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A Hybrid Cognitive Radio Reporting Scheme for Wireless Regional Area Networks

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Abstract: Due to the wireless network imperative impact, it is being widely used nowadays. Increasing number of users have also increased the requirement for bandwidth. Main challenges for these netwroks are to reduce overhead for communication, to utilize the bandwidth effectively and to minimize the reporting time .The effective solution for sensing and utilizimg the spectrum are provided through applying Cognitivr Radio Based Networks. Modern research trends in the domain of wireless networks are to address the challenges to minimize the reporting and sensing time for the wireless channel. This paper presents a hybrid scheme for reporting using the contention window for Wireless Regional Area Network. The contention window sensing mechanism is used in the proposed scheme that works in a cooperative manner where based on specific reliability criteria base station collects reports from all secondary usres.Only users with the highest probability are cconsidered eligible to send their reports. All reports are collected to the base station and the probability values are used to make global decsion. The proposed scheme and methosd is evaluated through simulations and performance is assessed of throughput, detection probability and detetction of false alarm. Results indicate the effectivness of proposed scheme over orderless reporting schemes.

Keywords: Wireless Network; Cognitive Radio; Wireless Regional Area Network.

1. Introduction

Heavy use of mobile devices has resulted in wireless media networks gaining strategic importance in our day to day lives. The uses and applications of wireless networks have shown significant growth over the last decade due to more efficient way of usage and mobility. The fast growth of wireless networks use has also resulted in the demand for spectrums due to the advent the Internet of Things (IoT) which has opened lots of opportunities for various applications and the use of cloud computing. Basically the radio channels used by such networks have a constrained number of frequencies, and most of the portion of spectrum have been allotted to licensed users who may be cellular network companies, service providers for sattellits ,television or radio etc. These primary or licenced users get allocated spectrum based on region wise locations. The spectrum allocated to other licensed users constitutes primary usage for other wireless devices. Unlicensed mobile devices can use the rest of the available spectrum. In a lot of situations, spectrum allocated for the use of licence holders is not used at all, and the unlicensed spectrum bands get more and more occupied, more and more overloaded. Spectrum-effective use of licensed bands is becoming a big problem for all the players in the field of wireless networks worldwide, and experts and research institutions in this field are looking for ways to use spectrum in an effective way.

Considering providing a standard is one of the most efficient and powerful yet fully used methods that accomplished in satisfactory way. Cognitive Radio (CR) [1, 2] standard designed for the problem solution of spectrum shaing among all users of the network. The spectrum is normally idle-left in licensed spectrum by Primary users (PUs) and Secondary Users (SUs) are the un licensced usres, suffer spectrum-shortage problems. All these spectrum problems can be solved if the unused licensed spectrum or white spaces are assigned to SUs that increase the usage of unused bands. The characteristics of white spaces or unused licensed spectrum are described in [3] then, the white spaces allocation can be applied in terms of time, space and frequency utilization in order that it is not interference nor damaging PUs.

Trustedly, this trading between spectrum models is named as spectrum sharing; sharing of the unused bandwidth in the networks following shared and models used exclusivly. These let SUs detect and search for free white space to utilize without notifying any involved PUs; alternatively, exclusive models oblige SUs to purchase bandwidth for certain period of times from PUs' service providers. IEEE 802.22 has introduced a promising standard defined by the Federal Communication Commission (FCC) aimed at accessing radio spectrum more efficiently. The emerging standard proposed as Wireless Regional Area Network (WRAN)[4] includes various cells work on the paradigm of master or slave. Every cell in the network has one Base Station (BS) to provide links and control some customer premise equipments (CPEs), the cell may comprise on CPEs. MAC functionalities are applied to BS to its CPEs. The Base Station (BS) plays a pivotal role in managing and controlling traffic in a cellular area. Every piece of data traffic passes through the BS, and it doesn't permit any Customer Premises Equipment (CPE) to engage in direct communication. Typically, licensed users such as mobile wireless gadgets or radio/TV regions are known as incumbents. In contrast, the unlicensed users receive the label of CPEs.

The WRAN system works within unused UHF/VHF TV frequencies, running from 54MHz to 862MHz. It can cover distances up to 100 km [5]. It uses Orthogonal Frequency Division Multiple Access (OFDMA), using Time Division Multiplexing (TDM) for data storage and high uneven data traffic [6]. This system helps avoid signal interference and supports earlier WRAN protocols. Various methods are in place for network monitoring, regulation, and identification [7]. Energy detection evolved as most engaging method, as PUs previious information is not required in it. However, they have a maojor issue related to hidden node problems, node fading and shadowing. Hidden node problem solution is provided through Cooperative Spectrum Sensing (CSS) [8] ,it also solves the problem of fading. It senses the channel, then informs about the availibilty of the spectrum. On the basis of availibity ,SU selection is done through the global decisions.

This paper contains a hybrid scheme for CR based network using WRAN. The approach works on a technique that provides reporting and operates sequential order based approach. The D-S evidence theory ismerged with it for reducing the reporting time. Energy detection technique is utilized for sensing the spectrum. Each network SU determine the value for Basic Probability Assignment (BPA)to satisfy reliability criteria that is setteed by the BS. The channel is ssnesed by each SU and each SU tries to compete for the channel access. The free spectrum is assigned to the SU that contains highest value that can send the reports to the BS. In collision is occurred then, the specific SU has to wait for some time to acquire the specified slots assigned to it. If the spectrum is not free in that specific time, the station again comoetes for the availibity of the spectrum. At final stage, the decision is taken globally by the BS to select and broadcasts the BS who succeeds to get the spectrum.

The subsequent is a detailed overview of subsections . Related work is provided in Section II. Section III contains the CSS working with CR networks. Proposed scheme working is explained in Section IV. The proposed algorithm for the scheme is prented in Section V . Results for experimentaions containing discussion given in Section VI. Section VII contains the conclusion part.

