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Design MAC protocol for Cognitive Radio Wireless Sensor Networks based on network requirements

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ABSTRACT

Cognitive radio (CR) technology is envisaged to solve problems in wireless networks resulting from the limited available spectrum usage by exploiting the existing wireless spectrum opportunistically that are not utilized. CR allows unlicensed users to access licensed frequency bands, under the condition of protecting the quality of service of the licensed networks. Thus, attaching Wireless Sensor Networks (WSNs) with CR technology, spectrum scarcity problem can be solved. This paper introduces a new definition for Cognitive Radio Wireless Sensor Networks (CRWSNs). It shows a brief overview on WSNs and CR tasks. It states the potential advantages of attaching cognitive radio capability with wireless sensor network. An investigation about designing a special MAC protocol for CRWSN is proposed. Study some parameters that affect the MAC protocol designing. Paper also discusses some challenges and open researches that face CRWSN MAC protocol. Finally, we present health care network as an example on WSN applications to clarify network's requirements based on application.

Keywords:-Cognitive Radio; Wireless Sensor Networks; MAC protocol.

1.INTRODUCTION

For more than a decade, a huge number of researches have been published in Wireless Sensor Networks (WSNs) topic, due to its importance in modern human life. Nowadays, WSNs have numerous numbers of applications [1]. Military applications, environmental monitoring, e-health, home/building automation, industrial etc... are some important applications of WSNs. WSNs consist of "spatially distributed autonomous devices [1] which make use of sensors to cooperatively monitor physical or environmental conditions, such as temperature, humidity, sound, pressure, motion or pollutants etc...". Recently, WSNs become the interface between real world and digital world.

In order to provide this wireless service currently, industrial, scientific and medical (ISM) band become the unlicensed operating frequencies for these networks. Unfortunately, with the explosive application of 802.11b, 802.15.1 and 802.15.4, it is notable that the human world will be full of electronic devices and most of them work on the same or overlapping frequency spectrum. Table 1 shows some services for certain standards which operate in ISM band including their number of channels and bandwidth of each channel.

Table 1 some standards that operate in ISM band

Standard	Service	Operating Band	Number of channels	Chanel Bandwidth
IEEE 802.11	Ad hoc network	2.4 GHz	78	1 MHz
IEEE 802.11.b	WiFi	2.4 GHz	14	5 MHz
IEEE 802.15.1	Bluetooth	2.4 GHz	79	1 MHz
IEEE 802.15.4	Wireless Sensor Network	2.4 GHz	16	5 MHz

When these electronic devices, such as wireless keyboards, wireless PDAs, wireless cell phone headsets and wireless sensor networks, are bought home and used in the same building, it is obvious that the 2.4 GHz ISM band will be congested and overloaded. What is worse, the widely used electric appliances like microwaves can also generate very strong interference. To obtain a better understanding of the crowded spectrum, in the presence of electronic devices as well as electric applications, in [2], the authors measured the 2.4GHz ISM band spectrum usage with a Spectrum Analyzer. They showed that these devices cause interference covers almost half of the 2.4 GHz of the spectrum. In addition, it is expected that in 5-10 years, there will exist many thousands, if not millions, of sensor networks. All these problems will cause a huge interference for existing wireless sensor networks [3].

One solution for this crowded spectrum is to introduce more unlicensed frequency band, and the Federal Communications Commission (FCC) [4] is responsible of this issue, and hence is beyond our scope and ability. A second solution is to use spread spectrum techniques to reduce interferences among devices which also is out of our scope. Using Cognitive Radio technique (CR) is the third solution which is our focus in this paper.

The FCC report “spectrum policy task force” [4] states that a large portion in the licensed bands is still unutilized or unused most of the time. Therefore, the FCC has permitted for the unlicensed users to access these bands but under some constraints.

The concept of cognitive radio (CR) has been proposed to make use of the unused spectrum at a given time and place [5]. Using CR concept, unlicensed (secondary) users can make use of under-utilized licensed frequency bands without violating the licensed (primary) users. In CRs, Secondary Users (SUs) do not have pre-assigned frequency bands but they dynamically search, find and operate in an available band without constraining the Primary Users (PUs).

To have the ability to coexist with PUs, SUs should be equipped with Dynamic Spectrum Access (DSA) functions. DSA techniques allow the cognitive radio to operate in the best available channel. More specifically, the cognitive radio technology will enable the users (SUs) to determine which portions in the spectrum is available and detect the presence of licensed users when a user operates in a licensed band (spectrum sensing), select the best available channel (spectrum management), coordinate access to this channel with other users (spectrum sharing), and vacate the channel when a licensed user is detected (spectrum mobility) [6].

By applying CR technique, the wireless networks will be more intelligence to be capable of choosing the best available channel in the spectrum (at a certain time and place). So, it is possible to attach WSN with CR technique to enhance the network performance. This new network is called Cognitive Radio Wireless Sensor Network (CRWSN) and its nodes are called Cognitive Radio Sensor Node (CRSN). The authors in [7] defined a Cognitive Radio Wireless Sensor Network (CRWSN) as “it is a distributed network consists of wireless sensor nodes which equipped with Cognitive radio to sense a specific event and send collected data dynamically over available spectrum bands”. Also, a CR-based WSN can be defined as “a clustered network of wireless cognitive radio sensor nodes, which sense event signals and collaboratively communicate their information dynamically over available spectrum bands in a multi-hop manner to ultimately satisfy the application-specific requirements” according to [8]. In addition more researches define CRWSN in other several ways [9]- [12].

The next sections are organized as follows. Section II introduces a brief explanation of a traditional WSN and cognitive radio tasks. While section III states the advantages of using CR over a WSN. In section IV, some recommended features required for designing a MAC protocol for CRWSN are shown. Some challenges and open research issues are discussed in Section V. health care example is showed in section VI to make clear network requirements based on a certain application. Finally, section VII concludes the paper.

2.TRADITIONAL WSN AND CR TASKS

This section presents an overview on a traditional WSN and its topology. Also, CR tasks that needed to be attached for each node will be shown.

A. Traditional WSN

Most WSN is a network consisting of distributed low-cost devices equipped with sensing hardware to monitor and report environmental values. Sensor nodes should be aggregated to form clusters based on their power levels and proximity to

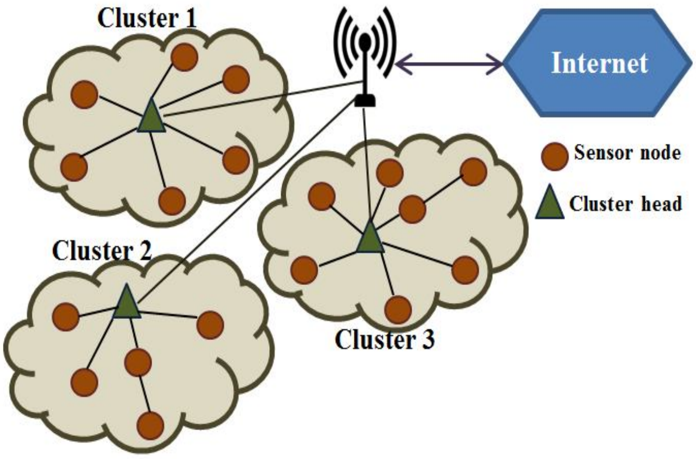

Fig 1. The model of a traditional WSN

make the communication process easier. The aggregation process should also be recursively applied to form a hierarchy of clusters, shown as figure 1 [8].

