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Robust approach for spectrum sensing and spectrum allocation using cooperative game theory approach in cognitive radio wireless sensor networks

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ABSTRACT*:* A cognitive radio wireless sensor network is one of the candidate areas where cognitive techniques can be used for opportunistic spectrum access. Research in this area is still in its infancy, but it is progressing rapidly. The aim of this study is to classify the existing literature of this fast emerging application area of cognitive radio wireless sensor networks, highlight the key research that has already been undertaken, and indicate open problems. This paper describes the advantages of cognitive radio wireless sensor networks, the difference between *ad hoc* cognitive radio networks, wireless sensor networks, and cognitive radio wireless sensor networks, potential application areas of cognitive radio wireless sensor networks, challenges and research trend in cognitive radio wireless sensor networks. The sensing schemes suited for cognitive radio wireless sensor networks scenarios are discussed with an emphasis on cooperation and spectrum access methods that ensure the availability of the required QoS. Finally, this paper lists several open research challenges aimed at drawing the attention of the readers toward the important issues that need to be addressed before the vision of completely autonomous cognitive radio wireless sensor networks can be realized.

Keywords**:** sensor networks, cognitive sensors, cognitive wireless sensor networks.

I. INTRODUCTION

A. Wireless Sensor Networks

A wireless sensor network is composed of a large number of sensor nodes, which are densely deployed. They are able to observe a wide variety of ambient conditions which include temperature, humidity, vehicular movement, lighting conditions, pressure, the presence or absence of certain kinds of objects, etc. [1]. For current WSN solutions, a key feature is operation in unlicensed frequency band i.e. the worldwide available 2.4 GHz band. However, other popular wireless applications such as Bluetooth, WiFi and other proprietary technologies also share the same band. As a result, the unlicensed band is becoming overcrowded and eventually one network may degrade the performance of the other. That is why; coexistence in unlicensed band is one of the key issues in research.

Conventional WSN. Communications in wireless sensor networks (WSNs) are event driven. Whenever an event triggers wireless sensor (WS) nodes generate bursty traffic. In a dense network environment, wireless sensor nodes deployed in the same area might try to access a channel whenever an event occurs. Recently, many sensitive and critical activities are being monitored and observed increasingly using WSNs. Several heterogeneous WSNs can exist, which causes a long waiting time for the delay sensitive data. Wireless sensors are normally deployed in inaccessible terrain. Therefore, the self-organizing ability and lifetime of the WS nodes are very important. WSNs consist of hundreds of WS nodes deployed throughout the sensor field and the distance between two neighboring WS nodes is generally limited to few meters. A sink node or base station is responsible for collecting the data from the WS nodes in single or multiple-hop manner. The sink node then sends the collected data to the users via a gateway, often using the internet or any other communication channel. Figure 1 shows the scenario of conventional WSNs.

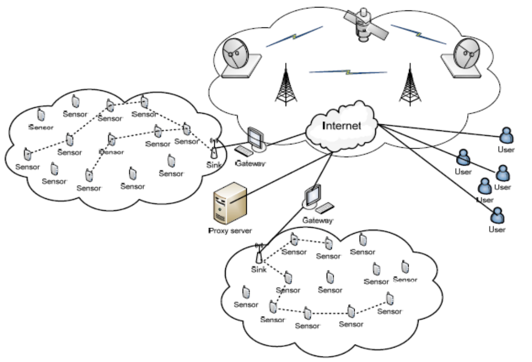

Fig.1. Conventional WSN network.

Current WSNs operate in the ISM band, which is shared by many other successful communication technologies. Research has shown that this coexistence in the ISM band can degrade the performance of the WSNs. The wide deployments, large transmit power, and large coverage range of IEEE 802.11 devices and other proprietary devices can degrade the performance of WSNs significantly when operating in overlapping frequency bands. The coexistence of wireless personal area networks (WPAN) with other wireless devices operating in an unlicensed frequency band is addressed in reference [2].

WSN devices are not only a victim but are also an interferer sometimes [3]. The coexistence interference can be avoided by the intelligent use of three types of diversity, namely frequency, time and space. Coexistence issues in unlicensed bands have been the subject of extensive research. Some solutions are also suggested in references [4–6]. Researchers and industry are working to improve the performance of WSNs in terms of cost, energy consumption, data rate, robustness, networks throughput, QoS and security, etc. Considerable hardware and software enhancement has been implemented in recent years to enhance the network performance. A range of logical techniques have been employed to achieve the required network performance, such as power aware MAC, cross-layer design technique, efficient sensing technique, and significant enhancement in hardware design, etc., but these techniques have their own limitations.