2. Materials and Methods

This section reviews existing research on Cognitive Radio (CR) wireless networks, specifically focusing on schemes that are relevant to our work. One study by Chu et al.[9] developed a dynamic method for acessing the specrum using CR networks supporting traffic of various types. It ensures the priority of Primary Users (PU) over Secondary Users (SU), evaluating likelihood of SU being blocked or dropped. Another study by Hoque et al.[10] proposed a queuing-based system for CR networks with preemptive resume capabilities. Their goal was to establish a model for estimating buffer size, using M/G/1/K queues as their theoretical basis.

Oyewobi et al. [11] analyzed wireless communication methods (CR) tailored for networks using handoff and industrial sensors. They identified challenges faced by applications with specific quality demands. Their approach addresses these issues, optimizing bandwidth utilization while minimizing communication delays and interference.

Afzal et al.[12] studied the initial connection process in WRAN, using contention window sizes and CPE data to estimate the likelihood of collisions. They developed a Markov chain-based model for CPE registration. Capriglione et al.[14] proposed a technique for spectrum sensing in CR networks. It uses a two-step approach: identifying potentially occupied bands in the spectrum, then further examining those bands to enhance detection.

Wang et al.[15] suggested a model for wireless network cells based on trust, using past behavior of devices to assess trustworthiness. Khan et al.[16] developed a system using fuzzy logic to dynamically select communication channels in cognitive radio networks, specifically within the IEEE 802.22 framework. Yu et al.[17] proposed theory of trunking into spectrum using the Grade of Service (GoS) to optimize traffic load and spectrum utilization for secondary users.

Researchers have extensively studied Cooperative Spectrum Sensing (CSS) used in Cognitive Radio (CR) based networks. A scheme using a random access process was proposed [18], providing insights into methods for gathering local sensing reports. Additionally, Alhamd et al. [19] introduced strategies forrandom access and channels reporting using the protocol of ALOHA. They utilized an reservation based on ALOHA to track probabilities for detection avoiding false reports.

Several researchers have developed methods for Channel State Sharing (CSS).So et al. [20-22] proposed a Cooperative Relaying (CR) network approach for CSS, which can generate reports to a limited extent. Alhamad et al. [23-24] created a scheme for reporting channels based on random access. It uses Forward Compatibility (FC) and "K out of N" rules for making global decisions. Qihang et al. [25] developed a CSS method using Dempster-Shafer (D-S) fusion theory. This approach improves detection and reduces false alarm probabilities.

Researchers proposed a system for cooperative detection of spectrum availability, designed by Zou et al. [26], using a sequential method to enhance detection accuracy and decrease detection time. However, this system lacked a structured sequential approach, typically used to improve detection precision and reporting abilities. Contemporary research in wireless networks built on Cognitive Radio (CR) technology emphasizes the significance of adaptable spectrum access, queue-based designs, trust models, fuzzy logic methods, and cooperative sensing approaches. These advancements seek to enhance spectrum utilization, reduce delays, and boost the overall efficiency of the network.

CSS in CR networks:

The orderless reporting scheme is utilized with Cognitive radio (CR) networks for cooperative channel sensing,. Here, the fusion center (FC) sends requests to secondary users (SUs) in a set order. In the presence of PU,Energy detection method is applied by the SU. After determining PU status, it assesses the Basic Probability Assignment (BPA) to gauge the parameter selection. BPA values are calculated based on the Cumulative Distributive Function (CDF) defined in [26-28]. The reliability of data from multiple reporting devices (SUs) is determined by the central authority (FC). Each SU reports its reliability to the FC. These reliability values are combined at the FC using a specific mathematical method (Dempster-Shafer theory). If the FC receives multiple reports, it can make an overall decision. However, if it doesn't receive enough reports, it can't reach a final decision. Using D-S theory or similar methods can be resource-intensive, resulting in longer processing times and higher energy consumption, especially when reporting is unordered.

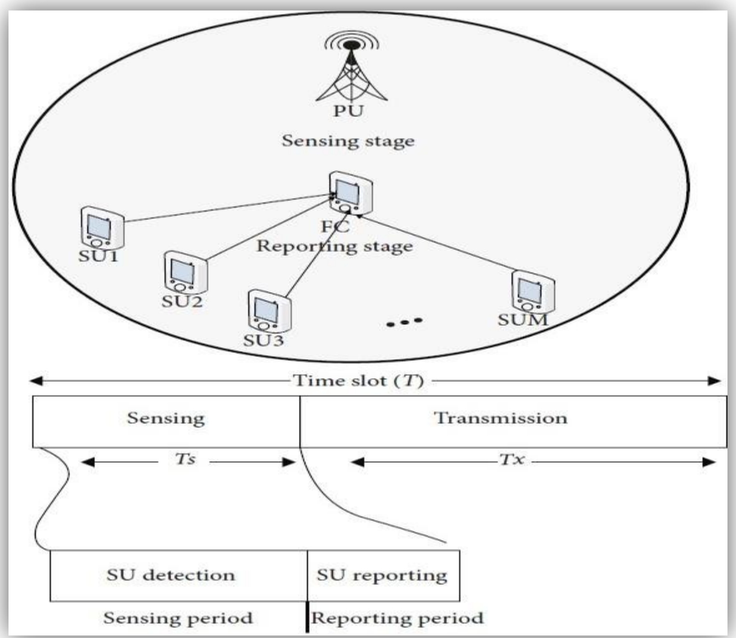

Figure 1. CSS in CR Networks [25]

Khan et al. [29] introduced a contention window (CW)-based ordered sequential approach, offering a substantial improvement over the issues encountered in the orderless scheme for reporting through minimizing overhead involved in processing. The reprorts are send to the FC in order of sequence. BPA is calculated at each PU using prescribed criterion, then the sensing of SU is synchronized with explicit balance times for accessing channel assigned to specific SU. During this designated time, each SU contends for channel access to send its reports to the FC. When an SU successfully accesses the channel, it transmits its reliability values. The FC then evaluates the reliability within its predetermined range. When the data values satisfy the predefined requirements, the central controller grants permission to a particular unlicensed user to access the wireless communication channel.

