A Survey on Radio Resource Allocation mechanism with modulation techniques in Cognitive Radio Sensor Networks

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Abstract- Wireless Sensor Networks (WSNs) make use of the Industrial, Scientific, and Medical (ISM) band to transmit the information. But, as the needs and increase in the application of these networks, the widely used ISM band cannot fulfil the transmission demands. This drawback of insufficient communication spectrum is addressed by incorporation of the opportunistic spectrum access ability of Cognitive Radio (CR) into the current wireless network, thus, contributing to a new Cognitive Radio Sensor Network (CRSN). The CRSN sensor elements rely on limited power consuming power sources. Thus, in order to efficiently allocate the available spectrum among the constituent sensors in the network on a dynamic basis, smart, high tech radio resource allocation techniques are must. These techniques are intended towards the optimization of energy consumption of sensors in the wireless network on an individual level. Radio resource allocation schemes work such that QoS guarantees, network life-time maximization, lowering the interferences within the network as well as between the sensor nodes are ensured. The wireless network's lifespan can be expanded hugely by applying modulation. Therefore, a variety of modulation techniques in the past will be considered for the study. In this paper, a survey of the recent advancements in radio resource allocation in CRSNs is presented. The existing Radio resource allocation methods for CRSNs are categorized into three broad categories, namely centralized, clustered and distributed. The concerns involved and challenges are also focused in this paper provided with directions for carrying out future research are distinctly stated.

Index Terms -Cognitive radio sensor network, wireless sensor networks, cognitive radio networks, radio resource allocation, Modulation Techniques

I. Introduction

Wireless signal band includes a small communication range and obtaining explicitly a few MHz frequency of a signal incurs high cost. As an illustration, Vodafone's bandwidth resource acquisition of two 10 MHz resources in 800 MHz wireless spectrum, two 20MHz as well as one 25MHz bandwidth resources in 2.6 GHz spectrum cost neared about 1.22 billion USD in a UK auction held in 2013[1]. The extremely high spectrum band prices are owing to the progressive developments and wide demands of the wireless data bands. The global spectrum consumption statistics show that in reality only 5-10% of licensed wireless spectrum is utilized by authorized end users [2]. Thus, almost in many of the cases this high priority resource in fact remains underutilized. This created the way to the coming up of newer technology called Cognitive Radio (CR) which basically involve highly intellectual wireless devices to make effective utilization of parts of the underutilized licensed spectrum(termed as "spectrum holes") belonging to licensed end users/networks ("primary users/networks") given a specific location and time point[3]. Therefore, the name Cognitive Radio Networks (CRNs- also called secondary networks) is designated to the wireless networks incorporating CR technology and users of such networks are facilitated with CR devices (secondary users). The main distinction and advantage of a CRN is that no license is provided to any spectrum band. A spectrum hole is available for use upon detection by a licensed user, with the constraint of vacating it the moment a primary user initiates communicating in that band. The intelligent sensing and identification of spectrum holes for dynamically accessing the bandwidth resource are made possible by the combination of the below cognitive abilities of the CR devices [3]. Intelligent Spectrum Sensing: CR wireless device senses the frequency bands in the spectrum for the successful identification of the spectrum holes existent therein. Further, detecting the primary user entering the spectrum hole which is at present occupied by the secondary user is also the competency of spectrum sensing.

Spectrum Decisiveness: This can be described as deciding the most useful spectrum bands from the already detected bands as per a specified condition. Spectrum Sharing: The spectrum holes after detection from the underutilized spectrum band can be shared among multiple secondary users. But, the accessing the same spectrum band concurrently by more than one secondary users is subject to collisions and resource contention. In order to reduce the network interferences and collisions, properly managing the overall spectrum use among many secondary users is the key. Spectrum Mobility: The communication in a particular spectrum band is started once a suitable band is selected. But, with regard to the wireless networks being dynamically changing, some primary user might choose to communicate in the same selected band. As a result, the secondary user has to change the current operational band to ensure primary user is not interrupted. This transition between the spectrum bands of CR devices itself refers to spectrum mobility. CR technology promotes the wireless frequency spectrum to be shared simultaneously by many devices in absence of licensed spectrum. This is achieved by continuing to provide wireless communication services by making considerably small investments in network infrastructure as well as high tech spectrum sensing innovations avoiding acquisition of high cost licenses altogether [4]. The same can be leveraged to smaller networks also. Apart from CRNs, the technology breakthrough of intelligent sensing and spectrum sharing can be integrated into regular wireless sensory networks (WSN) also.

