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Flexible channel selection mechanism for cognitive radio based last mile smart grid communications

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ABSTRACT

Smart grid (SG) operation requires a reliable, accurate and effective communication link between the distributed meters and the control center. However, dedicating a portion of the spectrum is difficult due to the spectrum scarcity problem. Cognitive radio (CR) technology has been nominated as a good candidate for SG communications due to its efficiency and flexibility. Indeed, channel selection in CR-based SG systems is still an open issue, and it is investigated in this paper. The paper proposes a novel channel selection mechanism that is able to adapt the selection criteria based on the type of transmitted data. The proposed mechanism is proven to provide high performance compared to the non-adaptable mechanisms.

1. Cognitive radios for smart grid communication

The communications infrastructure for smart grid (SG) has recently received an increasing attention. Given the heterogeneity of the SG, it is necessary to clarify that the considered scenario in the paper consists of the communication links used to interconnect the distributed meters at the customers' side and the local control center. To some extent, from a communications perspective, this could be considered the last mile of the SG system. Many wireless technologies have been nominated in the literature as candidate infrastructures for SG communications in such scenario [1,2]. However, two main properties that may distinguish SG nature from other wireless systems: first, both the transmitter and receiver are always fixed, which alleviate many problems generated by mobile transmitters, such as fast channel variation, frequent handovers, etc.; second, a considerable part of the transmitted data has a regular (fixed) generation rate, i.e., both transmitter and receiver know who will send these data and when. Moreover, such types of data usually tolerate a relatively long delay (in communication terms). These properties should be taken into account in order to identify suitable, efficient and reliable communication infrastructures for the SG.

Cognitive radio (CR) technology is one of the candidate technologies to serve for last mile SG communications [3–5]. CR is an intelligent software-defined radio technology that facilitates efficient, reliable and dynamic use of the unused portions of the radio spectrum by adapting its configuration according to the environment radio conditions [6]. The IEEE 802.22 is the first standardization activity on CR networks based on opportunistic utilization of TV spectrum bands [7].

CR based on IEEE 802.22 represents a good candidate for last mile SG communications for several reasons, (i) Unlike other wireless technologies, CRs operate in unused TV frequencies, which, in view of spectrum scarcity, represents an extremely useful feature. (ii) high data rates up to tens of Mbps can be achieved by CR. (iii) Due to the long-range propagation characteristics of the TV bands, the coverage area can reach up to 100 kM. (iv) CR is adaptive, programmable

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and flexible, since it is built on a software-defined radio platform.

Although the above mentioned reasons can make CR a preferred choice for SG communication, three main issues should be still addressed. First, identifying the unused TV frequencies represents a key issue in CR implementation. Usually, information about band occupancy is obtained by a pre-process called spectrum sensing, which consumes time and energy [8]. Second, errors can occur in identifying the availability of the TV bands due to probable imperfect spectrum sensing, which is reflected on the reliability of cognitive transmission [9]. Third, cognitive transmission is a threatened transmission due to the possible and unpredictable appearance of the original licensed user during transmission. However, the last issue becomes less significant in case of CR based on IEEE 802.22 since a TV frequency that has been identified as vacant cannot be reused during CR's usage in the same area. As a consequence, the former two issues (the first and the second) are taken into consideration throughout this work.