2.1 Proposed Methodology

Proposed approach to improving Cognitive Radio (CR) network efficiency involves two main elements: 1. An ordered sequential reporting system, as described in [30], which allows for a structured flow of information in CR networks designed for the Internet of Things (IoT). 2. A dynamically adjusted contention window size, as suggested in [31], designed for Wireless Regional Area Networks (WRANs), which helps optimize network performance. This part of the system improves how the contention window is controlled. This reduces the resources needed to process data and makes the whole scheme work better for WRAN systems.

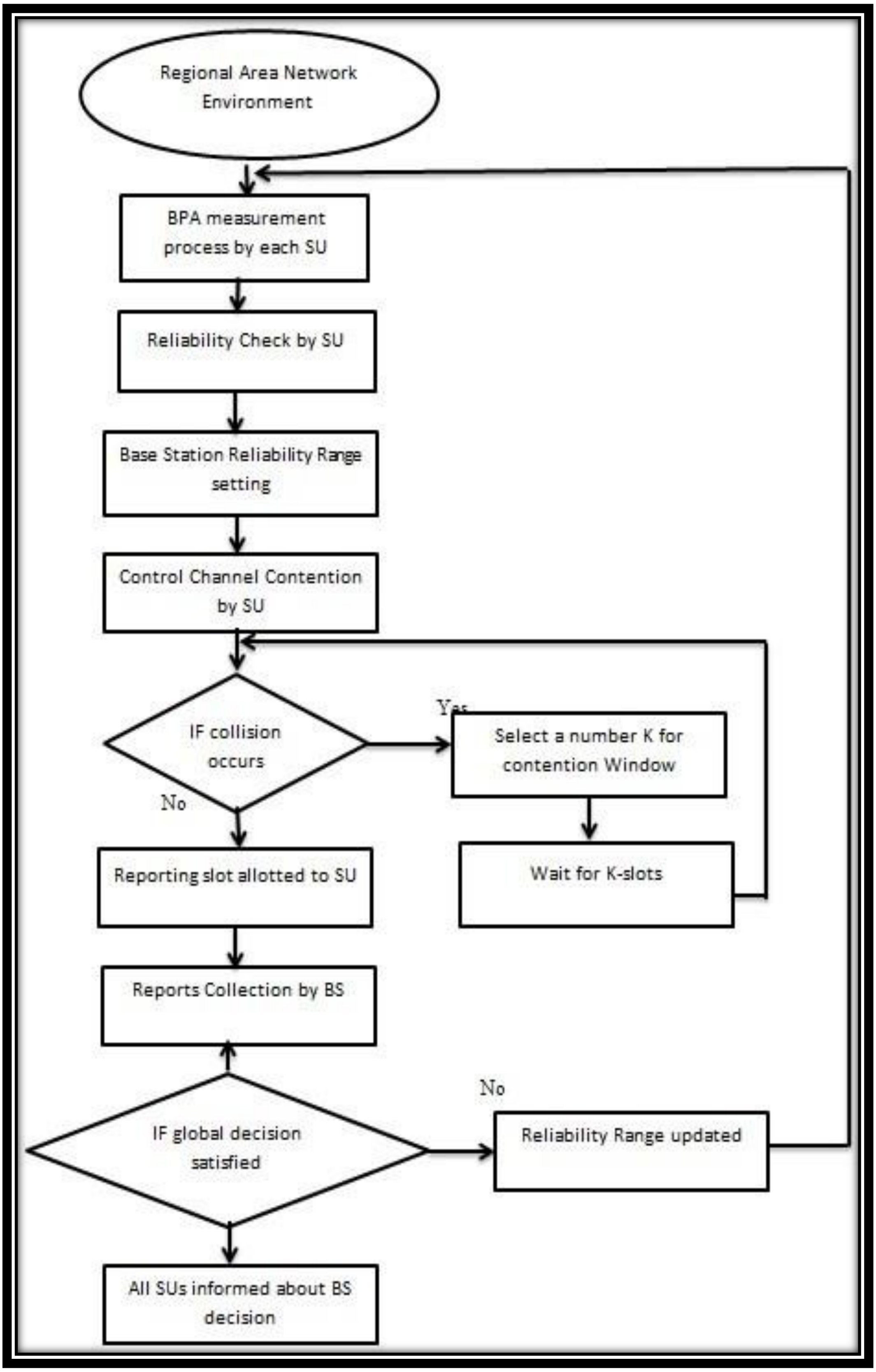

Figure 2. Flow chart for proposed Reporting Scheme

Proposed method improves the existing reporting strategy to suit Wireless Reconfigurable Ad-hoc Networks (WRANs). The diagram in Figure 2 shows how our approach works. Each user calculates its reliability using the Basic Probability Assignment (BPA) method and checks it against a reliability range set by the base station. This process can be represented as:

A reliability check indicates that the blood pressure (BPA) of a patient is within a specific range, with a lower limit and an upper limit. The base station (BS) plays a central role in updating and sharing its reliability score. This score changes over time and helps make the whole system more flexible. The BS calculates its new reliability score (Reliability_BS) based on its previous score and any recent measurements (New Measurement).