B. Cognitive Radios

Increasing usage of wireless communications triggered the development of dynamic spectrum access schemes. The key enabling technology providing dynamic, i.e., opportunistic, spectrum access is the cognitive radio (CR) [7]. Cognitive radio has the capability to sense the spectrum and determine the vacant bands. By dynamically changing its operating parameters, cognitive radio can make use of these available bands in an opportunistic manner surpassing the traditional fixed spectrum assignment approach in terms of overall spectrum utilization. With these capabilities, cognitive radios can operate in licensed bands as well as in unlicensed bands. In licensed bands, wireless users with a specific license to communicate over the allocated band, i.e., the primary user (PU), has the priority to access the channel. Cognitive radio users, called secondary users (SU), can access the channel as long as they do not cause interference to the PU. Upon the natural habitants of a specific frequency band, i.e., PU, start communication; the cognitive radio users must detect the potentially vacant bands, i.e., spectrum sensing. Then, they decide on which channels to move, i.e., spectrum decision. Finally, they adapt their transceiver so that the active communications are continued over the new channel, i.e., spectrum handoff. This sequence of operation outlines a typical cognitive cycle [8], which can also be applied over an unlicensed band by all cognitive radio users with the same priority to access the channel. The capabilities of cognitive radio may provide many of the current wireless systems with adaptability to existing spectrum allocation in the deployment field, and hence improve overall spectrum utilization. Among many others, these features can also be used to meet many of the unique requirements and challenges of wireless sensor networks (WSN), which are, traditionally, assumed to employ fixed spectrum allocation and characterized by resource constraints in terms of communication and processing capabilities of low-end sensor nodes.

In fact, a WSN comprised of sensor nodes equipped with cognitive radio may benefit from the potential advantages of the salient features of dynamic spectrum access such as:

• Opportunistic channel usage for bursty traffic:

Upon the detection of an event in WSN, sensor nodes generate traffic of packet bursts. At the same time, in densely deployed sensor networks, a large number of nodes within the event area try to acquire the channel. This increases probability of collisions, and hence, decreases the overall communication reliability due to packet losses leading to excessive power consumption and packet delay. Here, sensor nodes with cognitive radio capability may opportunistically access to multiple alternative channels to alleviate these potential challenges.

• Dynamic spectrum access: In general, the existing WSN deployments assume fixed spectrum allocation. However, WSN must either be operated in unlicensed bands, or a spectrum lease for a licensed band must be obtained.

Generally, high costs are associated with a spectrum lease, which would, in turn, amplify the overall cost of deployment. This is also contradictory with the main design principles ofWSN [9]. On the other hand, unlicensed bands are also used by other devices such as IEEE802.11 wireless local area network (WLAN) hotspots, PDAs and Bluetooth devices as shown in Table I. Therefore, sensor networks experience crowded spectrum problem [10]. Hence, in order to maximize the network performance and be able to co-operate efficiently with other types of users, opportunistic spectrum access schemes must be utilized in WSN as well.

- Using adaptability to reduce power consumption: Time varying nature of wireless channel causes energy consumption due to packet losses and retransmissions. Cognitive radio capable sensor nodes may be able to change their operating parameters to adapt to channel conditions. This capability can be used to increase transmission efficiency, and hence, help reduce power used for transmission and reception.

• Overlaid deployment of multiple concurrent WSN:
With the increased usage of sensor networks, one specific area may host several sensor networks deployed to operate towards fulfilling specific requirements of different applications. In this case, dynamic spectrum management may significantly contribute to the efficient co-existence of spatially overlapping sensor networks in terms of communication performance and resource utilization.

• Access to multiple channels to conform to different spectrum regulations:
Each country has its own spectrum regulation rules. A certain band available in one country may not be available in another. Traditional WSN with a preset working frequency may not be deployed in cases where manufactured nodes are to be deployed in different regions. However, if nodes were to be equipped with cognitive radio capability, they would overcome the spectrum availability problem by changing their communication frequency.