Within a cluster, a cluster head will be elected to perform information filtering, fusion, and aggregation from the others sensor nodes. The clustering algorithm will be constrained with the wireless communication capability, and will involve localized interactions among sensor nodes.

In case of the cluster head fails or runs low on battery power, the clustering process may be reinitiated again [8]. In addition, the clustering algorithm architecture may be centralized or distributed.

B.CR tasks

Cognitive radio cycle consists of four spectrum management functions which are spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility [13]:

- **Spectrum sensing:** A CR user should monitor the available spectrum bands to allocate the unused channels in the spectrum, and then detect holes that exist in this spectrum. Spectrum sensing could be done by primary transmitter detection or, primary receiver detection or, interference temperature management.
- **Spectrum decision:** Once the available channels are recognized, then CR users select the most suitable band due to their QoS requirements. It is essential to specify the spectrum band in terms of both network environment and the statistical behaviors of the PUs. To design a decision algorithm that incorporates dynamic spectrum characteristics, it is required to obtain information about the PU activity.
- **Spectrum sharing:** in case of multiple CR users trying to access the band, their transmissions should be coordinated to avoid interference and collisions between users or between networks that share the same band. Spectrum sharing provides the capability to share the spectrum between CR users which also try to avoid interference with the primary network. This function requires a special CR medium access control (MAC) protocol to facilitate the sensing control to be distributed among shared nodes as well as the required time to access the spectrum for transmission.
- **Spectrum mobility:** once a PU is found in a certain part of the spectrum, users should vacate this portion immediately and transmit in another channel in the spectrum. So, spectrum mobility necessitates a spectrum handoff scheme to detect the link failure and to switch the current transmission to a new route or a new spectrum band with minimum quality degradation. This requires collaborating between spectrum sensing, neighbor discovery in a link layer, and routing protocols. Also, SUs may switch their channel in case it doesn't meet their QoS requirements.

3.ADVANTAGES OF USING CR IN WSNS

CRWSN is a new paradigm in a WSN area that utilizes the spectrum resource efficiently for bursty traffic. This section discusses the benefits of using cognitive radio in WSNs.

A.Capability of developing new technologies and utilizing spectrum efficiently

As stated before, ISM bands are overcrowded which cause limitation in adding new technologies. However, FCC has stated that many licensed spectrum bands are unutilized (i.e. TV band). Cognitive radio wireless sensors can use the unutilized spectrum, without interfering with PUs. Unlicensed users can use those bands with no cost. Therefore, more technologies can be developed and added for these bands.

B.Multiple Channels' Utilization

In WSNs, upon the detection of an event, sensor nodes generate the traffic of packet bursts. In heavily WSNs, numerous number of wireless sensor nodes within same area, they try to access the same channel at the same time. In most WSNs, a single channel is used for transmissions [14]. Unfortunately, single channel usage increases the collisions probability, and reduces network throughput due to packet losses. This leads to more power consumption and packet delay. CRWSNs are able to access multiple channels opportunistically to ease this potential challenge, hence, using multiple channels reduce collision and increase network utilization which leads to save more power.

C.Minimum spectrum handoff

The other primary objective of WSNs is longest time functionality. However, the dynamic spectrum access leads to supplemental energy consumption at each sensor due to the spectrum handoff. The authors in [15] have simulated ZigBee standard radio using OMNET++ 3.3 and measured the amount of energy, which is consumed when a spectrum handoff occurs. The simulation results show that a single spectrum handoff consumes approximately 96.06% of the average receiving energy or 110.75% of the average transmitting energy. It means that the more instant spectrum handoffs lead to the more power consumption. Hence unnecessary spectrum handoff should be eliminated which save more energy. This issue can be done using CR capability by choosing the most stable channels that are rarely used by PUs.

D.Less number of devices in large areas

CRWSN will allow covering large areas with less devices as the lower the operating frequency the lower noise and the higher powered the signal at the receiver (i.e. the sink), or we can say that network can have more sensor nodes with less transmitted power.

E.Global Operability

Each country has its own spectrum regulation rules. Each one assigns a certain band for WSN which might not be available in another. On the other hand, if sensor nodes attached with cognitive radio capability, they can overcome the spectrum incompatibility problem by changing their used frequency band. Therefore, CRWSN may have the capability to operate anywhere in the world.

F.Avoiding Attacks

Unlike CRWSN, most traditional wireless sensors work only on certain frequency bands. That is why they are easily attacked or spammed. Taking advantage of the wide range of spectrum usability and dynamic spectrum access, SUs in CRWSNs can avoid several types of attacks.

4.DESIGNING CRWSN MAC PROTOCOL

Cognitive Radios (CR) are a type of radios capable of switching channels and adapting their transmission parameters in real-time. Common MAC protocols do not provide, in general, mechanisms for channel switching. When having multiple independent channels to be used simultaneously, the need for enhanced Multi-channel MAC protocols becomes essential.

Secondary users equipped with a cognitive radio, in a multi-channel environment, may improve the efficiency of spectrum utilization and thus increase the network throughput. There are several desired features for an efficient cognitive MAC protocol:

- It should be able to predict future spectrum usage based on statistics of local spectrum utilization up to the current time instance. To implement this feature, a CR device should monitor the spectrum usage continually to maintain an accurate view of spectrum utilization.

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- Reduce interference among secondary users and share available frequencies between them.
- It should protect PUs against harmful interference.
- Try to increase network throughput due to simultaneous transmissions on different channels.
- Try to reduce the number of CRs affected by the return of a licensed user.

Also in WSN, there are some attributes that should be considered in designing a MAC protocol for these networks such as:

- Energy efficiency and power consideration as the battery-operated nodes are often very difficult to change or recharge.
- The protocol should fit the topology of the WSN, which here means that the protocol should be adaptable to the multi-hop WSN, instead of networks with just a few nodes.
- Optimization of network parameters such as throughput, network life time, latency and packet loss etc.
- Sharing the available frequencies among nodes in the network.

So, the challenge here is to achieve the requirements of each network type (WSN and CRN) by designing a proper MAC protocol suiting both. This section shows our thinking about designing a proper MAC protocol based on networks requirements.

Figure 2 shows the infrastructure of CRWSN. This infrastructure consists of the number of radios on each CRSN user, the transmission channel protocols, network architecture and the common control channel management. These elements affect a corresponding MAC protocol design. Each element is selected based on a certain application or feature. The detailed analysis of the infrastructure perspectives is presented in the following subsections.

A. Network Architecture

Generally, the type of network architecture becomes one of the major factors which should be considered before designing a MAC protocol. When a PU starts communication, the cognitive radio sensor node must detect the potentially vacant bands (spectrum sensing), decide onto which channel to move (spectrum decision), and then finally adapt its transceiver so that the active communication continues over the new channel (spectrum handoff). According to the application requirements, cognitive radio sensor networks may exhibit different network topologies such as cluster, centralized and distributed CR network.

1)Centralized networks

A centralized CRWSN network is equipped with a center to collect and process all network information (i.e. Base station) as clear in figure 3. In general, the center will require every sensor node to inform their states and objectives, and then make the decision for all DSA functions based on system objectives. In [15], [16], [17], a centralized network for CRWSN is proposed. As number of users increase in the

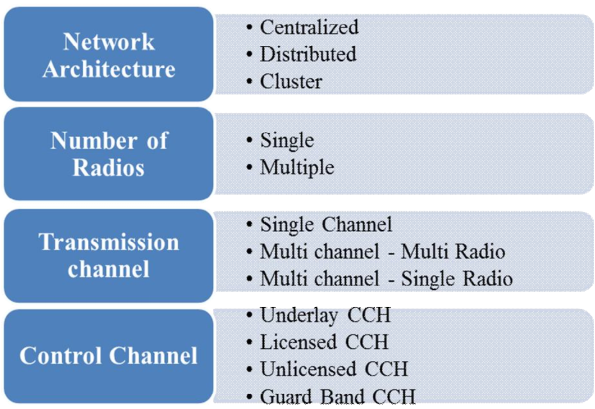

Fig 2. Network Infrastructure

network, centralized networks show higher performance than distributed networks. Therefore, these types of networks are more suitable for WSN networks as they have a large number of nodes.