To complete the communication process, during the specific time intervals Sensor Units (SUs) send tranfer reports to the Fusion center (FC). Setting of these access time intervals is very important aspect to achieve less interupted transmission of data. During this allocated interval time, each SU has to compete for the channel access. In case of multiple SU need to access the channel simultaneously, the time frame is adjusted accordingly to facilitate all the SUs of the network. The proposed scheme uses 'N' slot mechanism for this time intervals. SU have to wait for the specific period of time after sending the access request. When that time frame expires that SU resubmits the channel access request. When the SU is successfully connected to the channel, it sends its own calculated BPA value to the BS. Then the global decision criteria is tested and matched to the BS reliability value. In case of failure BS repeats the channel acccess and reporting process to qualify for the channel. Hence, the proposed haybrid scheme provides effective spectrum usage using the efficient reporting mechanism for a better solution to the issuses existing in WRAN. Results show that the hybrid scheme provide the effective and complete solution to the problems of orderless channel access in wireless networks.

2.2. Proposed scheme Pseudo Code:

In Wireless communication based networks, global decision based relaibily criteria setting relies on the BS. BS is also responsible in allocation of the channels to all the SUs of the networks. It also communicates the channel allocation results to all SU. After the global decision about succussful channel allocation is taken, BS informs and broadcasts this slecetion to all SU of the network. This ensures a well coordinated way for channel access and also provides ordered reporting for the wireless network. Using the proposed dynamic method ensures the effective spectrum utilization that results in improving the overall performance of the WRAN. The Proposed scheme algorithm for reporting based on contention window for WRAN is presented in Figure 3. At first step each SU assess its reliabity value. BS collects and combines the BPA values from all the SUs. Reporting starts with the BS senses the channel during the specific backoff time interval. At this time collision value is also set for the transmission. Backoff time is used to set a certain number for slots for the SU and window size is also defined. Backoff time is used for the SU to wait for the channel access.

```
MAIN PROCEDURE HYBRID-CW Reporting
BEGIN
    For each iteration
        For each SU
            Calculate Basic Probability assignment
            SU measures reliability values
            SU BPA combined using D-S theory
        END
IF the SU has available channel and interference
```

```
10  SU burst the reporting in another slot
11  Else
12      window backoff is set internally
13      SELECT a N randomly from contention window
14      SEND Nth initial ranging slot request
15          IF no RNG-CMD RECIEVED THEN
16          CALL PROCEDUE process_BACKOFF
17            Go to line 13
18            ENDIF
19        IF RNG- CMD received with status 'continue' THEN
20              MAKE correction
21          Go to line 13
22      ENDIF
23        IF received RNG- CMD with status 'success' THEN
24              BS collects reports from SU
25        IF BS global decision satisfied
26  Allocate channel to SU
27    Else
28   Go to line    9
29            ENDIF
30            ENDIF
31    END
32  PROCEDUE backoff_process
33  BEGIN
34  DOUBLE the window back off to max window back off value
35  END
```

Algorithm 1. Proposed Scheme

The BS is the main component of the network that defines criteria for reliability and also slelects and finalizes the best channels for all the SUs presented in network. If the channel meets the criteria, the BS assigns the channel to the SU and lets all other SUs know about the decision. If the selected channel is successful, the BS informs the SU that was chosen, and the network is notified, which helps with coordinating channel access and reporting. This way, the network can use the available channels effectively, which makes the wireless regional area network (WRAN) perform better overall.

3. Results

This section provides simulation findings and analysis for our proposed reporting system for Wireless Regional Area Networks (WRANs). Developed for Cognitive Radio Networks, our scheme operates on a contention window-based reporting system following the IEEE 802 standard. Assuming a 50% probability of Primary User (PU) presence and a bandwidth of 6 MHz, simulations were run using MATLAB with 50-100 Secondary Users (SUs) and a reporting interval of 1 millisecond. Efficiency was evaluated with a contention window size of 20.

Figure 3 illustrates the false alarm probability (PFA) and also the detection probabilities (PD) for the proposed scheme. The graph depicts the reporting percentage for various threshold values ranging from

0.5 to 3. With the increased threshold value the energy detection probability decreases across all Secondary Users (SUs). Additionally, Energy detection false alarm probability for in each SU is minimized for varying threshold values. This justifies the reporting mechanism based on global decision.

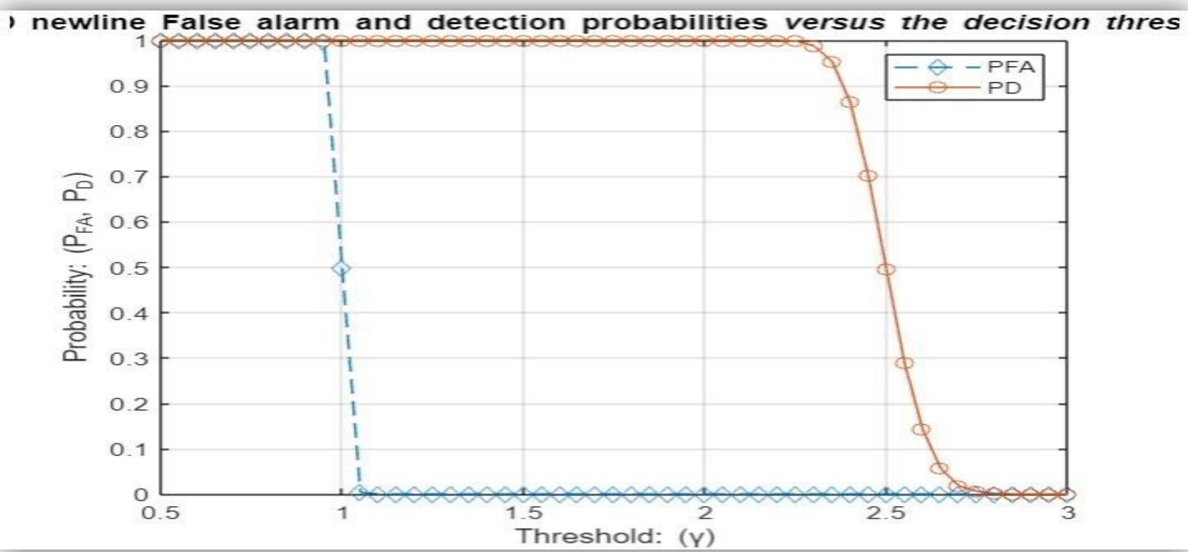

Figure 3. PFA and PD vs.Threshold

The probability of false alarm (PFA) is nearly 100 percent for a threshold value of 1. As we increase the threshold values, it effectively minimizes the PFA. It provides a 100% probability of detection (PD) up to a maximum threshold of 2.3, but it gradually decreases for higher thresholds. Both the PFA and PD exhibit a decreasing trend with an increased number of threshold values.