A WSN is characterized typically by huge number of low power consuming sensors that operate in geographically dispersed regions especially to actively monitor and report specific physical conditions [5]. These application specific sensors operate in the Industrial, Scientific, and Medical (ISM) bands which are unlicensed in nature by collecting significant data for reporting the same to the network sink. In some of the applications, where there is a requirement of huge number of sensor nodes, (like in healthcare and defence), the offered bandwidth in ISM spectrum bands is not enough to complete every single communication resulting in data loss. To overcome this loss, a leading practice in WSNs remains equipping the wireless sensors with cognitive radio technology's core abilities [6]. Hence, this solution assures that the spectrum holes in other licensed spectrum bands are accessed as and when required when need arises. The network created as result of these changes is called as a Cognitive Radio Sensor Network (CRSN). The maximum advantageous utilization of CRSNs is guaranteed if effective radio resource allocation is done dynamically. The different damages that are vulnerable to wireless networks include sudden fading, shadow fading and loss of path.

The wireless network channels are subject to variations with respect to time, frequency of signals as well as spatial arrangements. As a consequent, the strength of the signal at the receiving end is different in differing time instants, frequencies and geographic points. The strength of the signal received is characterized by diverse time, space, frequency and user community. On the basis of the channel's status, the wireless resources of time intervals, frequency bands, transmitter antennas, transmission power, etc., are allocated. Since dynamic resource allocation procedures exploit these differences well, they lead to even better performance in contrast to the static allocation techniques [7]–[9]. Additionally, dynamic resource allocation techniques also ensure the allocation of resources to multiple contending nodes in a fair way without any collisions.

Dynamic resource allocation techniques efficiently manage the spectrum mobility and guarantee QoS needs with different services and nodes differently prioritized. Wireless radio resource allocation in CRSNs is very important just as in rest of the wireless channels for the following reasons:

1. Maximal energy optimization to improve the sensor battery lifetime
2. Allocating the spectrum bands fairly amongst contending sensor nodes
3. Proper utilization spectrum after sensing
4. Assigning and ensuring priority based spectrum division to all sensors and data
5. Providing QoS guarantees
6. Interference free network to primary users

In this paper, we present a detailed survey of radio resource allocation schemes existing for CRSNs. Throughout this paper, the terms "radio resource allocation", and "resource allocation", are used interchangeably.

1.1 Motivation and Background of the Survey

WSNs are considered to play a vital role in our day-to-day life in coming days due to their broad applicability in almost every field e.g., healthcare, safety, battlefield, environmental conservation, disaster management and relief, emergency response, and automation etc. [10]. In medical domain, WSNs are extremely useful for diagnosing, remotely monitoring patients based on clinical records, and tracking the healthcare providers inside the hospitals, etc. [11]-[16].The safety and public security driven by WSNs involve the physical terror possibilities to be detected, identified with timely reporting to the security personnel through Internet [17]. In military, surveillance of the border regions to keep vigil for enemy forces, find out for new paths, intelligent targeting through arms equipped WSNs, assessing war damage, and inspection of biological or nuclear attacks, etc [5]. In automation of home appliances, WSNs provide fully automated easy management of the appliances at local and remote levels [18]-[20]. In the area of environmental conservation, WSNs are utilized to monitor the natural resources for vulnerability and destruction. Some of these applications include detecting wild land fire, severe floods, pollutants affecting air, water, soil etc., safe drinking water without pesticide, and environmental studies etc. [21]- [30]. One of the distinguishing and new vision of wireless sensor networks is their integration with the Internet so fulfilling Internet of Things (IOT) ideology where every wireless sensor device is freely accessed without regard to time and space [31].

