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Applications of Clustering in Cognitive Radio Networks

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***Abstract*— With the use of cognitive radio (CR) technology, wireless devices can utilize licensed spectrum when it is unused by the licensed users. CR was developed as a response to the wireless spectrum shortage issue caused by the static spectrum allocation. Using CR technology, the unlicensed users can opportunistically access the spectrum during the absence of usage by the licensed users. Clustering is a widely used technique in Cognitive Radio Networks (CRNs) to efficiently manage network resources, optimize spectrum utilization, and enhance overall network performance. This study focuses on the applications of clustering techniques in the area of CRNs like spectrum management, QoS Support, topology management, energy efficiency, routing etc.**

***Index Terms*— clustering, cognitive radio, dynamic spectrum allocation, energy efficiency, spectrum aware and wireless sensor networks.**

I. Introduction

The increasing requirement for wireless devices and communication has created a significant need for the wireless spectrum, which refers to the range of frequencies used for wireless communication. However, the available spectrum band is becoming scarce due to the rapid growth in wireless technology and applications [1]. This scarcity has prompted the exploration of alternate mechanisms to efficiently manage and allocate the limited spectrum resources. Traditionally, spectrum allocation has been done using a static method, where specific frequency bands are assigned to different wireless services or users. However, this static approach has proven to be inefficient for several reasons.
Firstly, static spectrum allocation results in inefficient utilization of the available spectrum resources. Since assigned frequency bands are allocated to specific services or users permanently, even when they are not fully utilizing the allocated bandwidth, other services or users cannot access those unused frequencies. This leads to wastage of valuable spectrum resources [2]. Secondly, the static allocation approach is not adaptable to the varying demands of different wireless services or users. Some services may experience high traffic loads at certain times, while others may have lower demand. Static allocation cannot dynamically adjust to these changing demands, leading to inefficient spectrum utilization [3]. To address these challenges, alternative mechanisms have been developed to improve spectrum efficiency. These mechanisms aim to enable dynamic and flexible allocation of the wireless spectrum, allowing for more efficient utilization of the available resources. Some of these mechanisms include:

A. Dynamic Spectrum Access

DSA allows for opportunistic spectrum access, where secondary users can access unused or underutilized spectrum

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bands temporarily. This approach enables more efficient utilization of spectrum resources by making unused frequencies available to other users when they are not in use by primary users [4].

B. Cognitive Radio

Cognitive radio systems employ intelligent radios that can dynamically access the available spectrum bands without interfering with the primary users. Such systems sense the spectrum environment, adjust their transmission parameters, and perform the transmission [5]. By utilizing unused or lightly used frequency bands, cognitive radio improves spectrum utilization efficiency.

C. Spectrum Sharing

Spectrum sharing [6] models promote the coexistence of multiple wireless services or users within the same frequency bands. By sharing spectrum resources, different services or users can utilize the available bandwidth based on their current demand, maximizing spectrum efficiency.

D. Dynamic Spectrum Management

This approach involves real-time monitoring and optimization of spectrum allocation based on the current traffic conditions and user requirements [7]. It allows for efficient allocation and re-allocation of spectrum resources to maximize utilization and meet the varying demands of different services or users.

These alternative mechanisms aim to address the inefficiencies of static spectrum allocation and enable proper usage of the limited wireless spectrum resources. By dynamically allocating spectrum based on demand and sharing unused frequencies, these approaches help mitigate spectrum shortage and improve the overall utilization of the spectrum.

II. COGNITIVE RADIO

Cognitive radio is a technology that enhances spectrum utilization efficiency by intelligently accessing and utilizing the wireless spectrum. It employs intelligent radios capable of sensing the spectrum environment, adapting their transmission parameters, and dynamically accessing available spectrum bands without causing interference to licensed users. Such users are called as Secondary Users (SUs). The key elements of cognitive radio systems include:

Spectrum Sensing: The process of detecting and identifying the occurrence or non-occurrence of primary users (incumbent users) in each frequency band is known as spectrum sensing. The licensed users of each specific frequency band are known as the Primary Users (PUs) and they have the inherent rights to use that band. By performing spectrum sensing, cognitive radio devices can detect spectrum opportunities or unoccupied frequency bands, allowing them to access and utilize those channels without interfering the PUs.