Adopting Cognitive Method in WSN

Recently, cognitive techniques have been used in wireless networks to circumvent the limitations imposed by conventional WSNs. Cognitive radio (CR) is a candidate for the next generation of wireless communications system. The cognitive technique is the process of knowing through perception, planning, reasoning, acting, and continuously updating and upgrading with a history of learning. If cognitive radio can be integrated with wireless sensors, it can overcome the many challenges in current WSNs. CR has the ability to know the unutilized spectrum in a license and unlicensed spectrum band, and utilize the unused spectrum opportunistically. The incumbents or primary users (PU) have the right to use the spectrum anytime, whereas secondary users (SU) can utilize the spectrum only when the PU is not using it. Some recent papers in this paradigm, such as references [11–16], proposed wireless sensor equipped with cognitive radio as one of the promising candidates for improving the efficiency of WSNs. Table 1 lists the capabilities a wireless sensor with a CR needs to have.

Table 1: Prospective capabilities of a wireless sensor with CR.

FUNCTION	ACTION
COGNITIVE CAPABILITIES	
SPECTRUM SENSING	DETECT UNUSED SPACES BY THE INCUMBENTS IN THE SPECTRUM BANDS
SPECTRUM SHARING	USE THE UNUSED WHITE SPACES OF INCUMBENTS AND SHARE WHITE SPACE INFORMATION WITH COGNITIVE USERS,
PREDICTION	PREDICT THE ARRIVAL INCUMBENTS ON THE CHANNEL
FAIRNESS	DISTRIBUTION OF SPECTRUM UTILIZATION OPPORTUNITY FAIRLY AMONG COGNITIVE USERS
ROUTING	ROUTE THE PACKET TO THE DESTINATION EFFICIENTLY CONSIDERING THE NETWORK LIFE SPAN, LOAD BALANCING, SHORTEST ROUTE AND DELAY IN MULTI-HOP CR-WSNS
RECONFIGURATION CAPABILITY	RECONFIGURE AND ADJUST ACCORDING TO THE ENVIRONMENT OUTCOMES
ENVIRONMENT SENSING	SENSING THE ENVIRONMENTAL FACTORS AS IN CONVENTIONAL WIRELESS SENSORS.
TRUST AND SECURITY	BUILDING A TRUSTABLE ENVIRONMENT AND SECURE NETWORKS
POWER CONTROL	CONTROL TRANSMISSION POWER CONSIDERING THE LEGAL BOUNDARIES REQUIREMENTS

Therefore, it is conceivable to provide wireless sensor networks with the capabilities of cognitive radio and dynamic spectrum management. This defines a new sensor network paradigm, i.e., Cognitive Radio Sensor Networks (CRSN). In general, a CRSN can be defined as a distributed network of wireless cognitive radio sensor nodes, which sense an event signal and collaboratively communicate their readings dynamically over available spectrum bands in a multi-hop manner ultimately to satisfy the application-specific requirements.

While the above potential advantages and the definition of CRSN stand as a significant enhancement of traditional sensor networks, the realization of CRSN depends on addressing many difficult challenges, posed by the unique characteristics of both cognitive radio and sensor networks, and further amplified by their union. Among many others, inherent resource constraints of sensor nodes, additional communication and processing demand imposed by cognitive radio capability, design of low-cost and power-efficient cognitive radio sensor nodes, efficient opportunistic spectrum access in densely deployed sensor networks, multi-hop and collaborative communication over licensed and unlicensed spectrum bands are primary obstacles to the design and practical deployment of CRSN.

Despite the extensive volume of research results on WSN [8] and considerable amount of ongoing research efforts on cognitive radio networks [1], CRSN is vastly unexplored field. In [17], an energy-efficient and adaptive modulation technique is introduced for CRSN in order to achieve high power efficiency towards maximizing the lifetime of resource constrained sensor networks. In [18], CRSN is discussed for applications such as health care and tele-medicine, which require timely delivery of critical information. Authors propose a centralized spectrum allocation scheme with game theoretic approach in order to achieve fair allocation of spectrum bands with maximum spectrum utilization and energy efficiency. Potential of dynamic spectrum access in sensor networks is shown in [19] to achieve high power efficiency in sensing applications by reducing interference of concurrent transmissions through distributed channel selection and power allocation. Clearly, only a handful of studies reviewed above do not suffice to open the road towards the realization of cognitive radio networks. The abovementioned fundamental challenges and many others need to be precisely determined and effectively addressed in order to exploit the potential advantages of CRSN. In this paper, we introduce the main design challenges and principles, potential advantages and application areas, and network architectures of CRSN. The existing communication protocols and algorithms devised for cognitive radio networks as well as WSN are explored from the perspective of CRSN and the open research avenues for the realization of CRSN are highlighted. Our objective is to provide a clear picture of potentials of cognitive radio sensor networks, the current state of-the-art and the research issues on this timely and exciting topic.