The IEEE 802.22 [18] Working Group on Wireless Regional Area Networks (WRANs) is an example of a centralized network for CR. It is responsible for developing standards for a cognitive radio-based PHY/MAC/air interface for use by license-exempted devices on a non-interfering basis in spectrum that is allocated to the TV Broadcast Service.

IEEE 802.22 is a centralized protocol that provides three Mechanisms for Incumbent Protection:

- Sensing.
- Database Access.
- Specially Designed Beacon.

2)Distributed networks

Distributed CRWSN network (i.e. ad-hoc networks) hasn't any infrastructural element (i.e. Access point) as shown in Figure 4. Nodes transmit their data or readings to the sink in an ad hoc manner (may be in multiple hops manner). In this scenario, spectrum sensing is done by each node or in a cooperative manner. Similarly, spectrum allocation can also be based on the individual decision of nodes or in a cooperative manner. But, hidden terminal problem may cause spectrum sensing results to be inaccurate, which leads to degrade the performance of the network. This problem can be solved using RTS/CTS mechanism in IEEE 802.11[19].

Therefore, designing MAC protocols in such scenarios have to ensure mechanisms for collecting and exchanging network information in every sensor node independently. According to the individual behavior of users, there are two types of MAC protocols for distributed networks: cooperative protocol and non-cooperative protocol.

In a cooperative protocol, sensor nodes implement a collaboration process to exchange measurements information with each other, and then make decisions based on DSA functions according to network objectives.

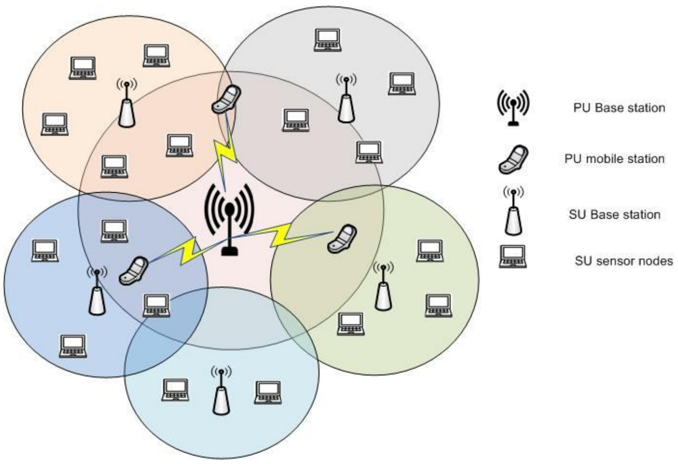

Fig 3. Centralized network topology of a CRWSN

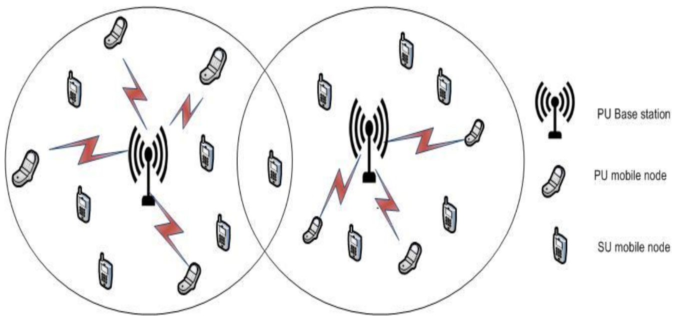

Fig 4. Distributed network topology of a CRWSN

The decisions in these circumstances are oriented more towards overall benefit than individual benefit. Optimal and fair decision could be made based on cooperative game theories (as in [15]) or optimization. These kinds of networks are usually used in WSNs.

In a non-cooperative protocol, a node uses collected information about the network environment to make decisions that maximize its own benefit only. The collected information about the network environment may derive from either its local observation or neighboring collaborated data.

Some researchers have been proposed for distributed networks such as, [20]-[23] which are considered as distributed CR networks while [24], [25], are considered as distributed CRWSN networks.

3)Clustered networks

A concept design for a CRWSN was proposed in [8]. They define CRWSN as "a clustered network of wireless cognitive radio sensor nodes, which sense event signals and collaboratively communicate their information dynamically over available spectrum bands in a multi-hop manner to ultimately satisfy the application-specific requirements".

Referring to the previous definition and figure 1, sensor nodes also perform sensing on the spectrum. Depending on the spectrum availability, they transmit their collaborative information in an opportunistic manner to their next hop CRWSN, and finally, to the sink (it may also equipped with CR capability). Moreover, sensors may exchange additional information with the sink including control data for group formation, spectrum allocation, and spectrum handoff-aware depending on PU's behavior or a specific topology.

Cluster-heads may be assigned to handle additional tasks such as the collection and broadcasting of spectrum availability information, and the local bargaining of spectrum. A new cluster-head selection and cluster formation algorithms may be developed for CRWSN which jointly consider the inherent resource constraints as well as the challenges and requirements of opportunistic access in CRWSN. Some of researches introduce MAC protocols based on cluster networks as in [26].

B.Number of Radios

Moreover, CRWSN network is classified into single radio-nodes networks and multiple radio-nodes networks. The number of radios affects most of DSA functions and hence determines the format of CRWSN-MAC protocol.

1)Single Radio

The advantages of a using single radio per node are low cost, less power consumption and simple hardware design. However, once the node that has a single radio senses the media and starts transmission process, it can't detect the presence of PU. Hence, these nodes have a higher probability in colliding with PU. In addition, single radio users also do not allow simultaneous multichannel transmission. Hence, these networks have lower data rate than multiple radio protocols.

To implement multichannel communication with single radio devices, channel bonding techniques are required as in [24]. Therefore, designing a MAC protocol that schedules appropriate slots to effectively perform signaling, sensing and transmitting data is a challenge, especially for the in-band control channel case. Many previous works consider CR-MAC protocol for networks equipped with single radio [20] - [23]. Also, related works are introduced for CRWSN-MAC using single radio [16], [25], [26].

2)Multiple Radios

Dissimilarity to single radio devices, multiple radio users are equipped with more than one radio. Thus, the multiple radio users require higher cost, more power consumption and need special balancing in hardware designing. However, it is possible to design CR-MAC protocols that utilize one separate radio for listening to the control channel or for out of band sensing. As a result, packet collisions would be decreased and the multi-channel hidden terminal problem would not occur. In addition, false alarm detection probability decreases. Many previous works in CR-MAC can be found in [18],[27] and in CRWSN-MAC can be found in [17], [28].

For a traditional WSN, it is preferable to use a single radio, due to power limitations of WSN nodes. Therefore, CR nodes need to reduce collision probability with PUs. This problem can be solved as will be explained later in section V.A.

C.Transmission Channels

One of the important issues that affects to communication techniques is the number of spectrum channels that are used for transmitting data. CRWSN-MAC protocols can be categorized to single channel and multi-channel protocols.

1)Single Channel Protocols

The single channel protocols are simple in design where the communication data is transmitted in only one channel for each transmitter and receiver pair. It is a half-duplex communication system.

