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Spectrum Sensing Techniques In Cognitive Radio Based Sensor Networks: A Survey

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Abstract

With the rapid growth of users of wireless sensor networks, the unlicensed spectrum bands are becoming over crowded. To overcome this problem cognitive radio (CR) technology is used that will help the users to access the licensed ISM 2.4 GHZ or 5 GHZ bands when not in use. The authenticated users are known as primary users (PU) and those who are not authenticated are known as secondary users (SU) of licensed band. The licensed bands are continuously monitored for free bands at different times when they are not used by PUs. The free slots are known as spectrum holes and thus can be used by SUs. Different sensing techniques are used to identify these spectrum holes. Once the information about spectrum holes is collected, spectrum allocation is done for different SUs. Dynamic spectrum access (DSA) is done to avoid interference of PU and SU. The efficiency of a spectrum sensing and allocation technique depends on time, frequency, collisions, fading capacity. In this paper, a review of different variations of spectrum sensing techniques is done along with their advantages and disadvantages.

Keywords: CR, WSN, CRSN, PU, SU, DSA

I. INTRODUCTION

A wireless sensor network (WSN) consists of different sensing devices also known as motes. The sensors are used to monitor temperature, pressure, or other factors. Sensors can be used for communication and computation both. These sensor nodes posses some challenges such as:

- As sensor nodes are battery operated, the battery power diminishes with time.
- Presence of heterogeneous nodes
- Due to changing network topology if some sensor nodes fails
- Different behavior due to different sensing environments
- Crowded WSN due to increase in use of these networks.

Due to all these challenges WSN needs a special attention while designing it for different layers. Out of all, the last but the most vigilant is overcrowdings of WSNs. As the market of mobiles phones and other electronic devices is increasing, so as the demand of frequency spectrum is increasing. These devices and WSN operate in unlicensed spectrum, but due to their over usage the unlicensed spectrum is becoming over crowded.

The solution to this problem is the use of Cognitive radio (CR) in WSN, which is collectively known as Cognitive radio based sensor networks (CRSN). CR is used to identify the white spaces also known as spectrum holes which are unoccupied free spaces in available licensed spectrum as shown in Figure 1. CR is responsible to find the spectrum holes in such a way that it does not collide with the primary user (PU) activity.

A cognitive radio first senses the white spectrum holes at different times. Once the sensing is over, its management and handoff should be taken care of. For example, if during the SU activity PU again start doing its activity than a handoff is required for SU. It is done to avoid interference with PUs. Last step is to allocate the best available spectrum space to the SU. So all these steps form a cognitive cycle. A typical cognitive cycle includes following as shown in Figure 2 also:

- Sensing Spectrum for white holes
- Spectrum hand off management
- Dynamic Spectrum Access- Allocating spectrum to SU and sharing by PUs and SUs.