Spectrum Mobility: An SU or a cognitive radio device can switch from one operating frequency band to a different available band according to the changes in the radio environment. This capability of the SU is known as spectrum mobility. It involves dynamically changing the operating frequency to avoid interference or to make efficient use of available spectrum resources. Spectrum mobility allows cognitive radios to adapt to varying conditions and ensure reliable and efficient communication.

Spectrum Decision: Spectrum decision involves making intelligent decisions on which channels should be utilized or to be left vacant depending on the availability and the policies defined by regulatory authorities or network operators. Cognitive radios analyze the spectrum sensing results, consider quality-of-service requirements, available spectrum resources, interference scenarios, and other relevant factors to make informed decisions on spectrum access. The objective is making the most possible utilization of the spectrum while adhering to regulations and avoiding harmful interference.

Spectrum Sharing: The usage of available spectrum in a cooperative manner by the different radio systems, including both primary and secondary users is known as spectrum sharing. Cognitive radios operate as secondary users, dynamically accessing and utilizing the channels which are not being used by the PUs. Spectrum sharing can take different forms, such as opportunistic spectrum access, in which the secondary users opportunistically access temporarily unused frequency bands, or dynamic spectrum access, where cognitive radios dynamically share and utilize the channels with the PUs based on predefined rules and interference constraints.

By combining these techniques, cognitive radio systems aim to improve spectrum efficiency, alleviate spectrum scarcity, and enable more flexible and dynamic access to the radio frequency spectrum. This allows for more effective utilization of spectrum resources, increased network capacity, and better support for emerging wireless communication applications.

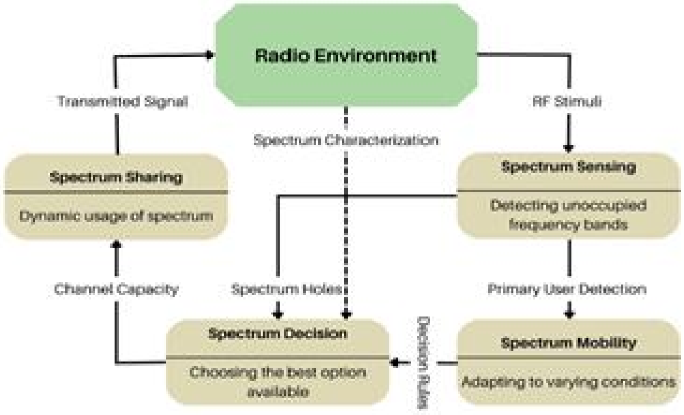

Figure 1. Key elements of a Cognitive Radio System

A. Clustering in Cognitive Radio Networks

Cooperative spectrum sensing and clustering are two important techniques used in cognitive radio networks (CRNS) to improve the process of spectrum sensing and the overall network performance.

Cooperative Spectrum Sensing: This sensing method involves collaboration among the CR devices to collectively perform spectrum sensing and make decisions about spectrum availability. Instead of relying solely on individual sensing results, cooperative spectrum sensing combines the sensing information from multiple devices to achieve more accurate and reliable spectrum sensing outcomes [8]. By pooling the sensing data, cognitive radios can mitigate the effects of individual sensing errors and improve the detection performance. Cooperative spectrum sensing can be performed through various cooperative strategies, such as fusion-based approaches, where the sensing data is combined at a fusion center, or distributed approaches, where devices exchange sensing information directly with each other.

Clustering: Clustering is a technique used to organize cognitive radio devices into groups or clusters to facilitate efficient communication and cooperation. In cognitive radio networks, clustering can be employed for various purposes, including cooperative spectrum sensing. Clustering helps create localized groups of devices that can share sensing information and collaborate effectively. By forming clusters, devices within a cluster can communicate and exchange sensing results more efficiently, reducing the overall communication overhead and improving the timeliness of decision-making processes [9]. Clustering also enables the selection of cluster heads, which are responsible for aggregating and reporting the data that has been sensed to a common point often called as a fusion centre.

Cooperative spectrum sensing along with clustering is used to achieve better spectrum sensing performance in CRNs. Devices within a cluster collaborate and share their individual sensing results, allowing for more accurate and robust detection of primary user activities. The cluster head (CH) or fusion centre (FC) fuses the received sensing data to make decisions about spectrum access or avoidance. Cooperative spectrum sensing with clustering improves the network's ability to sense and utilize spectrum opportunities, reduces the chances of false detections, and enhances the overall efficiency of the CRN.