Figure 4 illustrates the miss probability rate for detection in our proposed scheme. The miss detection rate occurs when SU overlooks the presence of PU. A contention window to the reporting scheme results in a decrease in the PU miss detection rate. SNR values range from -10 to 10. For higher SNR values, our proposed scheme yields a lower probability of miss detection. This demonstrates that each SU with a higher PBA can send reports to the BS. The FC declares and selects the SUs among all that meet the specified reliability range.

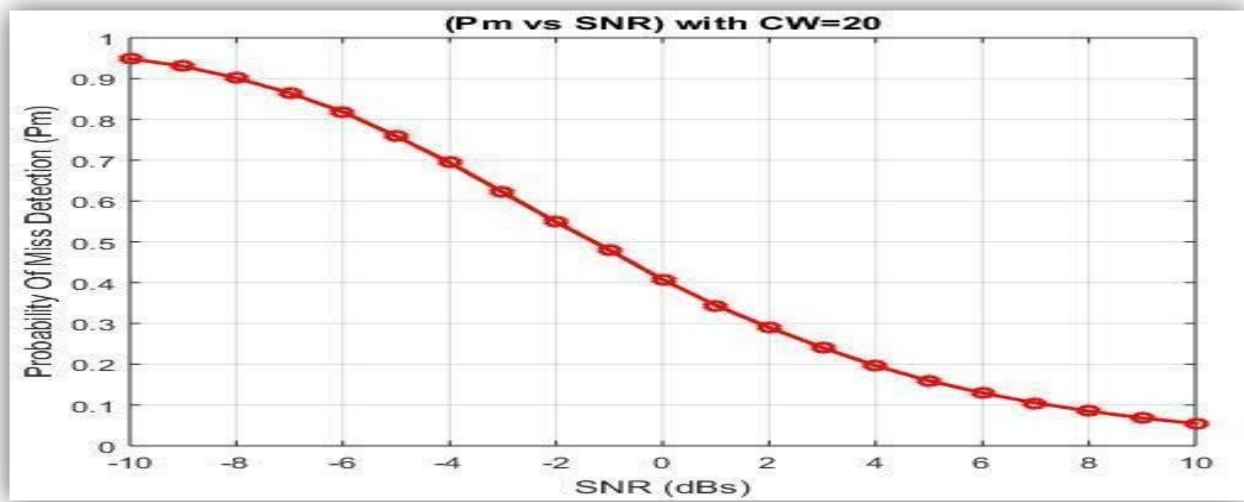

Figure 4. Probability of Misdetection

Figure 5 illustrates a comparison fot Probability of Detection (PD) to Signal-to-Noise Ratio (SNR) for the proposed metod. Using CW size of 20, the PD increases for SNR values ranging from -10 to 10. However, for higher SNR values, the PD decreases, consequently reducing collisions in the spectrum. This leads to better performance in selecting SUs for reporting and, overall, improves spectrum utilization by minimizing collisions among all SUs.

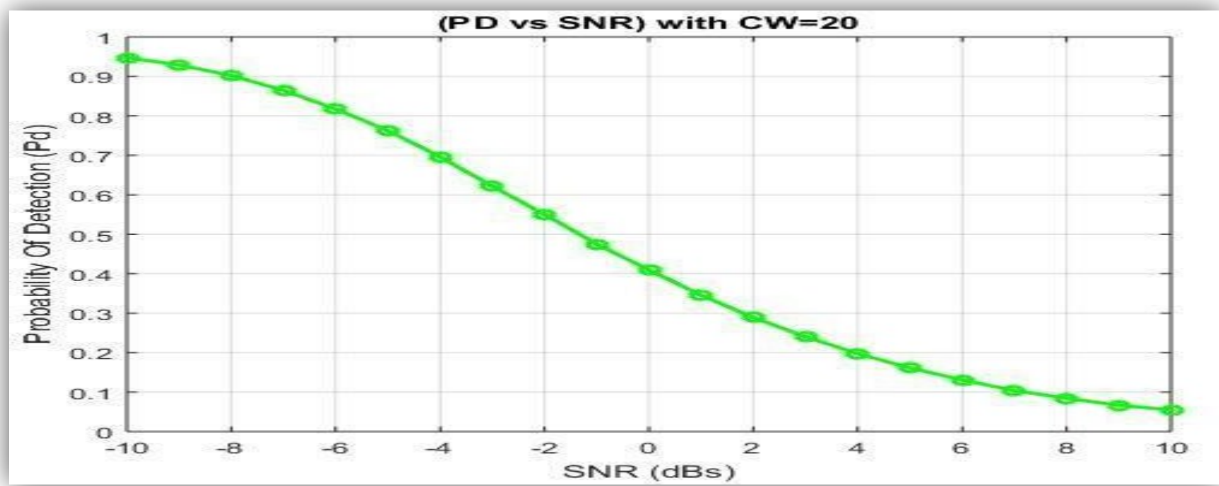

Figure 5. Probability of Detection

Figure 6 presents a comparison of local probability rates for miss detection across various SNR ranges. Different numbers of samples are selected for each SNR. As the SNR increases, miss detection probability also increased by the SU. However, the proposed reporting scheme, the miss detection rate is reduced for SUs. This is because each SU senses the medium and waits for its reporting turn in case of a collision. Only the SU that meets the reliability criteria set by the BS can sense the medium.