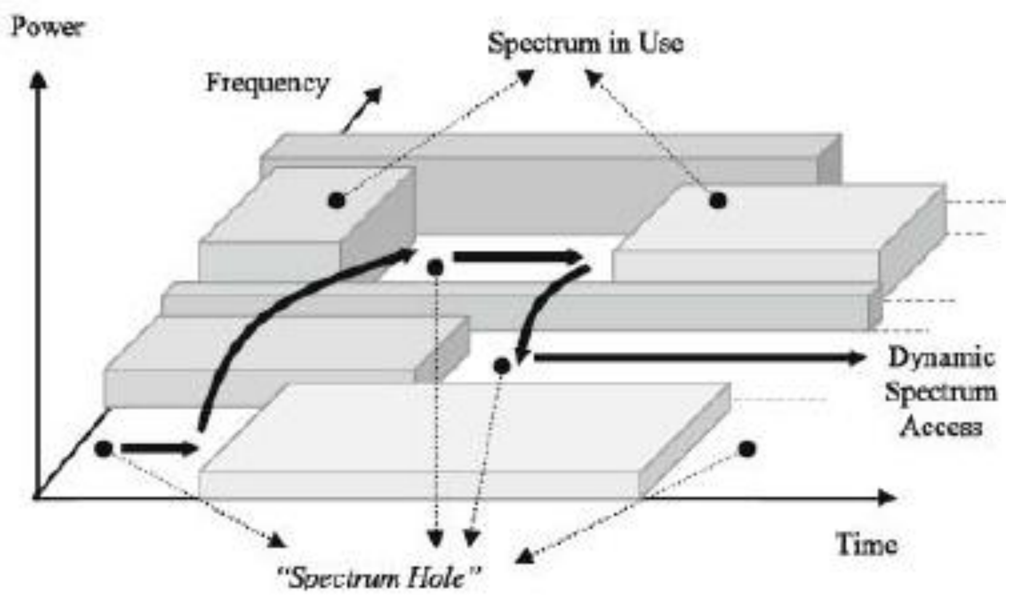

Figure 1: Identifying Spectrum holes

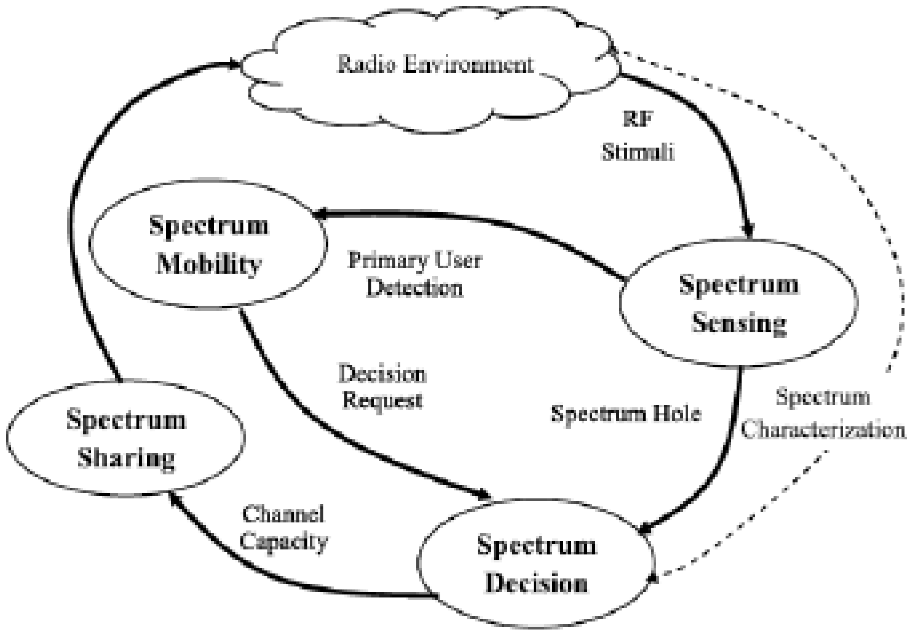

Figure 2: Cognitive Radio Cycle

II. SPECTRUM SENSING IN CRSN

Spectrum sensing using Cognitive Radio (CR) in WSN will assist different users to access the spectrum holes present in licensed bands. Spectrum sensing techniques can be categorized as shown in Figure 3.

