OFDM). This cellular technology operates in licensed frequency bands. Due to the bandwidth of 4G, many channels can be allocated to SG needs. These features of LTE make it a good choice for NAN and WAN layers. However, due to high monthly charges and high individual call costs, 4G communications are likely to be expensive for some remote sites that will be part of the SG network and data transmission. Another drawback is that 4G services are limited to cellular network coverage areas. If CR technology is incorporated into the 4G LTE network, resource blocks can be subdivided into smaller sub-channels, and CR devices can dynamically compete for the sub-channels that remain vacant.
- Fifth generation (5G) wireless systems are still under development and are proposed with high carrier frequencies and transmission bandwidths. The base stations will serve high densities of users and will be able to interact with other technologies. Therefore, 5G seems attractive to serve SG, as long as the service prices are profitable.

- One proposal to make CR in SG a reality is to use IEEE 802.22, the first television spectrum unused to provide broadband access to remote areas. This standard has various modes of operation, making it a candidate to have reliable communications in heterogeneous SG networks. This standard can transfer a large amount of data, and it can give bidirectional communication. In [14], the use of CR is proposed in a SG WAN network where the 802.22 standard is used for transmission, the authors show results for two scenarios: rural and urban, based on known propagation models. On the other hand, in [11], the authors describe the state of the art of communication technology for CR as open problems. They propose a network model that uses the 802.22 standard with a SDR (Software-defined radio) architecture.

V. IEEE 802.22 (WRAN USING TVWS)

Previously the VHF (54-216 MHz) and UHF (470-698 MHz) bands were used for licensed television transmission and wireless microphones. With the migration from analog to digital television, most of this spectrum became free. In 2010, the FCC allowed use of this spectrum to be used for secondary (unlicensed) wireless services. TVWS (TV White Spaces) means the unlicensed use of these gaps between occupied VHF and UHF channels [3].

IEEE 802.22 (TABLE 1) is a standard for wireless communication that provides broadband access to rural (hard-to-reach) areas using TVWS. It's intended to provide the service of cognitive radio (CR). According to the IEEE 802.2 specification of a CR, a network consists of a base station (BS) that manages access to the medium for all equipment in the coverage area. Multiple methods are considered to avoid interference to the primary user (PU). The first method is based on the recognition of the location of the primary user by equipping the BS with a GPS device that transmits the location of the PU's transmission on various channels to the central base. The database informs the BS about the vacant channels. The second method is based on spectrum sensing by the BS. Spectrum sensing can be done locally (by BS) or in a distributed manner in which CPEs (Consumer Premise Equipment) can also sense the spectrum and share information with the BS, which then decides which blank space to assign each CPE.

Due to the characteristics possessed by the VHF and UHF propagation band combined with CR technology, the IEEE 802.22 standard is one of the main proposals for SG [3]. In [12], the authors compare the performance of several IEEE 802.2 modes. The main objective of the work is to investigate which of these modes can be used in SG applications being one of its main contributions to the determination of limits in the channel quality to support the reliability requirements for each of these applications.

TABLE I. IEEE 802.22 (WRAN)

	IEEE 802.22 (WRAN)
Range	30-100 km
Maximun delay	11 to 60 s
Bandwith	6, 7, 8 MHz
Modulation	QPSK, 16-QAM, 64-QAM
Channel coding	Convolutive Codes, CTC, LDPC, STBC
Date rate	18 Mbps

VI. PROPOSED ARCHITECTURES FOR HOME NETWORKS (HAN) BASED ON COGNITIVE RADIO

An expected characteristic of the SG network is the interaction between the entities that form it using bidirectional communication. Within this new network model, there are diverse applications. Among them is AMI (Advanced Metering Infrastructure) (TABLE 2), constituted by a network of smart meters. These meters collect data and report to the service provider (SP) periodically instead of the monthly total of a conventional meter. It also caters to the SP with outage control and monitoring, disaster prevention, etc. Therefore, the communication in AMI is bi-directional and HAN and NAN networks are the right ones to provide the infrastructure. For example, a smart home communicates with meters on a HAN network, while meter-to-meter communication is through a NAN network.

TABLE II. COMMUNICATION REQUIREMENTS FOR AMI APPLICATIONS

Application	***Bandwidth***	***Latency***
AMI	10-100 Kbps/node 500 kbps for backhaul	2-15 s

There are several proposals in the literature to employ CR in the new smart grids. The following describes proposals that contemplate CR to enable SG using. The intention is to incorporate 802.22 as the cognitive channel (CH_2).

In [3] and [9], a HAN is proposed, which consists of smart meters as the main devices where the others equipment is connected (Smart appliances, etc.). These meters have the function of being a gateway between the HAN and the NAN. Therefore, they are called Home Gateways (HGW).

The HAN Network is useful at the application level as it is needed to implement the new SG functionalities. HAN provides consumption data to the smart meter in real-time and provides dynamic energy price information (two-way communication). HAN is essentially a heterogeneous network with several complementary technologies that are license-exempt. The devices that make up the network are HGW, smart meters, sensors, actuators, and other smart equipment, and the suggested topology is the star.

On the other hand in [15] propose a model they call CogHAN (Cognitive HAN), where smart meters periodically transmit measurement data to a HGW. They consider that the information can be transmitted on two wireless channels in the unlicensed spectrum, which they refer to as the source channel *Ch1*. The other is in the licensed spectrum, which they call the cognitive channel *Ch2*. The selection of one of the channels is done by the spectrum sensing technique. They propose to incorporate this function into the transreceiver smart meter. The authors consider Gaussian additive noise in the smart meter. In their simulation model they consider that the primary user at *Ch2* has a bandwidth W= 6 MHz. The minimum sampling rate is twice the PU bandwidth. The noise is AWGN. The authors consider a scenario with a low SNR level where $\gamma = -15\, dB$. The detection probability is set to 90% and P1= 0.25. The main contribution of this work is that by introducing spectrum sensing and channel switching techniques the reliability and delay time of communication can be improved.

According to SG's vision, in the home domain, a HAN network provides connectivity to the end-user. The authors of [10], [4] and [16] show a comparative study of current technologies and which of them are the most suitable for the new network. According to these studies, it is proposed that for the HAN network level, wireless communication technologies should be used.

VII. Conclusions

In this work, a literature review was done on the incorporation of Cognitive Radio (CR) in the next generation power grid. Based on the above sections, it is concluded that CR is an effective solution proposal to serve SG networks through IEEE 802.22 WRAN to satisfy the network applications.

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