Figure 7 illustrates a comparison between the probabilities of miss detection and false alarms in both our simulation and analytical results. Upon comparing the analytical results with the simulation, it is evident that the simulation results closely align with the theoretical predictions. Additionally, our proposed scheme effectively reduces false alarms, also decreases the rate for miss detection for all SUs. The false rate alarm is maintained at less than 10% for the proposed scheme. An increase in miss detection also corresponds to an increase in false alarms.

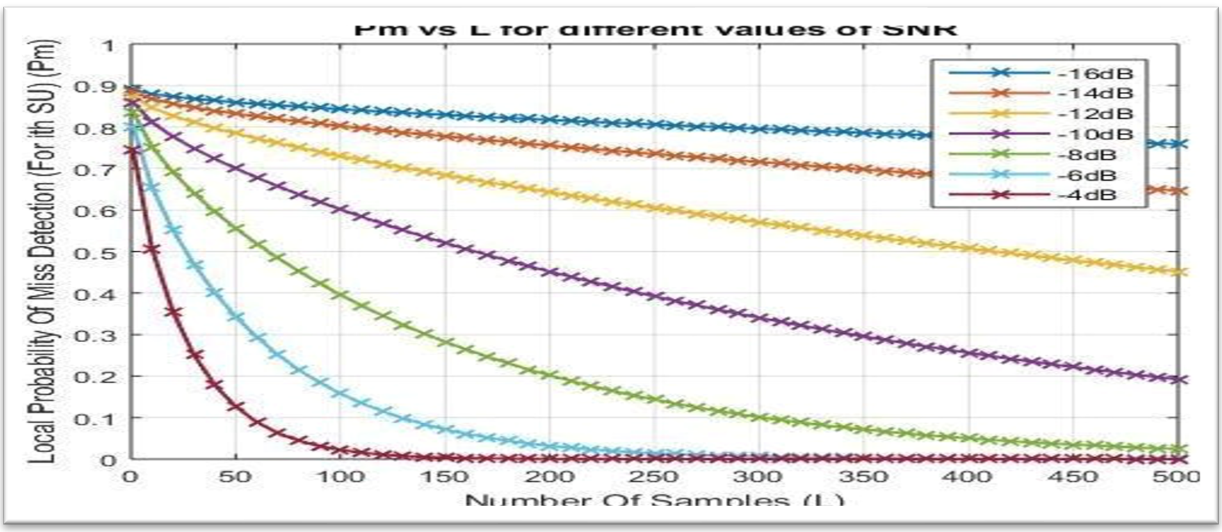

Figure 6. Local Probability of Misdetection

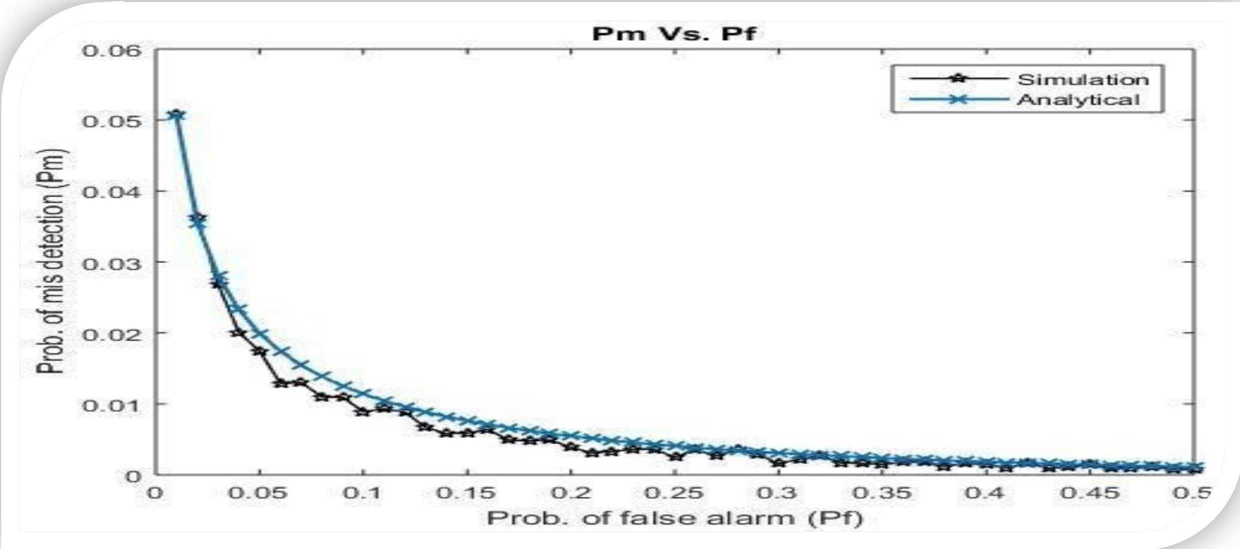

Figure 7. Probability of misdetection Vs. Probability of False Alarm

The global decision is made for the available channel allocation to the SUs that meet the certain criteria made by the BS. All SUs calculate their PBA, and if they meet the criteria for contention, they report to the BS to qualify for the spectrum. In the event of a collision, a contention window (CW) is utilized to add time slots for SUs to wait for reporting. In Figure 8, the results are presented for the global probability of detection with varying numbers of SUs. The proposed CW-based reporting scheme effectively reduces the misdetection rate. Simulation results demonstrate the number of SUs increase in the prposed scheme almost uniformly reduces the misdetection rate. This is because all SUs first wait to sense the medium. The SU with a higher PBA waits for k slots in case of collisions. The BS then makes the decision regarding SU selection with the highest PBA. Consequently, the overall misdetection rate is decreased by incorporating the ordered contention window-based scheme for spectrum sensing.