The advancements in clustering techniques in CRNs aim to address various challenges such as energy efficiency, adaptability to dynamic environments, collaboration, scalability, and intelligent decision-making. By improving the clustering process, cognitive radio networks can achieve better spectrum utilization, enhanced performance, and more efficient management of available resources.

III. Application Of Clustering Techniques In CRNs

In the area of CRNs, clustering techniques have been applied to improve the performance and efficiency of the network. Some notable applications are being discussed in this section.

M. Bradonjić et. al. [10] proposed a graph-based criteria for clustering in CRNs which is also spectrum aware. The authors propose a novel approach where the idle spectrum is represented using a graph model. Three different criteria for clustering are proposed which can be used along with existing clustering algorithms to perform spectrum aware clustering. The clustering methodology developed in this manner produces clusters with many shared channels and thereby results in better communication within the cluster and performs cooperative spectrum sensing. The clustering performance of each criterion is being analyzed with respect to the number of clusters possible, size of the clusters and the number of idle channels which are common in each cluster.

In [11] S. Liu et. al. presents a novel methodology based on clustering to enhance the efficiency and reliability of assigning control channels in CRNs. The network is divided into clusters based on geographical proximity and the cluster heads are responsible for control channel allocation within their respective clusters. By leveraging the available spectrum opportunities, the cluster heads dynamically allocate control channels to secondary users to enable efficient communication and minimize interference. The main advantage of this methodology is the ability to improve control channel utilization and reduce interference in opportunistic cognitive radio networks. The cluster-based approach allows for localized control channel allocation, which enhances network performance and overall system capacity.

A spectrum-aware clustering methodology driven by events specifically designed for cognitive radio sensor networks (CRSNs) is introduced in [12] by M. Ozger et.al. to optimize the performance of CRSNs in dynamic spectrum environments. The nodes that detect the events are considered for clustering and form clusters with similar eligible nodes that are one-hop neighbors. Event detection must happen first as the clustering is only performed in the occurrence of an event. The clusters formation also takes into the account the spectrum availability and hence known as spectrum aware. The clusters are retained till the end of the event. Hence re-clustering is not needed, thereby improving the energy efficiency. This method is scalable and can adapt to varying network sizes and event densities, making it suitable for practical deployment in dynamic environments.

R.M. Eletreby et.al in [13] introduces a protocol called CogLEACH, which involves joining the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol with cognitive capabilities to create clustering scheme for CRSNs which incorporates spectrum awareness. CogLEACH Is a probabilistic clustering algorithm where the number of empty or unused channels is being used as the weight factor while considering the chance of every node to be selected as a CH. By incorporating spectrum awareness, the protocol intelligently allocates channels to different clusters based on the available spectrum bands, reducing interference, and improving overall network performance. This results in enhanced throughput, reduced energy consumption, and increased network lifetime.

In [14] G.A. Shah et.al. presents a spectrum-aware clustering methodology specifically tailored for effective routing of multimedia in CRSNs. A clustering algorithm is developed to perform DSA (dynamic spectrum access) and quality of service (QoS) routing of multimedia in CRSNs. Here the channels clustering is done based on the spectrum sensing done by every node and on the previous usage. Clustering is the basis for routing in this method and the criteria for CH selection is residual energy and spectrum awareness. The number of clusters is also optimized to reduce the effect of latency and packet loss on the quality of multimedia.

An adaptive uneven clustering hierarchy to optimize the CRSNs energy consumption was employed in [15] by E.Pei at.al. In CRSNs, devices need to efficiently use available frequency bands while minimizing energy usage. The proposed method, called LEAUCH, employs adaptive uneven clustering hierarchy to optimize the network's energy consumption. The nodes with a greater number of idle channels are assigned higher weights and are considered for the CH selection. The uneven clustering method is useful in balancing the energy usage among CHs. The proposed method is shown to improve the network lifecycle and energy consumption in comparison with other methods.

H. Wu. et. al. in [16] introduced a novel approach for improving energy efficiency in cognitive sensor networks through cluster based collaborative spectrum sensing. The maximization of energy efficiency in a Cognitive Sensor Network (CSN) is framed as an optimization problem by considering false alarm probability and collision as the constraints. The optimized parameters considered here was the number of cognitive sensors which were clustered, the threshold and time fraction of local detection. Also, a fictitious cognitive sensor (FCS) was created to get over the problem of determining the optimal threshold value for detection. Instead of determining the optimal value of the detection threshold the optimal received signal to noise ratio (SNR) of the FCS was searched. Extensive simulations were performed to evaluate the performance of the proposed approach which demonstrated significant improvement in terms of energy efficiency and throughput for various scenarios.