Although the supported data rate with single channel communication is lower than that with multiple channels, the low requirement for spectrum resource results in a longer connection of secondary access. In addition, since this type of protocol includes single radio devices, the cost for it is usually low.

2)Multi-Channel Protocols

In a multi-channel communication scheme, each pair of transmitter and receiver is allowed to transmit data through multi-channel simultaneously. Generally, depending on the number of radios equipped on devices, there are two classifications for multi-channel protocols, i.e., multi-channel multi-radio protocols and multi-channel single-radio protocols.

In multi-channel single-radio protocols, a CR device equipped with a single radio will transmit data through multiple channels with the support of channel aggregation/bonding techniques [24]. However, it is difficult to perform the aggregation for non-contiguous channels with a single radio due to the limitation of the radio technique.

While in multi-channel multi-radio protocols, a CR device equipped with multiple radios, and each radio operates on a certain channel. Therefore, the multi-channel transmission can be conducted easily, even in the non-contiguous channels case. Although, the total network throughput increases, the cost for CRSN devices will increase due to using multiple radios as stated before.

D.Common Control Channel Selection

A Common Control Channel (CCCH) is introduced for the negotiations between SUs in order to inform them about the available channels. By using CCCH, the hidden terminal problem had been solved [19]. To access this channel, SUs will depend on CSMA protocol with a random backoff to reduce the probability of collisions between the active SUs desiring to access the CCCH at the same time.

In addition, Management control signaling is a critical issue for designing a MAC protocol for CRWSN as it used for network initialization, nodes negotiation, reporting available channels and neighbors list ….etc. Since a CRWSN network requires a larger amount of control signaling than a conventional network (i.e. reporting the existence of PU). Beside, signaling on establishing connection, networks have to manage control signaling on implementing dynamic spectrum access functions. There are four possible approaches in selecting the location of CCCH [29]: out-of-band CCCH, in-band CCCH, underlay CCCH and guard band CCCH. The two first approaches adopt interweave access mode, whereas the third approach utilizes underlay access mode finally the fourth approach is OFDM access mode.

1)Out-of-Band CCCH

An out-of-band CCCH is separated from in-band data channels, for exchanging only control information. However, it is difficult to obtain such a free from interference CCCH for a CR network since users have to perform opportunistic secondary access to a licensed band. Thus, there are two possibilities for a dedicated CCCH: licensed out-of-band CCCH and unlicensed out-of-band CCCH. The first approach requires more cost and may not be easy to get such a certain channel but it is through a stable CCCH and doesn't require sensing. Unlike licensed dedicated CCCH, unlicensed out-of-band CCCH is not guaranteed and needs continuous sensing but has no cost. It may hop in time intervals according to primary user operation. Therefore, designing the protocol requires more efforts, especially for designing network startup and node joining procedures.

2)In-Band Control Channel

Another approach for managing control information that solves the above problems is in-band signaling, i.e., transmission data and control messages are exchanged in the same channel. Therefore, control messages can be exchanged without any CCCH. This type of signaling is suitable for distributed/ad-hoc CR networks since it is difficult to obtain a commonly available channel between nodes due to the limitation of the available resources. Channel hopping for both transmission data and control messages is an example for this in-band CCCH method. The disadvantage of this approach is bandwidth waste due to splitting the channel into control phase and data phase [30]. It is also a non-reliable channel for CR.

3)Underlay Control Channel

Another suggestion in choosing a stable band for the CCCH is using underlay scheme. Underlay [13] or interference avoidance model allows concurrent transmission of primary and secondary users in a certain band where the primary users are protected by enforcing spectral masks on the secondary signals so that the generated interference is below the noise floor for the primary user. The devices will use spread spectrum technique or UWB mode in signaling transmission in the CCCH. The advantage of applying this technique is ensuring that the PU activity doesn't affect the CCCH and it also protected from the SUs activities. But in this technique a special antenna design is required to be equipped with devices in order to operate with large bandwidth and it also requires a Software Defined Radio to control the transmission processes as they will use spread spectrum scheme in signaling transmission and Interweave scheme in data transmission.

4)Guard Band CCCH

In order to choose a channel that acts as a CCCH, the most stable channel is needed. Therefore, working on guard areas or guard bands between channels without interfering with primary users have been suggested in [31].

The guard band is an unused part of a certain spectrum between the channels, for the purpose of preventing interference. It is a narrow frequency range used to separate two wider frequency ranges to ensure that both can transmit simultaneously without interfering each other. It is also forbidden to transmit data on these bands by PUs.

The advantage of using the guard areas is that they are unused by PUs, so they are the most stable areas in the entire band. But if these guard areas have a very small bandwidth then it may lead to CCCH saturation. Therefore, one of the suggested ideas is to use multiple guard areas for a CCCH and transmit information via these areas by using load balancing technique or OFDM access mode. This approach needs a special synchronization in this network. Unfortunately, synchronization issue is very difficult to be applicable in some networks, i.e. ad hoc. The number of guard areas required for a CCCH depends on the number of SUs in the network. The total bandwidth required is proportional to the number of SUs. The mathematical relation that controls the number of guard areas is still under discussion.

Finally table 2 summarizes advantages and disadvantages of each parameter stated before.

5.CHALLENGES AND OPEN RESEARCH ISSUES

As mentioned, CRWSNs differ from WSNs in many features in order to protect licensed users (PUs). Hence, CRWSNs have many new challenges besides the challenges that exist in normal WSNs. This section discusses the challenges affecting the design of a CRWSN. It also presents our suggested solutions for these challenges.

A. Channel assignment

As stated, cognitive radio networks has no dedicated channel to send data. Channels should be elected taking into consideration the PU's behavior.
In order to predict the PU’s behavior, CRSNs should have a separate transceiver or radio for in-band sensing (current used channel). This solution ensures full protection to the PU. Unfortunately, as discussed this issue is not preferable by sensor nodes.

Then, in order to solve consuming power issue for sensor nodes, they should have one transceiver for transmitting data and sensing. On the other hand, to reduce the collisions among SUs and PUs as stated before, there are several suggested proposed solutions. These solutions like:

- Using a database besides sensing (i.e. IEEE 802.22) [18]. Some applications (such as TV) have their own database. It contains number of currently used and unused channels which can be used to know the availability of PU in a certain channel.
- Using a prediction model [32] to expect the PU behavior in occupancy a channel. Some of this prediction models are neural networks, Hidden Markov Model (HMM), Exponential smoothing model (ESM) [20], Auto Regressive

model (ARM) and Bayesian Interference model (BIF). These models have been used to reduce sensing requirements times in order to maximize network throughput and reduce consumed energy by channels sensing.

- Sense the channel periodically between SU's transmitted frames as in [22], [23]. This period should be less than the time of PU's frame in order to avoid collisions with PUs. But, this solution is not desirable by SN's as it require more power to be used in sensing durations.