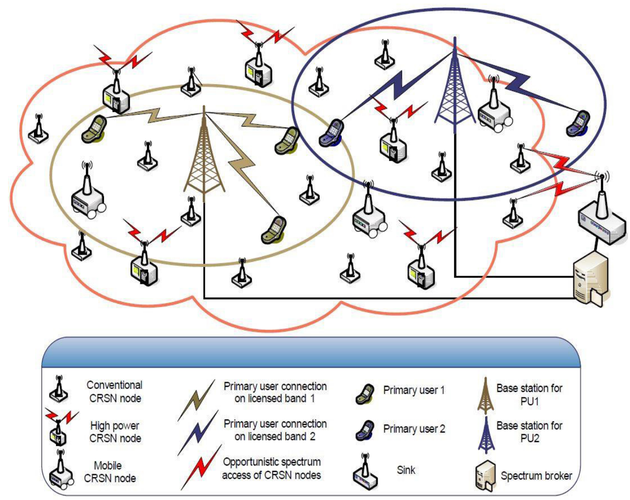

Fig. 2. A typical cognitive sensor network (CRSN) architecture.

A wireless sensor network (WSN) composed of sensor nodes equipped with cognitive radio is called cognitive radio sensor network (CRSN). In general, a CRSN can be defined as a distributed network of wireless cognitive radio sensor nodes, which sense event signals and collaboratively communicate their readings dynamically over available spectrum bands in a multihop manner to ultimately satisfy the application-specific requirements. A typical CRSN architecture is shown in Figure 2. Over which the information obtained from the field is conveyed to the sink in multiple hops. The main duty of the sensor nodes is to perform sensing on the environment. In addition to this conventional sensing duty, CRSN nodes also perform sensing on the spectrum. Depending on the spectrum availability, sensor nodes transmit their readings in an opportunistic manner to their next hop cognitive radio sensor nodes, and ultimately, to the sink. The sink may be equipped with cognitive radio capability, i.e., cognitive radio sink. However, it is a great challenge to adopt the CR principle to sense the underutilized spectrum dynamically. Moreover, applying the existing protocols and algorithms for CRNs and WSNs in CRSNs is the key issue raised in research.

Problem identification

Medium Access Control has an important role in several cognitive radio functions: spectrum mobility, channel sensing, resource allocation, and spectrum sharing. When a primary user is detected, spectrum mobility allows a SU to vacate its channel and to access an idle band [4]. Channel sensing is the process of collecting the information about spectrum usage and maintaining the information of available channels dynamically. Several techniques for channel sensing in the physical layer have been proposed in this literature. This sensing is abstracted in the MAC layer to identify whether the channel is occupied by PUs or not. Available channels are assigned to cognitive users opportunistically by resource allocation. There may be multiple cognitive users trying to access the spectrum. SUs should coordinate their access to the available spectrum channel. Spectrum sharing is employed to prevent multiple users colliding. MAC layer functions in a cognitive radio can be summarized as follows [4]:

- To obtain information on channel occupancy. This information will be used by a SU to decide whether to transmit data or not and whether to switch to a new channel or not.
- To perform negotiation among PUs and SUs for spectrum allocation, and also among SUs to perform channel sensing and channel access.
- To synchronize transmission parameters (e.g., channel, time slot) between transmitter and receiver.
- To facilitate spectrum trading functions (e.g., spectrum bidding and spectrum pricing), which involve PUs (or primary service providers) and SUs (or secondary service providers).

Recently, number of studies associated to CR MAC protocols and WSN have been proposed and a few publications have already been made reviewing the CRSN. In [20], advantages and limitations for the realizations of CRSN have been discussed. Furthermore, using multiple channel availability provided by CR capabilities to overcome the problems caused by the dense deployment and bursty communication nature of sensor networks has also been discussed. Performance of a CR-based WSN with standard Zigbee/802.15.4 has been compared in [21]. In [22], infrastructure based and ad-hoc cognitive MAC protocols are classified according to the exploited medium access scheme. In [23], a general review in CRN spectrum management has been provided. MAC functionalities and current research challenges of Cognitive Radio Ad Hoc Networks (CRAHNs) are discussed in [24]. In [25] opportunistic networks are divided according to the infrastructure, in centralized and distributed networks. Moreover, several MAC protocols have been reviewed according to their classification. A comprehensive overview of state of art for cognitive radio network has been presented in [26]. In [27], route selection strategy combined with spectrum characteristic in decentralized cognitive radio network has been studied. In [28], signal feature detection method using SCF (Spectral Correlation Function) is discussed. It analyzed main signal patterns using the SCF method and compared main special points of several signal types by simulation factors as follows: center carrier frequency, modulation type, signal pattern, and so on. In [29], an improved version of Cyclostationary feature detection spectrum sensing technique is proposed and it shows better performance even in low SNR environment.