In [17] A. Ali et. al. proposed a method to enhance the performance of multi-channel CRNs by introducing channel clustering and Quality of Service (QoS) level identification. Multimedia applications have very strict QoS requirements and it is usually difficult to achieve this owing to the dynamic nature of CRNs. The proposed channel clustering scheme based on Gaussian Mixture Model groups available channels based on their similarity in terms of QoS characteristics and the traffic pattern of the PUs. This technique generated clusters of varying sizes and hence can be considered as a highly flexible method. The channel clustering and QoS level identification together provide a comprehensive solution to manage the complexities of multi-channel cognitive radio networks and enhance user experience by offering better service differentiation and performance.

A novel routing protocol designed for energy efficiency and spectrum awareness in distributed cognitive radio sensor networks was proposed by Yadav et. al in [18]. The method utilizes a self-organized method for performing distributed clustering and aims to reduce the average power consumption by nodes. An optimal number of clusters with a higher number of common channels is formed using this method. It also incorporates cooperative sensing in channel selection for intra-cluster communication to counter the effect of PUs. To enhance inter-cluster communication, this protocol selects the gateway nodes based on the energy levels, the proximity to the sink node, and a higher number of shared channels with nearby nodes.

T. Wang et. al. introduced a clustering algorithm [19] which is also spectrum-aware. It utilizes a weighted clustering metric and model for optimization to achieve the most optimal clustering arrangement. The novel weighted clustering metric assesses the correlation between time and space, confidence level, and the remaining energy simultaneously, enabling a comprehensive evaluation to select cluster heads and their associated member nodes. The clustering process is optimized by using this metric, to ensure efficient utilization of network resources. Following the clustering phase, cluster heads take on the responsibility of spectrum sensing, eliminating the need to involve all member nodes in this process. This strategic approach significantly reduces energy consumption during spectrum sensing while increasing the data transmission opportunities within the clusters. Performance comparisons between other algorithms and the proposed approach was conducted through comprehensive experiment and the results show improvements in network performance and energy efficiency in CRSNs.

In [20] Zheng M. et. al. proposed a clustering protocol in CRSNs for IoT which seamlessly combines spectrum variations and energy consumption considerations into its design. In this approach, each Cognitive Sensor (CS) transmits the channel availability and residual energy to its neighboring CSs. The Maximum Edge Biclique (MEB) is searched based on the collected information from its neighbors and channel qualities. For each CS, the weight is determined by considering factors such as the residual energy, the number of cognitive sensors, and the Common Control Channels (CCCs) quality within its MEB. Among the neighboring CSs, the one with the highest weight becomes the cluster head, and the remaining CSs in its MEB become cluster members. This process will continue until all CSs are appropriately clustered. Experimental results demonstrate that the proposed protocol is significantly better than the existing methods in terms of network stability and energy consumption.

An improvement of [20] was proposed by V. Shakhov et. al. in [21] by modifying the metric for assessing the channel quality and the weight calculation of a cognitive sensor (CS). In this method only the channel availability is considered for evaluating the channel quality and the average idle duration is not included. The clustering technique is also modified to restrict the cluster size to a fixed value determined using analytical methods. Analysis results are included to substantiate the improvements as mentioned.

R. Prajapat et. al developed a clustering scheme focused on improving the energy efficiency CRSNs with a specific emphasis on Internet of Things (IoT) applications in [22]. IoT applications need continuous communications within the cluster and between the clusters. To achieve bi-channel connectivity and maximize the network's lifespan, the study proposes two clustering schemes based on greedy k-hop method and an algorithm for neighbor discovery. The method considers several parameters, including the nodes' remaining energy, spectrum knowledge, the chances of primary users (PUs) appearing on the frequency band, quality of the channel, resilience to PUs' presence, and the Euclidean distance between nodes. These factors play a crucial role in selecting the appropriate hop number and the channels which are common for forming clusters. Experimental results highlight the effectiveness of this approach in enhancing the overall performance and efficiency of CRSNs for IoT applications with respect to network lifetime, stability of the network, clusters formed etc.