WSNs are very popular due to their wide application domains but, they too are accompanied with certain challenges for efficient functioning. The fact that these sensor nodes forming the wireless network are to be kept operational even in the most rugged and safety critical environments that are even not facilitated with simple communication networks makes them more adaptable in the form of self-organizing nodes without any control. These special abilities of the wireless sensors are all due to the in-built processing unit that dynamically records, analyses and computes on the sensed data with self-organizing and power saving nature. Lastly, one of the important concerns is the challenge of the scarce spectrum bands available for Wireless networks due to increasing competition for communication bands. Since WSNs use freely available ISM spectrum for communication that is already populated by other unlicensed networks including LANs, Wireless Telephone networks etc. This contention between the WSNs and other networks has to be carefully managed for sufficient spectrum needs to be met.

In this survey, the sensor networks considered for the study are chosen based on their spectrum bands in which they are functional. The general commercial wireless sensor nodes with respective four operational spectral bands are described and illustrations for sensors within each category of spectrum band are also provided. From the following table, it can be concluded that almost every commercially popular sensor node is functional in a spectrum band that is simultaneously used by multiple other wireless networks. Within these, the mobile and Zigbee networks particularly overlap each single sensor node with telemetry leaving the sensors that remain functional in 2.4 GHz frequency band. The sensors in 2.4 GHz band are influenced by Bluetooth networks and IEEE 802.11 b/g/n. Overlapping of the sensors in 315 MHz, 433 MHz, 868 MHz or 916 MHz frequency ranges is observed due to satellite communication mode. The spectrum shortage issue is complicated again coupled with marginal power, compactness of the sensors ad cheap transceiver requirements resulting in only few spectral bands ensuring particular range of frequency band can ensure efficient transmissions in WSNs [35].

II. LITERATURE REVIEW

The topic of how to allocate resources has been often chosen for study in case of wireless sensor networks. In the wireless network literature, many of the researchers have carried out survey on resource allocation for variety of networks like cellular, CRN, telemetry etc. Here, we review the past resource allocation schemes implemented so that distinguishing it from our work with analysing the positive and negative points from them is done. Further, we focus specifically on the certain peculiar characteristics of CRSNs regarding resource allocation techniques that are not applicable to other wireless networks.