The Major Challenges in WSN network:

In spite of the attractive features of WSNs, there are several challenges that have to be considered in the design of the protocols and architectures that can achieve the end-to-end goals and requirements of the network. Some examples of these goals are the maximization of network lifetime, maximization of throughput, or achieving a target level of reliability of communications, among others [2] [3]. Thus, some of the important WSN challenges include:

- **Limited Energy of Nodes**: this is usually the most important challenge in WSNs. This is because the deployed network has a target lifetime specified by the designer, which can be several months or even more than one year. However, nodes typically have small sizes and operate using non-rechargeable batteries. Replacing these batteries after deployment is highly challenging to several reasons that may include the remoteness of the location or the large size of the network. Thus, energy efficiency is essential in all aspects of the WSN, including protocols, hardware, firmware, etc. Management of energy resources must be done from a network perspective and not just at individual nodes, since the collective lifetime of the network needs to be maximized. Since communication tasks typically consume the most energy, issues such as interference management, transmission scheduling, and energy-efficient routing become critical. Even if some renewable energy resources are available at nodes, such as solar panels, network protocols have to ensure that the rate of energy consumption is slower than the rate of energy generation.

- **Architectural Issues**: WSN topologies are dynamic. Nodes may die over time, changing the topology of the network. They may also be mobile. Moreover, nodes within a WSN usually employ sleep scheduling in order to conserve energy and increase lifetime. These issues must be considered by network protocols such as routing and scheduling. The heterogeneity of nodes is also important and should be exploited by protocols to improve network efficiency. Nodes with higher capabilities can relieve some of the processing and communication burdens of nodes with lower capabilities.

- **Different Traffic Patterns**: Data delivery in WSNs may have different patterns. They may be event-driven, query-driven, or periodical. Furthermore, communication in WSNs may be point-to-point (P2P), point-to-multi-point (P2MP), or multi-point-to-point (MP2P). For example, individual nodes may exchange data, the sink node may send packets to several nodes simultaneously, or several nodes may send their data to the sink. Therefore, network protocols should be flexible in supporting all the patterns required by the application.

- **Connectivity and Coverage**: The WSN is deployed to cover a specific area or some specific targets. Sometimes the application requires that each target area be covered by more than one sensor node. In addition, every node must be able to find a path to a sink node. Thus, network protocols must guarantee connectivity and coverage when performing sleep/active scheduling. This must be done in an energy-efficient manner in order to avoid rapid energy consumption.

- **Quality of Service (QoS) Requirements**: With the progress made in hardware and software design for WSNs, some advanced applications may now be supported. Therefore, some applications may require the support of strict metrics such as latency, reliability, bandwidth, or throughput. These metrics must be supported end-to-end, not just for individual links. This may be a highly challenging task due to the limited processing and communication capabilities of nodes. Network protocols must strive to support the requirements of different applications in an energy-efficient manner.

- **Other Challenges**: Scalability and fault-tolerance are common challenges in WSNs, since networks typically operate for extended periods of time and are often large in size. In addition, it is recommended that protocols be designed in a distributed way since centralized protocols requires gathering information from all parts of the network, which may be very expensive in terms of energy consumption. However, distributed protocols typically rely on localized information which means that decisions may not be optimum for the whole network. This trade off must be considered during protocol design.

II. RELATED WORK

In [P. Spachos and D. Hantzinakos, 2014] the authors have presented a cognitive networking with opportunistic routing protocol for WSNs is introduced. The objective of the proposed protocol is to improve the network performance after increasing network scalability. The performance of the proposed protocol is evaluated through simulations. An accurate channel model is built to evaluate the signal strength in different areas of a complex indoor environment. Then, a discrete event simulator is applied to examine the performance of the proposed protocol in comparison with two other routing protocols.