In [23] a node clustering algorithm suitable for CRWSNs was developed based on evolutionary game theory (EGT) by P. Rai et. al. The clustering process starts by dividing the nodes to create the first set of clusters. These clusters are later combined to develop the final set of clusters. The sink node plays a central role in forming the clusters and selecting CH nodes for each cluster. The algorithm based on EGT is employed to determine the CH. During the selection of the CH, factors such as the remaining energy, node location, node mobility, and the chances of the PU returning etc. are considered. This leads to more efficient and effective cluster formation and the clusters, along with the CHs, are distributed evenly thereby optimizing network coverage and resource utilization.

IV. SUMMARY OF TECHNIQUES

A summary of the various applications of clustering in Cognitive Radio technology discussed in the previous section is shown in the below given table.

TABLE I. SUMMARY OF APPLICATIONS OF CLUSTERING IN CRNS

Author	**Year**	**Proposal**	**Methodology**	**Algorithm**	**Spectrum Awareness**	**Energy Efficiency**	**WSNs**
M. Bradonjić et. al.	2012	A graph-based criteria for spectrum-aware clustering	Constructing bicliques of maximum size from bipartite graphs		Yes		
S. Liu et. al.	2012	Cluster based control channel allocation	Formulation of clusters using a bipartite graph problem	Spectrum Opportunity-based Clustering (SOC)	Yes		
M. Ozger et. al.	2013	Event-driven clustering protocol	Clustering is done in the occurrence of an event	Event-driven Spectrum Aware Clustering (ESAC)	Yes	Yes	Yes
R.M. Eletreby et.al	2014	A spectrum-aware improvement of the LEACH protocol	Uses the number of vacant channels as a weight factor in selecting CHs	Cognitive Low Energy Adaptive Clustering Hierarchy (CogLEACH)	Yes	Yes	Yes
G. A. Shah et. al.	2014	Multimedia routing protocol based on clustering	Determining the number of clusters optimally	Spectrum Aware Cluster-based Energy Efficient Multimedia (SCEEM)	Yes	Yes	Yes
E. Pei et. al.	2015	Adaptive clustering protocol for CRSNs	Uneven clustering method for balancing energy consumption	Low Energy Adaptive Uneven Clustering Hierarchy (LEAUCH)		Yes	Yes
H. Wu et. al.	2017	Cluster based collaborative spectrum sensing	Optimization problem for maximizing the energy efficiency			Yes	Yes
A. Ali et. al	2018	Clustering for QoS level identification in multi-channel CRNs	Bayesian non-parametric channel clustering scheme				
R. N. Yadav et. al.	2018	Routing protocol for CRSNs based on clustering	Self-organized distributed clustering to generate optimal number of clusters	Energy Aware Cluster based Routing Protocol (EACRP)		Yes	Yes
T. Wang et. al.	2019	Spectrum-aware clustering algorithm based on weighted clustering metric	Weight based metric to evaluate the cluster head		Yes		Yes
M. Zheng et. al.	2019	Clustering protocol in CRSNs for IoT for network stability	Cluster head selection based on weight factor	Network Stability Aware Clustering (NSAC)		Yes	Yes
V. Shakhov et. al.	2021	Improvement of NSAC	Weight calculation based on channel availability only			Yes	Yes
R. Prajapat et. al.	2021	k-Hop clustering in CRSNs for IoT	Clustering based on the hop count and number of common channels	k-hop Spectrum Aware Clustering for Bi-channel connectivity in CRSN (k-SACB)	Yes	Yes	Yes
P. Rai et. al.	2022	Mobility aware node clustering algorithm for CRWSN	Clustering based on evolutionary game theory (EGT)		Yes	Yes	Yes

III. Conclusions

Cognitive radio technology holds great promise in tackling the rising demand for wireless spectrum and the limited availability of resources. By intelligently accessing and utilizing the spectrum, cognitive radios contribute to more efficient spectrum utilization, improved wireless communication performance, and enhanced spectrum management overall. Clustering plays a crucial role in various aspects of Cognitive Radio Networks (CRNs), enhancing their overall performance and efficiency. Clustering in Cognitive Radio Networks provides a structured and organized approach to manage resources, spectrum access, and communication, contributing to better network performance, energy efficiency, and adaptability to changing network conditions. This study discussed the various research works focused on the application of clustering in CRNs.

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