In [15], a Modified Game Theory (MGT) has been used to allocate spectrum bands under some resource-constrained wireless sensor network: (1) as fairly as possible, (2) achieving maximum spectrum utilization, (3) reflecting the priority, and (4) with infrequent spectrum handoff. They adopt a cooperative game-based algorithm to solve the MGT in a reasonable time. The experimental results of MGT are well balanced between the two objectives: maximizing the proportional fairness while minimizing the number of spectrum handoffs. Comparing the solutions of MGT with other bounds have showed, and observed that the algorithm provides near optimal solutions.
Although the proposed scheme operates in a centralized manner, it may also be feasible to allocate spectrum band in a distributive manner by combining it with a non-cooperative game algorithm. Since the non-cooperative game algorithm operates on a resource-constrained sensor, it should be implemented as less computationally complex as possible and with low message overhead, this become part of future research work.
Another channel assignment algorithm is shown by [17] for CRSNs. By using multi radio for each node, the algorithm depends on grid based algorithm. It presents two advantages. First, low overhead used for the channel assignment mechanism. Second, the network is robust against inter and intra interference. Unfortunately using multi radio per device cause more power consumption and need special hardware balancing. This high consuming in power is not preferable by sensor nodes due to their limited energy.
While in [25], a new channel assignment technique for CRSNs has been suggested. They define CRSN' channel assignment as identification of spectrum white holes (vacant band) and allocating an appropriate single channel to each sensor network link. The advantages of this assignment technique that it has less sensing time which leads to reduce the consumed power. The other advantage is offering less collision and less handover. But this technique needs cooperation between PUs and SUs in order to manage the occupation of the available channels between them. Therefore, it needs some modifications in PU's hardware to execute this cooperation.
By using one transceiver, [21] also presents a channel assignment scheme based on Exponential Smoothing Model (ESM) [20]. This scheme can be applied on centralized or distributed networks and slotted or non-slotted structure. ESM tries to predict the behavior of PU in next OFF state to exploit this period by SUs (could be CRSNs). Its performance shows higher throughput and less sensing overhead but it also shows higher collision which is needed to be controlled.

B. Spectrum sensing

One of the challenging features of the white space is its variation across space and time. More specific the available channels are not contiguous and vary from one location to another due to PU's behavior. In addition, the white space available in a given location can vary through time if one or more of the primary users start/stop operation. Therefore, a sensing approach for the SU is needed to be able to detect correctly the used channels by PUs and report the unused channels to other SUs. It also has to protect the PUs from harmful interference caused by these CR devices.
However, the advantages of opportunistic spectrum access (e.g., more bandwidth, lower error rate due to the ability to switch to the best channel, smaller contention delay) come with

Table 2 Advantages and disadvantages of MAC parameters

Main Parameters		Advantages	Disadvantages
No. of Radios	**Single**	Low Cost Low power Consumption Simple H.W design	Higher probability in colliding with PUs Lower data rate
	Multiple	Less false detection Low collision MCHTP solved	Higher cost Power consumption Need balancing H.W design
Transmission protocol	**Single channel**	Simple Single radio	Lower data rate Half duplex
	Multi channel – single radio	Higher data rate Low power consumption Low cost	Limited resources Complicated
	Multi channel – multi radio	Higher data rate Full duplex No aggregation	More complicated High power consumption High cost

CCCH	**Guard band**	Stable - guarantee No CCCH bottleneck	Complicated High power consumption
	Underlay	Stable - guarantee No CCCH bottleneck Low power transmission	Short range Need routing or clustering strategies
	Licensed	Stable - guarantee No sensing	Cost
	Unlicensed	No cost Transmit data and control messages at the same channel	Need continuous sensing CCCH bottleneck

the additional power consumption imposed by spectrum sensing and distribution of sensing results. Therefore, thorough analysis of cost vs. benefits for a specific CRSN application must be performed. This issue adds more challenges in order to select the most suitable technique with less consumed power.

There are various spectrum sensing methods, which are examined below in terms of how they can be applied to CRWSNs [33]:

- Matched filter detection.
- Energy detection.
- Cyclostationary feature detection.
- Interference detection.

Matched filter approach, in [7],[33] a demodulation of the PU's information signal is required, such as the modulation type and order, pulse shaping, packet format, operating frequency, bandwidth, etc. CRSNs receive the required information from the PU's pilots, or spreading codes etc. This approach is the optimal spectrum sensing approach in case of Gaussian noise. The advantage of this approach is that it does not require a long time in processing and requires fewer samples of the received signal. This advantage reduces the received signal SNR. Unfortunately, this approach consumes much power and needs high complex design and perfect knowledge of the target users.

Energy detection approach [18], depends on measuring energy level of the pilot carrier for each channel. If this carrier is above a certain threshold then it means that PU occupies this channel and vice versa. Therefore, Energy detection technique is a simple technique that requires a very small time in sensing, compared to other techniques. It also consumes less power than others. In [34], they try to implement this technique on

CRWSN using MATLAB Simulink. But, they state that “The main drawback of energy detection is that it can’t distinguish between noise and energy of the signal. Under low SNR conditions energy detector detects that primary user is present in all around the spectrum if it is white noise”. It also can’t recognize the used channel exploited by PU or another SU.

Cyclostationary feature detection approach [7], [33] is used to determine if indeed the signal energy that is due to the presence of PU or another SU. Characteristics of the transmitted signal should be covered which a number of features that could be has exploited for feature detection algorithms such as: modulated signals are coupled with sine wave carriers, pulse trains, repeated spreading, hopping sequences, or cyclic prefixes. Therefore, this approach gives better performance than other types even in low SNR (highest accuracy). However, it is more complex than energy detection technique and high speed sensing cannot be achieved. It also consumes more power. This issue is considered a challenge for CRWSN and it is not a preferable approach for this reason.

Interference temperature approach makes nodes calculate how much interference they would cause at the PU receiver and adjust their transmission power such that their interference plus the noise floor does not exceed a certain interference temperature level. It is recommended by FCC and it guarantees a predetermined interference to PU is not exceeded. However, this method requires a priori PU location information, and is computationally too intensive for a low-end CRSN node.

Considering the mentioned approaches, two techniques of sensing would be applied to detect the primary user appearance which are energy and feature detection techniques. Energy detection can be used always to detect the presence of transmitted signal as its simplicity. In case of detecting one, then feature detection can be applied to recognize weather it is from PU or another SU or noise.

Also, [35] proposes a cooperative spectrum sensing scheme based on trust and fuzzy logic for CRSN. The CRSN nodes use the T-S fuzzy logic to make local decisions based on the presence or absence of PU. Simulation results show that the proposed scheme could improve the detection probability effectively with lower power consumption.

C.Power Consumption

CR wireless sensors are power constraint devices with a limited energy source. A lot of issues lead to more power consumptions such as spectrum sensing, route discovery, channel negotiation, transmission and reception of data packets, data processing, backoff and spectrum handoff. CRSNs need to sense the spectrum band frequently. Unfortunately, many sensing approaches need separate antenna to monitor the spectrum all the time, hence more power is consumed.

In [36], a distributed channel and power allocation scheme is proposed for each individual user to maximize energy efficiency in a wireless cognitive radio sensor network. A distributed power control algorithm is also suggested for multiple new users to share the same subcarriers efficiently while maintaining the required data rate by managing the co-channel interference.

Adjusting the constellation size using an adaptive modulation technique to achieve power efficiency was the proposed solution by [37]. The authors proposed a subcarrier detection mechanism for CRWSNs, where the user determines its optimal subcarrier, and minimize power consumption at each node.

Most sensor networks support the operation of power saving modes for the sensor node. The most obvious means of power conservation is to turn the transceiver off when it is not required. Although this power saving method seemingly provides significant energy gains, an important point that must not be overlooked is that sensor nodes communicate using short data packets. And the shorter the packets become, the more the dominance of startup energy. Thus, if the radio was turned off blindly during each idling slot, over a period of time it might end up expending more energy than if the radio had been left on. As a result, operation in a power-saving mode is energy-efficient only if the time spent in that mode is greater than a certain threshold.