In [S. Chatterjee, S. P. Maity and T. Acharya, 2014] the authors have considered a System model involves co-located multiple amplify-and-forward relays in single cognitive radio source-destination (S-D) environment with a primary focus on optimal relay power allocation strategy. The problem is mathematically formulated as minimization of total energy consumption under the constraints of sensing reliability (in terms of detection and false alarm probabilities), secondary user throughput and interference threshold to primary user. Then a cluster based nonequal relay power allocation is also suggested. Extensive simulation results illustrate the variation of the minimum energy consumption with the key system parameters.

In [M. L. Treust, S. Lasaulce, Y. Hayel, G. He, 2013] the authors have presented a decentralized network of cognitive and noncognitive transmitters where each transmitter aims at maximizing his energy efficiency is considered. The cognitive transmitters are assumed to be able to sense the transmit power of their noncognitive counterparts and the former have a cost for sensing. The Stackelberg equilibrium analysis of this two-level hierarchical game is conducted, which allows us to better understand the effects of cognition on energy efficiency. In particular, it is proven that the network energy efficiency is maximized when only a given fraction of terminals are cognitive. Then, study about sensing game where all the transmitters are assumed to take the decision of whether to sense (namely to be cognitive) or not is carried out. This game is shown to be a weighted potential game, and its set of equilibria is studied. Playing the sensing game in a first phase (e.g., of a time slot) and then playing the power control game is shown to be more efficient individually for all transmitters than playing a game where a transmitter would jointly optimize whether to sense his power level, showing the existence of a kind of Braess paradox.

In [A. Aijaz, S. Ping, M. R. Akhavan and A. H. Aghvami,2014] the authors have considered Wireless sensor networks (WSNs) have been widely recognized as a promising solution for enhancing various aspects of electric power grid and realizing the vision of smart grid. However, the challenging wireless environment in smart grid creates a number of challenges for WSNs, as a result of which energy efficiency and reliability become critically important. On the other hand, cognitive radio (CR) technology is expected to play a vital role in smart grid networks.

The CR equipped sensor networks [or cognitive sensor networks (CSNs)] can effectively address the unique challenges of WSNs in smart grid. In this paper, we aim to design an energy efficient and reliable medium access control (MAC) protocol for CSNs. In this regard, we propose CRB-MAC which is a receiver-based MAC protocol for CSNs. The CRB-MAC uses preamble sampling and opportunistic forwarding techniques for providing high energy efficiency and reliability. In addition, CRB-MAC explicitly accounts for the peculiarities of a CR environment. Analytical and simulation results demonstrate the effectiveness of CRB-MAC as a viable solution for CSNs.

In [R. C. Qiu *et al.,*2011] the authors have systematically investigated the novel idea of applying the next generation wireless technology, cognitive radio network, for the smart grid. In particular, system architecture, algorithms, and hardware testbed are studied. A micro-grid testbed supporting both power flow and information flow is also proposed. Control strategies and security considerations are discussed. Furthermore, the concept of independent component analysis (ICA) in combination with the robust principal component analysis (PCA) technique is employed to recover data from the simultaneous smart meter wireless transmissions in the presence of strong wideband interference.

In [S. Althunibat; A. Abu-Al-Aish; W. F. Abu Shehab; W. H. Alsawalmeh, 2016] the authors have proposed a novel data gathering scheme for Wireless Sensor Networks (WSN) that limits the energy expenditure, and hence, prolongs network lifetime. Data gathering is modeled as an auction where a node broadcasts its own result only if it is higher than the maximum already-broadcasted result by other nodes.

In [J. Ren, Y. Zhang, N. Zhang, D. Zhang and X. Shen,2016] the authors have investigated the dynamic channel accessing problem to improve the energy efficiency for a clustered CRSN. Under the primary users' protection requirement, resource allocation issues to maximize the energy efficiency of utilizing a licensed channel for intra-cluster and inter-cluster data transmission, respectively, study is carried out. With the consideration of the energy consumption in channel sensing and switching, condition when sensor nodes should sense and switch to a licensed channel for improving the energy efficiency, according to the packet loss rate of the license-free channel are determined. In addition, two dynamic channel accessing schemes are proposed to identify the channel sensing and switching sequences for intra-cluster and inter-cluster data transmission, respectively.

Research Gap. In the previous works, network performance is still a challenging task for the researchers. These challenges includes: network life time, network throughput energy consumption etc. In the literature, appropriate communication mode is node discussed which affects the network lifetime. To overcome this we propose cooperative game theoretic approach for the network lifetime improvement.

Existing approaches performance degrades when implemented for the large communication network or area. In this stage, energy consumption is main issue to be resolved.