Based on the dynamic smart grid communication environment and comprehensive communication applications in the smart grid architecture, researchers have explored different challenges of the CR-based SG communications in recent years [10,11]. Ghassemi et al. [12] studied current energy management requirements in the smart grid and employed CR as the solution for the communication requirements in the wide area networks (WANs) of SG, based on IEEE 802.22 standard. In particular, the additional bandwidth required for non-critical data is addressed by Ghassemi et al. [12]. Stand-alone radio and secondary radio were proposed for CR communication systems based on IEEE 802.22 standard. According to such two architectures, Ghassemi et al. [12] employed dual-radio scheme for CR-based transmission, which can offer an effective spectrum sensing process. Yu et al. [13] proposed a new spectrum access scheme named hybrid spectrum access (HSA) in which both licensed and unlicensed spectrum bands can be scheduled to guarantee the transmission services in SG. The HSA scheme is employed to balance the spectrum utilization and the QoS provisioning in different environments. Based on the HSA strategy, Yu et al. considered two types of spectrum sensing schemes, periodic and on-demand sensing. The transmission QoS in SG is improved via employing the various applications of the spectrum sensing schemes. Deng et al. in [14] delivered cognitive radio into SG to improve the communication quality in distribution network for balancing the real-time power demand and to schedule the peak load. Especially, in the data transmission process of smart meters, the decision of channel selection and the reduction the communication outage can be guaranteed by the spectrum sensing and channel switching, in which the licensed and unlicensed channels have equal opportunities to be selected. During the best sensing-performance tradeoff, the primary user using the licensed channel is protected. The sensing-performance tradeoff problem is formulated to explore the probability of lower communication cost. The collision of the communication outage is also analyzed for the power consumers.

The errors can occur during the process of spectrum sensing, maybe caused by dynamic parameters in the harsh SG environments, just as equipment noise, cross-tier interference and etc. According to this challenge, Shah et al. [15] presented a CR-based cross-layer framework to meet the QoS requirements of diverse SG applications. The proposed mechanism employed the emerging cognitive radio technology to reduce the noisy and congested spectrum bands, yielding reliable and high capacity wireless links for SG communications. Meanwhile, a distributed control algorithm (DCA) was also designed to support QoS via channel and control, scheduling and routing decisions, which maximizes the network utilization under the constraints of QoS.

Due to the features of IEEE 802.22 standard, CR based communication technologies can serve the SG applications with high reliability even in harsh environmental conditions. The growing demands of multimedia applications in SG communications require large bandwidth and network resources. In particular, large-size and time-sensitive multimedia delivery requires more reliability and stability in CR based SG communications. In this case, Wang et al. [16] and Huang et al. [17] explored related issues of CR based multimedia communications and delivered their own mechanisms. Considering the mutual interactions with the enhanced reliability and efficiency of whole SG system, Wang et al. [16] proposed a combined scheme of electrical and CR based networks to effectively support the wireless transmissions of large-sized multimedia data created by the dynamic SG applications. In order to achieve the required quality of experience (QoE) performance in the SG system, a CR networking paradigm is also proposed in [16] to efficiently manage the channel allocation for both primary users (PUs) and secondary users (SUs).

As we discussed previously, the CR based communication platform is essentially needed to support large-size multimedia data delivery in the SG environment. According to the various traffic types of SG communications, Huang et al. [17] developed CR-based channel allocation and traffic scheduling schemes to mitigate the risk in multimedia data transmission via employing CR based communication networks. In these schemes, two types of channel switch, including periodic switching and triggered switching are introduced. Meanwhile, the spectrum sensing errors are also considered for supporting such mechanisms. Based on the proposed schemes, the different traffic types in SG are prioritized for traffic scheduling of the SUs and the system utility optimization problem for SG communications system is solved as well.

In this paper, we focus on the channel selection in CR-based SG communications. Generally, several channel selection mechanisms in CR networks have been proposed. In [18], Jiang et al. created a dynamic programming approach to explore the channel selection scheme for an optimal sensing order with adaptive modulation. The optimal sensing order problem is settled in the scenario of multi-channel cognitive medium access control involved opportunistic transmissions. In the SNR-based channel selection scheme, the SNR is regulated in the time slot and changes stochastically in the previous and next time interval. The SNR is also denoted as the core parameter to create a common probability density function and the achievable transmission rate, in order to deliver the optimal selection mechanism of sensing order in even more complex scenarios. The dynamic transmission rate is settled to compare with expected rate on each