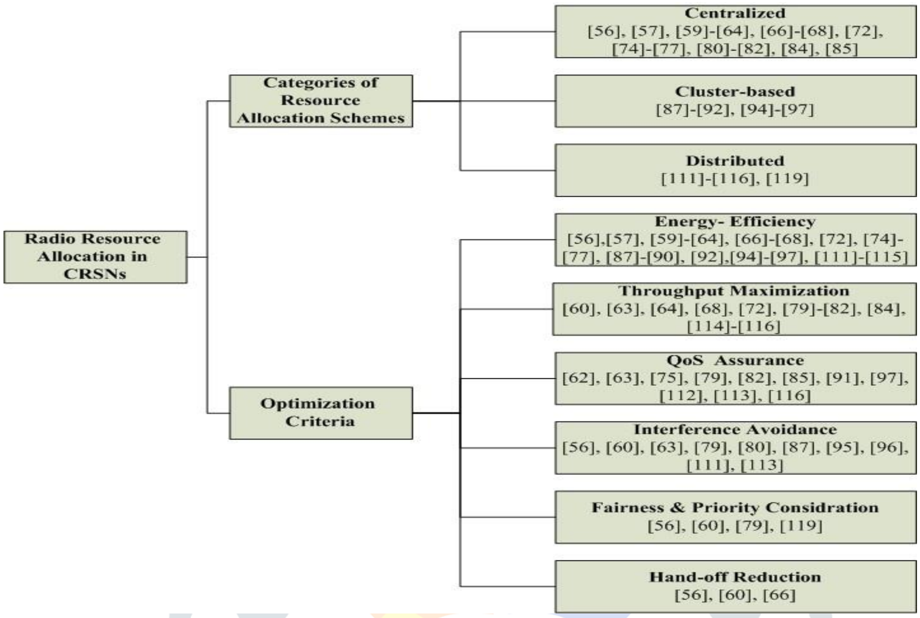

Fig. 1: Classification of radio resource allocation schemes for CRNs

A comparative and qualitative study of the state-of-the-art resource allocation methods in place applicable to CRSNs is taken up. Table II presents summarizes already prevalent surveys on WSNs, CRNs, and CRSNs comparing their unique features. In the paper [5], the authors have presented a general survey on Wireless Sensor Networks. The main theme of this work is not resource allocation issue rather it is described briefly. The CRSNs have been discussed in depth in the paper [6] highlighting the problem of spectrum management dynamically. Even this work describes on general terms the spectrum management issue but doesn't offer comparative survey on resource allocation methodologies. In [6], comprehensive tutorial-like notes on design foundations of CRSNs, the network organization, the available application domains, the interoperability between the WSN, CRN communication protocols with that of CRSNs and potential research opportunities in case of CRSN are provided. Thus, the problem of resource allocation schemes for CRSNs remains unaddressed and not published by any other research work in the past except the previous work carried out by us. This has led to actively carry out a comprehensive survey work on the same.

CRSNs have many unique features which readily distinguish them from rest of the trivial wireless networks including Cognitive Radio Networks, Wireless Sensor Networks and Wi-Fi networks. To list a few, burst level traffic, dynamically available communication channels, spectrum mobility, limitations on power and storage CRSN nodes and opportunistic access of spectrum bands by primary users [33]. The very reason for non- applicability of the techniques for ensuring fair allocation of resources in case of traditional wireless networks to CRSNs are its inherent peculiarities just mentioned. Precisely, the appearance of channels dynamically in CRSNs and subsequent spectrum band usage during primary user's activities lead to the resource allocation techniques not adaptable to a CRSN directly. Since there are restrictions on the power as well as storage amount reserved for CRSN nodes, this also contributes to the need of devising newer schemes for efficient distribution of network resources. Even the techniques that have proved to excellent for Wi-Fi and cellular networks also fail to be utilized to CRSNs since the core, distinct nature of CRSNs discussed earlier have not been taken into account. Therefore, it is absolutely necessary to incorporate the unique qualities of low energy, hardware compactness, minimal bursty traffic, dynamic access of the wireless spectrum and topology changes from primary user's actions are must have prerequisites. As per our knowledge and extensive studies on existing surveys, our work is the first and foremost survey on presenting schemes for efficient resource utilization for CRSNs taking into account all its qualities.

III. RADIO RESOURCE ALLOCATION AND MODULATION TECHNIQUES IN CRSNS

This section is dedicated to explore as well as review the allocation of radio resources namely power and radio spectral bands for CRSNs. These schemes can be classified into three broad classes namely centralized, clustered and distributed schemes. Further, the same have been subdivided into many performance optimization rules on the basis of the underlying objectives. These rules cover self-sufficiency in terms of energy needs, maximizing the throughput, assuring QoS guarantees, interference free communication, fair and priority based service, and hand- off minimization. Fig. 1 shows the classification tree for CRSN's radio resource allocation containing three main categories. The different performance optimization rules are also shown. To educate the readers, the respective references for every category and rule is depicted which clearly tells the breadth of work carried out. Following is a general description of these categories, the optimization criteria with pros and cons analyzed for the same. Apart from this, we also concentrate on briefing the influence of the inherent properties of CRSNs on the resource allocation technique chosen.