For larger networks, spectrum sensing and resource allocation is also challenging task.In the multihop scenario, sensors have a dual role: they sense the environment and they also route the packets of their neighbors towards the sink (and vice versa).

Packet forwarding and optimal path selection are performed by following an appropriate routing protocol.

Another issue is cognitive capability of the network which allows sensors to sense the environment for white spaces based on this a spectrum management strategy need to be developed to decide which band to use for transmission and how to estimate the related-to-transmission physical layer parameters (frequency, modulation type, power, etc.). The cognitive cycle consists of several mechanisms: (i) radio environment, (ii) spectrum sensing, (iii) spectrum analysis, and (iv) spectrum decision.

III. PROPOSED SYSTEM

The proposed system has the following objectives.

- Study about the wireless sensor networks and cognitive radios
- Performance evaluation of wireless sensor network
- Implementation of cognitive radio model for wireless sensor networks
- Implementation of game theory approach for cognitive radio wireless sensor network
- Performance evaluation of proposed approach of cooperative cognitive radio wireless sensor network
- Implementation of energy harvesting techniques for cognitive radio wireless sensor networks
- Improving the spectrum sensing and resource allocation strategies
- Comparative study of other state-of-art technology with proposed approach

IV. METHODOLOGY

Cognitive radio sensor nodes form wireless communication architecture of CRSN as shown Fig. 1 over which the information obtained from the field is conveyed to the sink in multiple hops. The main duty of the sensor nodes is to perform sensing on the environment. In addition to this conventional sensing duty, CRSN nodes also perform sensing on the spectrum.

Depending on the spectrum availability, sensor nodes transmit their readings in an opportunistic manner to their next hop cognitive radio sensor nodes, and ultimately, to the sink. The sink may be also equipped with cognitive radio capability, i.e., cognitive radio sink. In addition to the event readings, sensors may exchange additional information with the sink including control data for group formation, spectrum allocation, spectrum handoff-aware route determination depending on the specific topology.

A typical sensor field contains resource-constrained CRSN nodes and CRSN sink. However, in certain application scenarios, special nodes with high power sources, i.e., actors, which act upon the sensed event, may be part of the architecture as well. These nodes perform additional tasks like local spectrum bargaining, or acting as a spectrum broker. Therefore, they may be actively part of the network topology. It is assumed that the sink has unlimited power and a number of cognitive transceivers, enabling it to transmit and receive multiple data flows concurrently.

In our proposed approach, we apply cooperative game theory approach for cognitive radio wireless sensor networks.

CRSN Node Structure. CRSN node hardware structure is mainly composed of sensing unit, processor unit, memory unit, power unit, and cognitive radio transceiver unit as abstracted in Fig. 2.

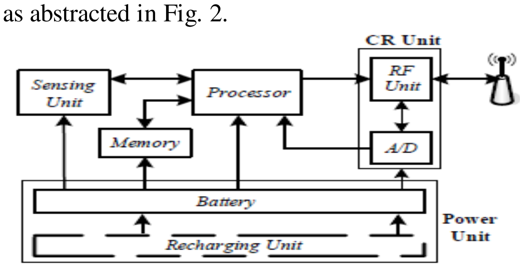

Fig. 3. Hardware structure of a cognitive radio sensor node.

In specific applications, CRSN nodes may have mobilization and localization units as well. The main difference between the hardware structure of classical sensor nodes [3] and CRSN nodes is the cognitive radio transceiver of CRSN nodes. As discussed in Section V-A, cognitive radio unit enables the sensor nodes to dynamically adapt their communication parameters such as carrier frequency, transmission power, and modulation. CRSN nodes also inherit the limitations of conventional sensor nodes in terms of power, communication, processing and memory resources. These limitations impose restrictions on the features of cognitive radio as well. For example, as will be discussed in Section IV-A, CRSN nodes may perform spectrum sensing over a limited band of the spectrum due to processing, power, and antenna size constraints. Consequently, CRSN nodes are generally constrained in terms of the degree of freedom provided by the cognitive radio capability as well.

CRSN Topology. According to the application requirements, cognitive radio sensor networks may exhibit different network topologies as explored in the following.

1) Ad Hoc CRSN: Without any infrastructural element, inherent network deployment of sensor networks yields an ad hoc cognitive radio sensor network as shown in Fig. 1. Nodes send their readings to the sink in multiple hops, in an ad-hoc manner.