A dynamic power management scheme for wireless sensor networks is discussed in [38] where five power-saving modes are proposed and inter-mode transition policies are investigated. The threshold time is found to depend on the transition times and the individual power consumption of the modes in question.

One of the proposed solutions for this issue is to use energy harvesting. Harvesting energy from the ambient environment is a promising approach to solve the energy problem of sensor nodes. Various energy sources, such as light, vibration or heat are available to be harvested.

Recently, the availability of the free RF energy has increased due to advent of wireless communication and broadcasting systems. Radio wave is ubiquitous in our daily lives in form of signals transmission from TV, radio, wireless LAN and mobile phone.

In [39] a cognitive radio sensor network comprised of sensor nodes that can harvest RF energy received from the primary network has been proposed. They state that “the RF energy harvesting enables the sensor node to operate with a potentially perpetual lifetime without periodic battery replacements or external power supply”. In addition, the opportunistic spectrum access offers a way of solving interference problems. Also, it assumes that the sensor node harvests RF energy received from the primary network and it cannot carry out RF energy harvesting and opportunistic spectrum access at the same time. Therefore, the sensor node should decide whether to access the spectrum or to harvest RF energy in each time slot to maximize an expected total throughput. The optimal mode selection policy was developed in order to cast this decision making problem in the framework of Partially Observable Markov Decision Process (POMDP). Numerical results show that the developed optimal policy finds a balance between obtaining the immediate throughput and harvesting the RF energy for future use.

D.Manufacturing Costs

In contrast to conventional WSNs, which require less memory and computation capability, CR-WSNs require moderate memory and computational capabilities. Figure 5 shows CRSN node hardware structure. Each node is mainly composed of sensing unit, processor unit, memory unit, power unit, and cognitive radio transceiver unit as obvious. Also, they may have energy harvesting units. In specific applications, CRSN nodes may have localization unit (GPS). The cognitive radio transceiver for CRSN is the main difference between the hardware structure of traditional sensor nodes [14] and CRSN nodes.

CR feature add some limitations to the SNs in such as power consumption, processing time, communication techniques and memory resources. These limitations add restrictions on the features of cognitive radio to fit the nature of WSNs. For example, CRSN nodes may select spectrum sensing technique with a limited performance due to processing time, consumed power, and complexity. Generally, CR-wireless sensors have been deployed in large numbers. Therefore, the cost should be significantly low. Unfortunately, all parameters that mentioned increase the production cost. Hence, designing such a sensor node with low cost is a challenging issue.

6.SPECTRUM ACCESS FOR CRWSN USERS

When secondary users try to access the same spectrum band, the CRWSN MAC protocol should be performed to avoid collision with PUs and also with other unlicensed users. A negotiated technique is vital for synchronizing transmission between users.

The following sub sections present different types spectrum access techniques such as (dedicated control channel approach, common hopping approach and split phase approach).

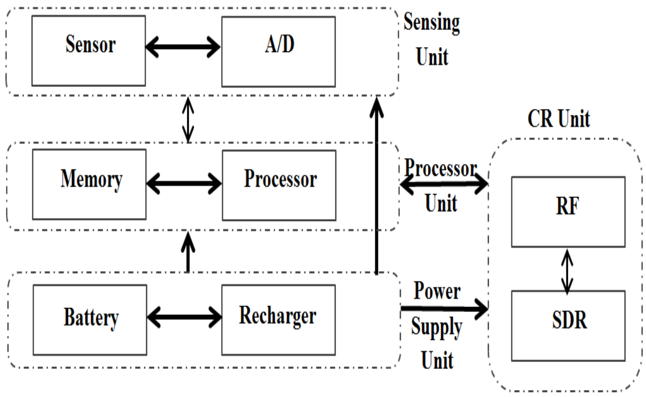

Fig:5 Hardware structure of a cognitive radio sensor node

A.Dedicated Control Channel Approach

This protocol uses at least two transceivers per node; one of these transceivers operates with a single channel only for control packets exchange.

This approach is similar to the mechanism of carrier sense multiple access with collision avoidance (CSMA/CA) in IEEE 802.11 DCF standard [19]. In this approach, the nodes always tune one transceiver to the control channel to make agreements on the data channel which will be used and be aware of neighbor's negotiations. The other transceiver is able to switch channels and is used for data transmission as shown in figure 6 where R and C is refer to RTS and CTS respectively.

This type of protocols is the simplest and doesn't require any synchronization. However in case of large number of nodes as in WSNs, high collision rate cause degradation in network performance and network also may face CCCH bottleneck problem.

B.Common Hopping Approach

This protocol can use one transceiver per node; which operates for both control and data packets. In this protocol there is no CCCH but each secondary user is assigned a unique control channel slot and a unique data transmission slot.

Figure 7 shows how Nodes hop synchronously through all available channels and pause hopping when sender and receiver agree on data transmission using their current channel. Therefore, there is no collision between nodes and no CCCH bottleneck problem. For this reasons this protocol shows better network performance. But, it is complicated to design this kind of protocol since there are many problems in allocating slots

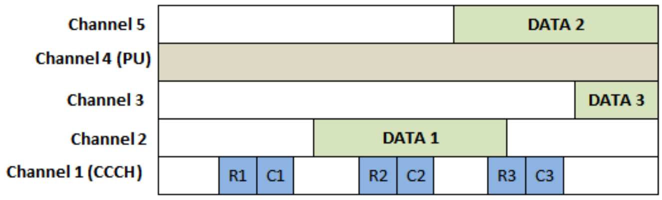

Fig 6 Dedicated Control Channel approach

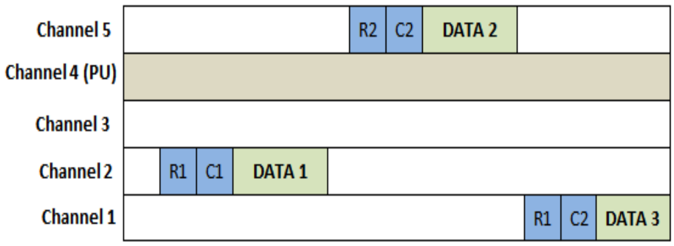

Fig7 Common Hopping approach

for each user especially in huge networks. Also there are some problems in synchronization time between users.

C.Split Phase Approach

This protocol mixes between the previous two types. It characterized between the simplicity of dedicated control channel and the spectrum utilization of common hopping approach. It may use one transceiver per node, time is divided into control phase and data phase which always predefined for users as shown in figure 8, and this division has the objective to ensure that all nodes listen to the control phase, thus avoiding the Multi-Channel Hidden Terminal problem (MCHTP) with lower complexity.

Unfortunately, the need for synchronization is a dynamic issue and this approach waste portion of data channels in exchanging signaling in the control phase.

7.EXAMPLE ON WSN APPLICATIONS USING CR TECHNIQUE (HEALTH CARE)

Here, health care example (as WSN application) is introduced in order to have a clear view about network requirements based on application.

In a health care system, such as telemedicine applications, wearable body sensors are being used. A wireless body area network (WBAN) is a special-purpose sensor network designed to connect medical sensors and appliances located inside and outside the human body and is used for long-term health monitoring within a hospital or remotely. A WBAN consists of numerous of biomedical sensors used to monitor physiological data, such as temperature, blood pressure, electrocardiogram (ECG), electroencephalography (EEG), heart rate, etc [40]. The key requirements of WBANs are low power consumption, negligible with the body, high reliability and effective communication [41]. These sensors also are critical and sensitive towards error and delay.