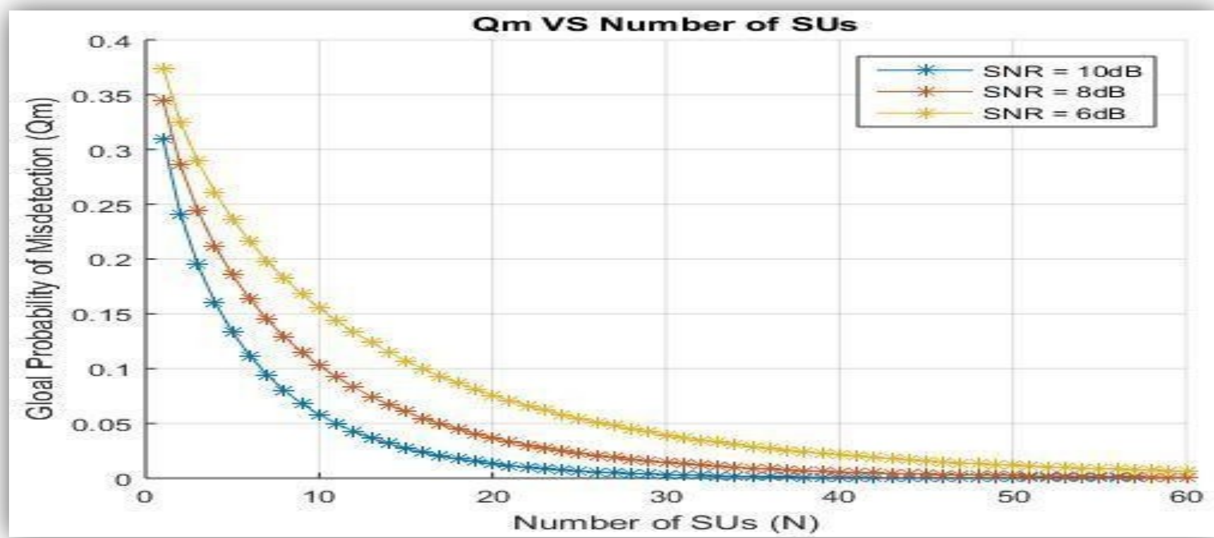

Figure 8. Global probability of misdetection

Figure 9 illustrates a comparison between simulation and analytical results of Pm versus SNR. Local probabilities of detection (Pdi) and false alarm (Pfi) are calculated. Pm represents the local probability of misdetection. Simulation results indicate that our proposed reporting scheme effectively reduces the misdetection for PU presence in the case of spectrum sensing. This results in a superior reporting scheme when compared to disorderly reporting mechanisms.

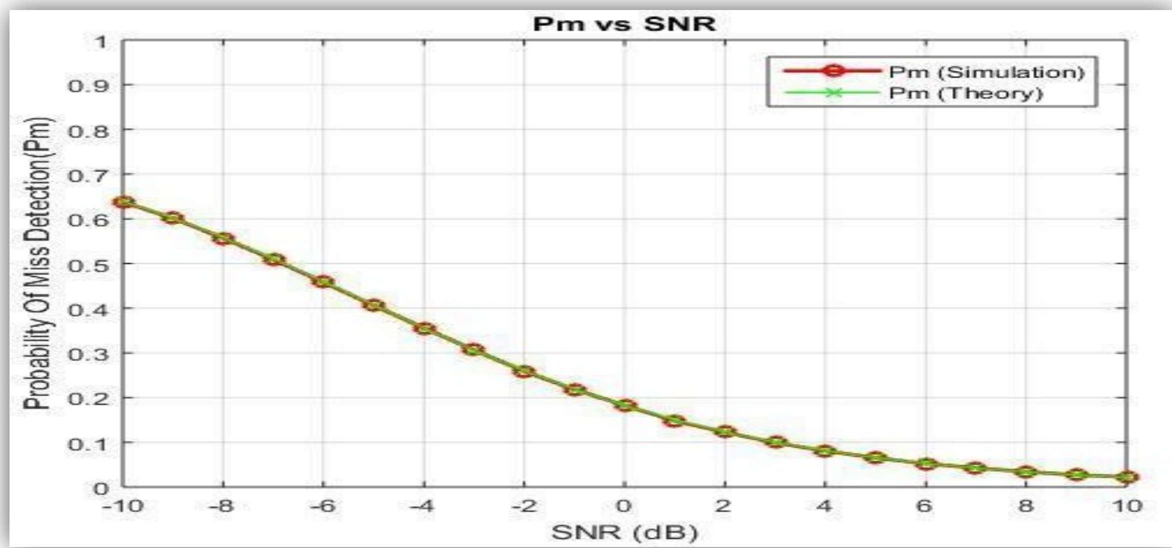

Figure 9. Probability of misdetection vs. SNR

Figure 10 displays the saturation throughput for 50 stations. With the addition of a contention window back-off scheme, each SU must wait for a specified time slot. As the number of stations increases, the throughput decreases. Most of the time, the SU waits for reporting when the spectrum is unavailable. If a collision is detected, the additional window prevents all stations from sending their reports to the BS. Consequently, it reduces the overall reporting rate for all the SUs.