3.1 Radio Resource Allocation Categories

3.1.1 Centralized:

A centralized radio resource allocation technique contains one node designated as the central node of the network (also called Base Station or Sink). It has the authority to completely control the energy needs and decide which spectrum bands to be allocated in the between the available sensors. The centralized environment is represented in figure. 2.

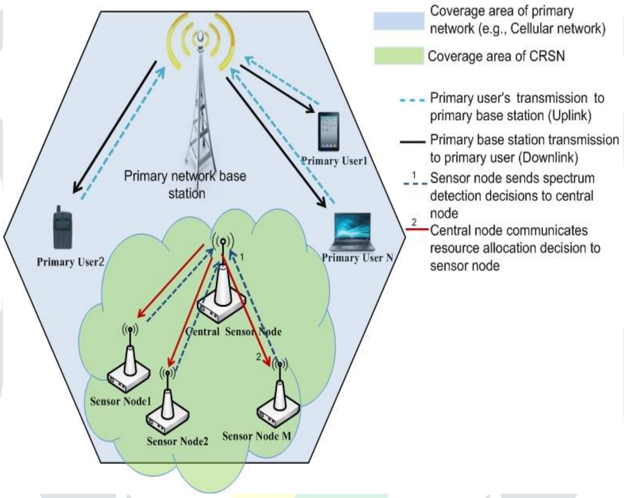

Fig. 2: Centralized radio resource allocation in CRSN

There are two different phases in this arrangement. The first phase is basically spectrum detection and identification phase wherein the sensors sense the available spectrum bands followed by identifying opportunities in that range. The phase 1 is shown by the number "1" in the figure with a dotted line. The next phase is the important decision making phase in which based on certain pre-specified performance optimization targets; resource allocation is decided [35]. The same is then passed on the network sensors. The indication for the second phase is the solid arrow annotated as number "2".

In centralized techniques, each sensor in the network is bound to communicate the radio spectrum sensed to the central node and the transmission of resource allocation decisions taken by the central node is done to remaining sensors on a common network link. The central node that takes the decisions of resource allocation has access to know the status of the whole network, leading to many advantages. In this category, fulfilling one or more performance optimizations is very easy: improving the network's throughput as a result of increase in resources allocated to the sensors having highly efficient links, reducing the disturbances or noise in between the nodes by properly adjusting the levels of transmission power, fair allocation of spectrum resources, priority based resource assignment. The central node transmits the allocated resource information by means of broadcasting it to all the sensors in the network. In case of CRSNs built over very wide geographic area, a surplus amount of energy is needed for guaranteeing the control decisions are received correctly.

Thus, these high energy dependent common network links cannot be afforded by economical CRSNs. The major setback of centralized scheme is that if the central node stops working, the whole network is affected. The side effects of this includes the individual sensors autonomously deciding the transmit power needed and channel selection which result in unfair and congested communication. Few applications resolve this issue by recording the sensor data collected by one specific monitoring node. A good example of this is environmental monitoring.

3.1.2 Cluster-based:

Cluster-based techniques address the drawbacks of the centralized as well as the distributed categories. In clustered schemes for CRSNs, the network spanning wide area is partitioned into small-sized clusters with compactly arranged sensors known as cluster members. One node is designated as the Cluster Head (CH) particularly for every cluster. Detection of spectrum bands and allocating radio resources are carried out locally within the cluster by the Cluster Head. The resources allocated and spectrum bands identified are communicated to reach each cluster member through the common controlling link. Clustered CRSN arrangement is pictorially depicted in below Fig.3.

Cluster-based resource allocation techniques have found place in many research works in the past [87]–[92], [94]–[97]. These schemes have many advantages from their counterparts. Since cluster acts like a tiny sub-network with tightly packed sensors, the power for that small area is also considerably low compared to centralized category.

By distributing the sensors in multiple clusters, spectrum utilization is improvised due to reuse of bandwidth resource.