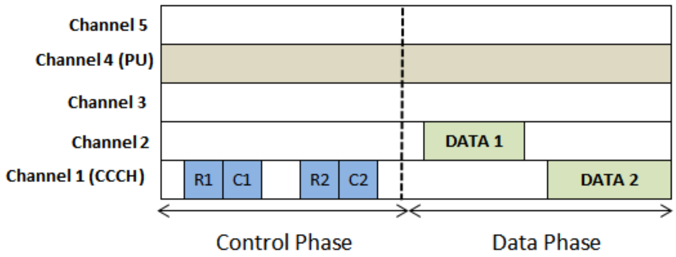

Fig 8 Split Phase approach

Consequently, the limitations of traditional WSN, as discussed in the previous section restrict the potentiality of telemedicine application. The QoS of this application may not be achieved at a satisfactory level if the operating spectrum band is crowded.

The use of ‘CR wearable body wireless sensors’ can mitigate these problems due to large bandwidth, high data rate, less packet losses and global operability, hence improve reliability. CR technology can be implemented also in WBANs in order to reduce interference caused by conventional wireless medical applications. Electromagnetic interference (EMI) may cause malfunction (e.g., wave distortion, shutdown, restart, etc.) in the network, which critically affects the operation and communication of various sensitive devices [42].

In order to achieve WBANs requirements, our suggestion in this case is to use single radio to reduce consumed power and interference. Also, centralized network is a preferable topology due to large numbers of sensor nodes that exist in this network. These nodes need to be controlled with a certain access point to coordinate communications between these nodes. Finally, transmission channel protocol should be single channel or multi channel – single radio protocol as only single radio is used. But as discussed before in previous sections using single channel cause degradation in network performance. Therefore, it is better to use multi channel – single radio which require channel bonding as in [24].

Some researches, [43]-[46] have studied the effect of using CR technology in health care networks.

8.CONCLUSION

Cognitive radio is considered to be one of the most promising solutions to alleviate the spectrum scarcity problem and support the increasing demand for wireless communications. Mixing CR technology with WSNs give new paradigm called Cognitive Radio Wireless Sensor Network (CRWSN). These new networks show more benefits in usage than conventional WSNs (i.e. ability to add new technologies, minimum spectrum handoff, avoiding attacks, multiple channel utilization….etc.). Also, this paper introduces suggested design for a MAC protocol fits this new network.

There are four main parameters must take into consideration in designing. First, network architecture (centralized, distributed or clustered) which specify depend on application requirements. In case of numerous nodes, distributed networks are not preferable solution due to overhead increasing. Second, Number of radios for each device which is preferable to be single radio to reduce consumed power for sensor nodes. Third, transmission channel that based on single channel or multi channels protocol. Selection of this parameters based on data rate requirements. It also depends on device capability, number of radios and network design. Fourth, common control channel selection which are still an open research issue.

In spite of CRWSN have a lot of benefits and possible applications; they face a lot of challenging such as channel assignment, power consumption, manufacturing cost and spectrum sensing. These challenges are still open research issues. Here, we try to introduce proper solutions for these challenges. Health care network was showed as an example to show how to select parameters based on application requirements. At the end, there are still many researches going on to improve the sensor capability using CR. We hope that this paper introduce better understanding for CRWSN and motivate research further explore this promising paradigm.

REFERNCES

[1] D. Culler, D. Estrin, and M. Srivastava, “Overview of Sensor Networks,” IEEE Computer, vol. 37, no. 8, pp. 41-49, Aug. 2004.
[2] G. Zhou, J. A. Stankovic, S. H. Son, “Crowded Spectrum in Wireless Sensor Networks”, in Proc. Third Workshop on Embedded Networked Sensors (EmNets 2006), 2006.
[3] Jian-guang Jia, Zun-wen He, Jing-ming Kuang, and Hui-Fen Wang, “Analysis of Key Technologies for Cognitive Radio Based Wireless Sensor Networks,” 6th International Conference on Wireless Communications Networking and Mobile Computing (WiCOM), Chengdu, pp. 1-5, Sept. 2010.
[4] FCC Spectrum Policy Task Force. (2002). Report of the spectrum efficiency working group.
[5] Nhan NGUYEN-THANH, Anh T.PHAM, Van-Tam NGUYEN, “Medium Access Control Design for Cognitive Radio Networks: A Survey,” IEICE TRANSACTIONS on Communications, Vol.E97-B, pp. 359-374, Feb.2014.
[6] Samuel Cheng, “Foundation of Cognitive Radio Systems,” March,16, 2012, InTech.
[7] Ozgur B. Akan Osman B. Karli Ozgur Ergul, “Cognitive Radio Sensor Networks,” Network, IEEE (Volume:23 , Issue: 4), pp. 34-40, Aug. 2009.
[8] Yi Peng, Hua Long, Tao Xie, QingZhi Du, “The Research of CR-based WSNs Architecture,” International Conference on E-Business and E-Government, Guangzhou, PP. 2179-2182, May 2010.

[9] Abolarinwa J.A, SalawuN, Achonu A, "Cognitive Radio-based Wireless Sensor Networks As Next Generation Sensor Network: Concept, Problems and Prospects," Journal of Emerging Trends in Computing and Information Sciences, Vol. 4, No. 8, pp. 642-648, August 2013.

[10] Akhila Asokan, AyyappaDas. R, "Survey on Cognitive Radio and Cognitive Radio Sensor Networks," International Conference on Electronics and Communication Systems (ICECS - 2014), pp. 1-7, Coimbatore, INDIA, Feb. 2014.

[11] Dave Cavalcanti, Sushanta Das, Jianfeng Wang, Kiran Challapali, "Cognitive Radio based Wireless Sensor Networks," 17th International Conference on Computer Communications and Networks (ICCCN '08), pp. 1-6, St. Thomas, US Virgin Islands, Aug. 2008.

[12] Kok-Lim Alvin Yau, Peter Komisarczuk and Paul D. Teal, "Cognitive Radio-based Wireless Sensor Networks: Conceptual Design and Open Issues," The 2nd IEEE Workshop on Wireless and Internet Services (WISe 2009), pp. 955-962, Zürich, Switzerland; Oct. 2009.

[13] Ian F. Akyildiz , Won-Yeol Lee, Kaushik R. Chowdhury, "CRAHN: Cognitive Radio Ad Hoc Networks," Ad Hoc Networks journal, Vol. 7 Issue 5, pp. 810 – 836, July 2009.

[14] Ian F. Akyildiz, Weilian Su, Yogesh Sankarasubramaniam, and Erdal Cayirci, "A Survey on Sensor Networks," IEEE Communications Society, pp. 102-104, Aug. 2002.

[15] Byun S.S., Balasingham I., Liang X., "Dynamic Spectrum Allocation in Wireless Cognitive Sensor Networks: Improving Fairness and Energy Efficiency," Proceedings of the IEEE 68th Vehicular Technology Conference (VTC 2008); Calgary, AB, Canada, pp. 1–5, September 2008.

[16] Jin Qi, Shigeru Shimamoto, "A cognitive mobile sensor network for environment observation," Telematics and Informatics 29 journal, pp. 26 – 32, 2012.

[17] Cardei, M. , Mihnea, A., "Channel assignment in cognitive wireless sensor networks," International Conference on Computing, Networking and Communications (ICNC), 2014 , Honolulu, HI, pp. 588 – 593, 3-6 Feb. 2014.

[18] Stephen J. Shellhammer, Ahmed K. Sadek and Wenyi Zhang, "Technical Challenges for Cognitive Radio in the TV White Space Spectrum ,"Information Theory and Applications Workshop, in San Diego, CA, pp. 323-333, May 2009.