In ad hoc CRSN, spectrum sensing may be performed by each node individually or collaboratively in a distributed way. Similarly, spectrum allocation can also be based on the individual decision of sensor nodes. This topology imposes almost no communication overhead in terms of control data. However, due to hidden terminal problem, spectrum sensing results may be inaccurate, causing performance degradation in the primary user network.

2) Clustered CRSN: In general, it is essential to designate a common channel to exchange various control data, such as spectrum sensing results, spectrum allocation data, neighbor discovery and maintenance information. Most of the time, it may not be possible to find such common channel available throughout the entire network. However, it has been shown in [22] that finding a common channel in a certain restricted locality is highly possible due to the spatial correlation of channel availability. Therefore, a cluster-based network architecture as in Fig. 3(a) is an appropriate choice for effective operation of dynamic spectrum management in CRSN. In this case, cluster-heads may also be assigned to handle additional tasks such as the collection and dissemination of spectrum availability information, and the local bargaining of spectrum. To this end, new cluster-head selection and cluster formation algorithms may be developed for CRSN which jointly consider the inherent resource constraints as well as the challenges and requirements of opportunistic access in CRSN.

3) Heterogeneous and Hierarchical CRSN: In some cases, CRSN architecture may incorporate special nodes equipped with more or renewable power sources such as the actor nodes in wireless sensor and actor networks (WSAN) [21]. These nodes may have longer transmission ranges, and hence, be used as relay nodes much like the mesh network case. This forms a heterogeneous and multi-layer hierarchical topology consisting of ordinary CRSN nodes, high power relay nodes, e.g., cognitive radio actor nodes, and the sink as shown in Fig. 3(b). While the presence of capable actor nodes may be exploited for effective opportunistic access over the CRSN, the associated heterogeneity brings additional challenges.

Among the others, sensor and actor deployment, increased communication overhead due to hierarchical coordination, and the need for cognitive radio capability over the actor nodes need to be addressed.

4) Mobile CRSN: When some or all of the architectural elements of a CRSN are mobile, this yields a more dynamic topology, i.e., a mobile CRSN. For example, the sensor nodes, actors if exist, and even the sink might be mobile depending on the specific application and deployment scenario. Clearly, mobility amplifies the existing challenges on most of the aspects of CRSN. First of all, the dynamic nature of the topology requires mobility-aware dynamic spectrum management solutions over resource-constrained CRSN nodes. Moreover, cognitive radio communication protocols for CRSN must consider mobility as well. Therefore, this specific CRSN architecture needs a thorough investigation of the challenges and solution techniques.

V. POSSIBLE OUTCOME

A CR wireless sensor network is a type of wireless sensor network that comprises spatially-distributed autonomous CR equipped wireless sensors to monitor the physical or environmental conditions cooperatively. This paper discusses the evolution of CR-WSNs, opportunities, technical issues, research trends and challenges. Some of the recent research results in CR-WSNs were surveyed. CR wireless sensor networks are still in their infancy. Several areas remain to be explored and improved. For the success of CR-WSNs, massive research is required in several aspects. Substantial developments in hardware, software and algorithms are needed to make smart CR wireless sensors.

Expected outcomes of the proposed approach are:

1. Energy efficient sensor network model
2. Better spectrum sensing when compared to non-cooperative approach
3. Reliable and improved throughput providing architecture
4. Spectrum handoff performance
5. Reliable information about channel and spectrum occupancy
6. Better results in terms of spectrum allocation

VI. CONCLUSION

A CR wireless sensor network is a type of wireless sensor network that comprises spatially-distributed autonomous CR equipped wireless sensors to monitor the physical or environmental conditions cooperatively. This paper discusses the evolution of CR-WSNs, opportunities, technical issues, research trends and challenges. Some of the recent research results in CR-WSNs were surveyed. CR wireless sensor networks are still in their infancy. Several areas remain to be explored and improved. For the success of CR-WSNs, massive research is required in several aspects. Substantial developments in hardware, software and algorithms are needed to make smart CR wireless sensors.

The following are the potential challenges for the success of CR-WSNs

- Development of a wireless sensor with the required cognitive capabilities,
- Development of extremely low power consumable CR wireless sensor with energy harvesting facilities,
- Capability of operating at high volumetric densities,
- Producing low cost CR wireless sensors,
- Development of autonomous and unattended operable algorithms and protocols,
- Highly intelligent and adaptive to the environment
- Should be robust on security for attacks and should work in an untrustworthy environment,
- Development of globally operable CR wireless sensor etc

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