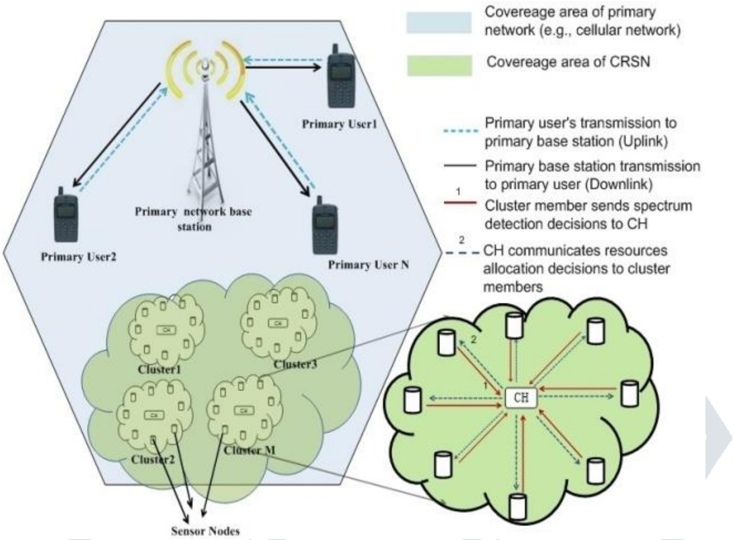

Fig. 3: Cluster-based radio resource allocation in CRSN

3.1.3 Distributed:

Distributed resource allocation functions by allowing autonomy to every single sensor in the network. The nodes cooperate themselves with neighbour nodes or take decisions for transmission of information individually.

Table 1: Major Categories of Radio Resource Allocation Schemes for CRSNS

Category	Description	Advantages	Limitations	Examples of Application Areas
Centralized	A central node acquires information from all sensor nodes, takes resource allocation decisions and broadcasts these decisions to sensor nodes	Efficient decisions via Global knowledge of The network, can achieve one or a combination of several optimization objectives: energy-efficiency, throughput maximization, interference minimization, fair spectrum sharing, priority consideration, and hand-off reduction	High signaling overhead, Needs high power for transmission on common control channel, Vulnerable-to central node failure	Applications where a centralized monitoring Node periodically collects sensor nodes measurements [36], e.g., environmental monitoring
Cluster-based	Network is divided into small clusters with each cluster consisting of a CH and several cluster members. The CH gathers information from cluster members, takes resource allocation decisions and broadcast them to member nodes	Needs low power for common control channel transmission, Reduced signaling over head at each CH due to small number of cluster members, Possibility of bandwidth reuse in distant clusters	Increased number of broadcasting and need of more common control channels (one for each cluster), In case of CH failure, the connectivity of its member nodes to neighboring CH(s) may fail due to congestion	Large-scale multi-hop CRSNs (with thousands of sensor nodes) [28], [29], e.g., used for wildlife monitoring [30] and target tracking [31].
Distributed	No need of central entity, Each sensor node makes decisions in an autonomous manner or by cooperating with the neighboring nodes, Neighboring sensors exchange messages to achieve satisfactory results	Low signaling overhead, Faster decision making, Quickly adaptable to changes & robust to time-varying environment and node failure	Local information based decisions can lead to non- efficient solution, Vulner- Able to inaccurate information and malicious activities, cannot achieve global fairness	Distributed ad-hoc CRSNs [23], e.g, networks deployed in disaster-affected areas

Thus on the basis of type of cooperation between consecutive nodes, distributed schemes are again divided into below two categories:

- Cooperative distributed resource management: The sensors opt for exchanging information about spectrum bands identified and transmission power with cooperatively deciding the allocation of resources.
- Non-cooperative distributed resource management: Here, an individual sensor does not rely on any other node to make decisions and no consideration is given to the effects on other nodes of the decisions made.

Since the distributed sensors work autonomously taking into account network changes, they are highly adaptable and robustness is ensured. In case of failure of one sensor in the wireless environment, the complete network is affected if it is centrally managed. But, if the same situation is found in distributed network, the neighboring nodes in the affected region make timely updates and communicate to the entire network. This not only makes network more tolerant to failures but also fast. In a CRSN, the spectrum bands dynamically vary over time period so distributed resource allocation is the best technique. Next, the information interchange taking place among a few nodes result in lesser communication overhead.