[19] IEEE 802.11 Standard, "Wireless LAN medium access control (MAC) and physical layer (PHY) specifications," 1999 (Reaff 2003) Edition.

[20] Hanan Hussein, Hussein A. Elsayed, Salwa Elramly, "A Predictive model for MAC Protocol (P-MAC) of Cognitive Radio Network Using Exponential Smoothing Model," MIC-WCMC 2012, MOSHARAKA International Conference, Palma de Mallorca, Spain, pp 51-56, June 2012.

[21] Hanan Hussein, Hussein Abdel Aty and Salwa Elramly, "Performance Evaluation of Cognitive Radio Network Predictive MAC (P-MAC) Access Algorithm and its Enhancement", 27th International Conference on Information Networking 2013 (ICOIN 2013), Bangkok, Thailand, January 28(Mon) - 30(Wed), 2013.

[22] Dongyue Xue, Eylem Ekici and Xinbing Wang, "Opportunistic Periodic MAC Protocol for Cognitive Radio Networks," GLOBECOM 2010 IEEE Global Telecommunications Conference ,Miami, FL, pp 1-6, Ref. Cited 13, Dec.2010.

[23] Dongyue Xue, Xinbing Wang, Ekram Hossain, "Optimization of Periodic Channel Sensing by Secondary Users in a Cognitive Radio Network", GLOBECOM 2010, 2010 IEEE Global Telecommunications Conference, Miami, FL, pp. 1-5, Ref. Cited 13, Dec.2010.

[24] Rehmani M.H., Lohier S., Rachedi A., "Channel Bonding in Cognitive Radio Wireless Sensor Networks," Proceedings of the International Conference on Selected Topics in Mobile and Wireless Networking (iCOST), Avignon, France, pp. 72–76, July 2012.

[25] Askari, M, Kavian, Y.S., Kaabi, H., Rashvand, H.F., "A channel assignment algorithm for Cognitive Radio wireless sensor networks," IET Conference on Wireless Sensor Systems (WSS 2012), London, pp. 1-4, 18-19 June 2012.

[26] Yanchao Xu, Chengyu Wu, Chen He, Lingge Jiang, "A Cluster-based Energy Efficient MAC Protocol for Multi-hop Cognitive Radio Sensor Networks," Global Communications Conference (GLOBECOM), Anaheim, CA, pp. 537-542, Dec. 2012.

[27] Noun Choi, Maulin Patel and S. Venkatesan, "A Full Duplex Multi-channel MAC Protocol for Multi-hop Cognitive Radio Networks," 1st International Conference on Cognitive Radio Oriented Wireless Networks and Communications, Mykonos Island, pp. 1-5, june 2006.

[28] Jin Qi, Shigeru Shimamoto, "A cognitive mobile sensor network for environment observation," Telematics and Informatics 29 journal, pp. 26 – 32, 2012.

[29] Brandon F. Lo, "A survey of common control channel design in cognitive radio networks," Physical Communication, Volume 4, Issue 1, pp. 36-39, March 2011.

[30] S. M. Kamruzzaman, "An Energy Efficient Multichannel MAC Protocol for Cognitive Radio Ad Hoc Networks", International Journal of Communication Networks and Information Security (IJCNIS), Vol. 2, No. 2,pp 112-119, August 2010.

[31] K. Chowdhury, I. Akyildiz, "OFDM based common control channel design for cognitive radio ad hoc networks," IEEE Transactions on Mobile Computing, volume 10, issue 2, pp. 228-238, Feb. 2011.

[32] Xiaoshuang Xing,Tao Jing,Wei Cheng, Yan Huo, Xiuzhen Cheng, "Spectrum Prediction in Cognitive Radio Networks," Wireless Communications, IEEE (Volume:20 , Issue: 2), pp. 90-96, April 2013.

[33] Tevfik Y ¨ucek and H ¨useyin Arslan, "A survey of spectrum sensing algorithms for cognitive radio applications," Communications Surveys & Tutorials, IEEE (Volume:11 , Issue: 1), pp. 116-130, March 2009.

[34] Hemant M. Baradkar, Dr. Sudhir G. Akojwar, "Implementation of Energy Detection Method for Spectrum Sensing in Cognitive Radio Based Embedded Wireless Sensor Network Node," International Conference on Electronic Systems, Signal Processing and Computing Technologies, pp. 490 – 495, Nagpur, Jan. 2014.

[35] Yonghua Wang, Yuehong Li , Fei Yuan, Jian Yang, "A Cooperative Spectrum Sensing Scheme Based on Trust and Fuzzy Logic for Cognitive Radio Sensor Networks," IJCSI International Journal of Computer Science Issues, Vol. 10, Issue 1, No 1, pp. 275-279, Jan. 2013.

[36] Song Gao, Lijun Qian, Dhadesugoor. R. Vaman, "Distributed Energy Efficient Spectrum Access in Wireless Cognitive Radio Sensor Networks," IEEE Wireless Communications and Networking Conference, WCNC 2008, Las Vegas, NV, pp. 1442 – 1447, Apr. 2008

[37] Gao S., Qian L., Vaman D.R., Qu Q., "Energy Efficient Adaptive Modulation in Wireless Cognitive Radio Sensor Networks," Proceedings of the IEEE International Conference on Communications (ICC '07), Glasgow, Scotland, pp. 3980–3986, June 2007.

[38] A. Sinha and A. Chandrakasan, "Dynamic Power Management in Wireless Sensor Networks," IEEE Design Test Comp., Mar./Apr. 2001.

[39] Park S., Heo J., Kim B., Chung W., Wang H., Hong D., "Optimal Mode Selection for Cognitive Radio Sensor Networks with RF Energy Harvesting," Proceedings of the IEEE 23rd Personal Indoor and Mobile Radio Communications (PIMRC 2012), pp. 2155–2159, Sydney, Australia, Sep. 2012.

[40] Movassaghi, S.; Abolhasan, M.; Lipman J.; Smith, D.; Jamalipour, "A. Wireless Body Area Network: A Survey," IEEE Commun. Surveys Tutorials, pp. 1658–1686, Jan. 2014.

[41] Sabin Bhandari, Sangman Moh., "A Survey of MAC Protocols for Cognitive Radio Body Area Networks," Sensors 2015, pp. 9189 – 9209, Apr. 2014.

[42] Phunchongharn, P., Hossain, E., Niyato, D., Camorlinga, S., "A Cognitive Radio System for e-health Applications in a Hospital Environment," IEEE Wireless Communication 2010, pp. 20–28, Feb. 2010.

[43] Ali, K.A., Sarker, J.H., Mouftah, H.T., "A MAC protocol for cognitive wireless body area sensor networking," 6th International Wireless Communications and Mobile Computing Conference, Caen, France, pp.168–172, June 2010.

[44] Han, J., Liu, J., Yu, H, Chen, C., Shen, Z., "HCVP: A Hybrid Cognitive Validation Platform for WBAN," International Conference on Wireless Communications & Signal Processing (WCSP), Huangshan, China, pp. 1–6, October 2012.

[45] Nhan, N.-Q., Gautier, M.; Berder, O., "Asynchronous MAC protocol for spectrum agility in Wireless Body Area Sensor Networks," 9th International conference on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM), Oulu, Finland, pp. 203–208, June 2014.

[46] Syed, A.R., Yau, K.-L.A., "On Cognitive Radio-Based Wireless Body Area Networks for Medical Applications," IEEE Symposium on Computational Intelligent in Healthcare and e-health (CICARE 2013), Singapore, pp. 51–57, April 2013.

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