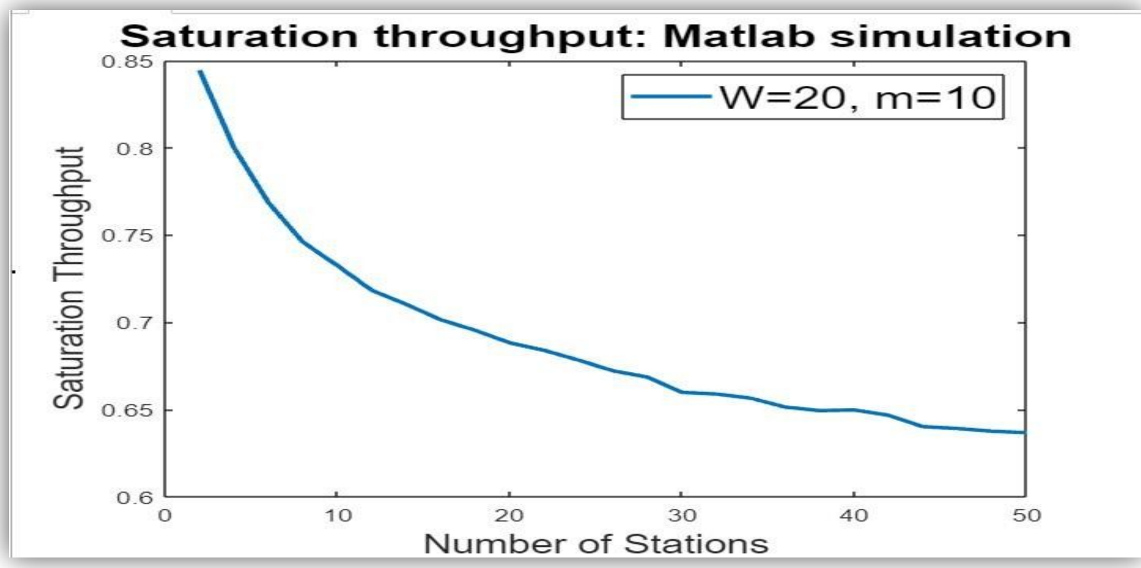

Figure 10. Saturation throughput across different number of stations

The presented graphs reveal the efficiency of our proposed method for sharing data in cognitive radio networks. In Figure 4, we see that proposed method lowers the chance of not detecting signals. Figure 5 shows that the likelihood of detecting signals goes up within a specific signal-to-noise ratio range, proving our method's ability to improve detection. Figure 6 gives a detailed look at the probability of missing signals at different signal-to-noise ratio ranges. Simulation findings closely match theoretical projections, demonstrating the plan's reliability. Figure 7 shows the scheme's ability to reduce missed detections and false alarms, improving reporting accuracy. Figure 8 illustrates the likelihood of detection in various scenarios, demonstrating the scheme's effectiveness in decreasing missed detections with the increase in users. Results highlights the effectiveness of the prposed method in using efficiency and scalability parameters. Figure 9 shows simulated and analytical results that demonstrate the scheme's low probability of misdetection, particularly when compared to less organized reporting methods. Effective contention management is explained in Figure 10, that decreases throughput saturation with the increased number of stations. Results show that the proposed scheme improves the rates for reporting and enhances the network performance for channel sensing. The proposed reporting system for cognitive radio networks utilizes flexible transmission schedules to optimize performance. Results show the enhanced detection accuracy, resulting in fewer errors. Proposed scheme reduced instances of false alerts, improving system reliability. It provides efficient handling of a sizable number of connected devices. Overall, the system exhibits improved data reporting effectiveness.

4. Discussion

Cognitive Radio Networks (CRNs) use cooperative sensing to let Secondary Users (SUs) use the channel with Primary Users (PUs), which effectively utilize the channel. But as more SUs use cooperative sensing, the average time it takes to report results goes up, which means more computing power is needed for spectrum sensing and use. To address the issue of excessive usage and high costs, this paper presents a new system that regulates how devices access wireless networks. The system works by having all devices try to access the network at the same time, and then shares the network among them. The system also allows the base station to monitor how well the devices are working, and devices that are working well are allowed to share information about the network to specific BS. Then the BS makes global decisions, uses received reports to select the secondary user (SU) that handles channel allocation. In situations where different SUs access the channel at the identical time (collision), our plan uses a contention window size system. When there is a collision, the involved SUs have to wait for a set amount of time before trying to use the channel again. This reduces competition and makes the system run better overall. Simulation results prove the effectiveness of the proposed hybrid contention window based scheme for WRAN. Proposed scheme performance is evaluated thorogh various standard metrics of detection of false alarm,throughput and the detection probability values. Results highlight the proposed scheme provides higher throughput and efficient reporting ways that make it more suitable and efficient for the CRN based problems and scenarios. It performs well for the cooperative sensing mechanisms for the networks.

5. Conclusions

Efficient spectrum usage for wireless networks is attained through the Cognitive Radio technology. Secondary Users (SUs) are allowed to access the channel when Primary Users(PUs) don't use the channel through cooperative sensing mechanism. In case of increase in the number of users, it becomes difficult for the SUs to share the channel access. In WRANs, the spectrum utilization by the SUs has been increased. Spectrum sensing and usage also increased with the increased number of SUs in the networks.It has increased computational requirements for the WRANs as well. It leads towards finding an efficient soultion for this sensing and reporting problem. The presented scheme provides a hybrid method based on contention window mechanism. Results show that it reduces the computational overhead in case of shared channel access to all the SUs presented in the network. All SUs have to compete for spectrum access and have to inform the BS their reporting informations. BS checks all the reports received from SUs and finally selects the SU for the channel allocation that meets the specific predefined criteria. This provides efficient and ordered based channel allocation. Collision problem is addressed by introducing a waiting period for the SUs. All SUs must have to wait for spectrum sensing during this waiting time period. Computer simulations using MATLAB software show that this approach is effective. Measurements such as data throughput, detection accuracy, and false alarm rate demonstrate that our method surpasses existing techniques, providing improved performance and a reliable reporting system for networks where multiple devices can use the same radio frequency (Cognitive Radio Networks or CRNs).

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