However, distributed allocation of network resources has its own disadvantages. The most critical problem is that the resource allocation decisions are solely made on the bais of locally communicated information from neighbor nodes not considering the global changes. This leads to less optimal solutions. Also, there are chances that wrong information is exchanges between nodes until the proper information is received by every cooperating node.

Table 1 summarizes the general notes, pros and cons, potential applications and references to the works in the discussed resource allocation environments for CRSN. From the data, it can be seen that almost many of the techniques adopted centralized category, with clustered arrangement considerably well utilized and distributed scheme negligibly used.\

3.2 Modulation Techniques:

The information as a signal can be interpreted and collisions may occur as a result of network link availability or other environmental activities reducing the network's overall functioning. If data during transmission is lost, information can be processed and redundancy results for lost packets. To address the issue of link disturbances, many protocols ensuring complete and efficient transmission exist. Modulation techniques are necessary to manage a steady signal noise ratio [38]. In radio wireless networks, many different modulation techniques are available.

Adaptive modulation [39] is a modulation method where the spectrum is at first detected by the sensors, following which the sub carriers are located on the basis of a pilot tone detection scheme. Once every sensor node has located the sub carrier spectrum, the data transmission on the most suitable link with the maximum gain is performed. Thus, an adaptive modulation technique can increase the network's life through the best constellation size.

An energy efficient modulation method called optimal modulation is discussed in [40]. This method comparatively analyzes the varieties of modulation schemes discussed earlier. The examples include M-ary QAM (MQAM), M-ary PSK (MPSK), M-ary FSK (MFSK) and MSK. After analyzing, the MSK scheme is better than rest of the schemes. The probability of bit error rate is less in case of MSK in comparison with rest of the techniques. We conclude that MSK is a good choice for WSNs. The advantages however are in the areas of higher bandwidth, simple to use, demodulation being quick and easy etc.

IV. PERFORMANCE OPTIMIZATION CRITERIA

4.1 Energy-efficiency:

To increase the network's life over time, it is necessary to establish energy optimization. Energy efficient techniques are most desired ones for CRSNs, as the sensors in a CRSN work on low power. But, while concentrating solely on power conservation with minimal power use, performance improvement is sidelined. Even though the option of battery replenishment is present, it can't be applied when the network field of operation is very uneven terrain like in minefield survey [32], forest fire early identification [33], natural calamity recovery and relief [34], etc. Accordingly, the energy efficiency ensuring techniques must be used to guarantee energy optimization and network life extension.

4.2 Throughput Maximization:

The throughput can be increased in two ways- one is by increasing the throughput individually on a sensor node basis or two, by maximizing totally the network's throughput. Resource allocation techniques based on maximizing the throughput combine the transmission power of the network and may lead to more noise. Further, these techniques result in improper and unfair resource assignment affecting sensor nodes badly. Throughput improvement techniques for CRSN are quite well considered by many research works.

For independent ad-hoc CRSN networks, resource allocation methods by maximizing the throughput are most suited. These networks find application in roadway transportation having strict time-sensitive data collected by sensors to be transmitted to many nodes. As an example, accident information must be transmitted as per time requirements to the nearby traffic.

4.3 QoS Assurance:

Few CRSNs are characterized by stringent QoS guarantees to be ensured. This prerequisite must be taken into account in the design phase of CRSN. The QoS parameters are application-specific like transmit speed, network delay, false positive rate and similar performance factors.

V. Challenges, Issues and Future Research Directions for Radio Resource Allocation in CRNS

This section is describes the problems, concerns with respect to allocation of radio resources with future research hints suggested.

5.1 Cross-Layer Resource Optimization

The power expenditure of the radio non-wired nodes and networks rely on each layer in the network stack from the physical to the topmost application layer. In case of traditional layered architecture, separate resource efficient usage designs are developed which contribute to high margins for available designs. On the other hand, in case of cross-layer architectures, inter-layer communication is utilized for improved energy usage and robustness to environmental factors, network congestion and services offered [35]. As an exception, cross layer networks for spectrum assignment combined with routing and access control, the past researchers have taken up only physical or MAC layer for optimal resource assignment leaving other layers. These earlier works are based on the assumption of routing process carried out as an independent process with the routes computed passed on to resource manager/scheme. Due to power constraints, the physical, MAC layers are integrated with energy conservation methods at the network and higher layers for optimal resource usage. A new topic for future research works is cross-layer resource optimal utilization in a CRSN.

5.2 Inter-network Interference Consideration

Generally, the resource allocation mechanisms for a CRSN only takes into account the interference caused within a network and it fails to cover the inter-network noises. This is very necessary because as the application of wireless sensor networks are rising, many networks may be working in close proximal areas. This fact also shows the possibility of noises due to interfering of the neighbor networks that may attempt to use the same ISM band or even the licensed spectrum which is not currently in use. The paper [36] discusses both the intra- and inter-network interference problem in wireless networks. In future, the solution to this problem may be provided by managing the inter-network resource usage in case of many networks functioning concurrently.

5.2 Inter-cluster Scenarios:

In clustered schemes of radio resource allocation, the activities within an individual cluster alone are studied involving the interaction between cluster members and cluster head. The same is the case with energy expenditure issue. Since every cluster in a network is a part of that particular network, the stability and movement of nodes in the cluster are highly dependent [99]. There is a need to examine the resource allocation techniques for tracking their performance ratio with respect to inter cluster situation.

5.3 Fairness and Priority Issues

A CRSN is a priority based sensor network. The timely transmission of sensor data of particular nodes is more important than rest of the others. Thus, to account for better network performance, judiciously allocating the network's resources with priority assigned to the sensors is utmost essential. There are some works that have carried out research in this topic yet the topic remains fresh to be worked on and unexplored.

5.4 Effect of Errors in Spectrum Sensing

The schemes for resource allocation prevalent now assume that the sensors carry out the identification of data from the network without any mistakes. But in reality this proves to be wrong as there are usually errors in the data sensed in the channel resulting in non-optimal allocation of resources and noises in the network's primary users. In the work in [34], the authors present a simulation that brings out the effects of incorrect sensing of sensor data on the life of the wireless network. Solving the fair resource allocation with spectrum sensing inaccuracies considered is a challenging research to be addressed.

VI. Conclusion

Our work surveys the existing radio resource allocation mechanisms available for a CRSN. The techniques are divided into three categories with each reviewed in detail. The first of these is the centralized resource allocation where a central node is responsible for spectrum resource assignment and energy usage decisions to be made, which are passed on to other nodes in the network. The second is the clustered scenario wherein the sensor nodes are arranged in the form of small-sized clusters and the cluster head is the main authority to take the important decisions. The CH communicates its peers regarding the allocated spectrum as well as energy resources. The last category is called the distributed allocation where autonomy is established for every sensor to either cooperatively or explicitly decide the resource usage while information transmission. The issue of errors in the signal transmission is offered a solution of modulation to effectively decrease the bit-level errors in the transmitted signal. Thus, there is room for improving the network lifetime for CRSNs by incorporating modulation techniques. Further, the modulation techniques are partitioned into many divisions based on the performance estimate chosen including energy optimization, throughput improvement, QoS guarantees, noise reduction, fair and proper allocation, priority-based services and hand-off reduction. Hence this paper describes the issues to be solved with possible application domains for the discussed mechanisms. We have also suggested future research directions for these unaddressed problems. From our study, we have notice that centralized schemes have been the theme of so many works for network resource management but clustered and distributed schemes are yet to be worked on. The directions for carrying out research in these schemes for radio resource allocation can be adopted actively with regard to CRSNs.

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