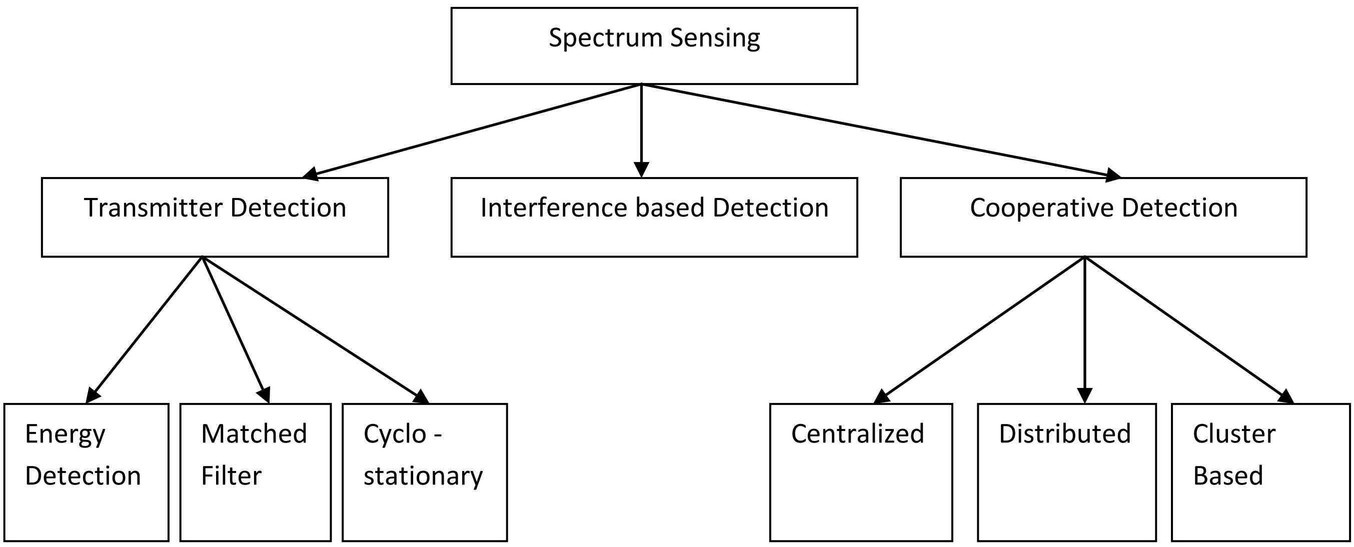

Figure 3: Classification of Spectrum Sensing Techniques

The first category of sensing techniques is based on gathering information about transmitter.

Energy Detection

Urkowitz et al. in [1] presented an energy detection technique. In this a threshold value is set for a channel. Channel is monitored for a particular interval of time. If the received signal strength is less than the threshold then the channel is assumed to be free and available for use. But if the received signal strength exceeds threshold then channel is assumed to be busy. Energy detection technique works well in power constraints sensor nodes in CRSN due to its simplicity. Energy detection technique has various downsides. First, the time required for computing energy is more and secondly, this technique cannot distinguish among the signal noise power. So, if a noise signal increases, it is difficult to discriminate whether it is because of PU undertaking or noise signal.

Matched Filter

Cabric et al. in [2] proposed a matched filter detection method. This technique infers PU transmission capabilities before starting sensing. It can also very well distinguish among signal and noise. This technique is best used in situations where PU activity scenario is already known. The shortcoming of this technique in CRSN is that each sensor node will require extra effort to maintain the behavior of different primary users.

Cordeiro et al. in [3] recommended that synchronization s required with the PU using preamble, pilot signals or synchronization messages. For example in television transmission narrowband synchronization using pilot bands is done. CDMA and OFDM also make use of codes and preambles respectively for synchronization.

Cyclo-stationary

Sutton et al. in [4] proposed a method to detect the PU signal by recognizing its cyclic prefixes, carriers, or hopping sequences. This signal has the property of spectral correlation that can identify this signal from noise and interference.

The advantage of cyclo stationary technique is that it can work in low SNR as compared to above stated energy detection technique. But the disadvantage is that realization of PU signal is required before separating it from the CR signal.

Interference Based Detection

Xing et al. in [5] defined a method that will simultaneously use of the spectrum by primary users and secondary users. The condition imposed is that the SU can only transmit at low power such that it does not interfere with PU signal. This can be treated as its limitation also. But the best thing about this technique is that there is no need of dynamic spectrum access as the spectrum can be used by a SU at any time but with low power constraint.

Bater et al. in [6] compares this technique of interference detection similar to the ultra wide band technique where the SU can access spectrum together with the PU.

Cooperative Detection

The next sets of techniques are cooperative spectrum sensing techniques. In this multiple CRs collaborate in different manners to find the available spectrum holes in the channel. The advantage of this collaboration is to avoid the existing problems of shadowing, fading, or hidden terminal problems. But it comes with a disadvantage of increased complexity and extra overhead in network traffic.

The different topologies for cooperation are: centralized, distributed and cluster head based.

Centralized Sensing

Ganesan, and Li in [7] discussed a centralized sensing technique under cooperative detection. In this, one CR node is responsible for finding the available spectrum holes. The information collected is passed to other CRs by this central CR. The advantage of this technique is that the sensing functionality is only required at one CR, as a result the battery power can be conserved for other CRs. Disadvantage of this technique is that if number of nodes in the network increases the overhead in network and the bandwidth required for communication among them will also increase.

Distributed Sensing

Ganesan, and Li in [7] also discussed distributed sensing technique where the information about the free spectrum holes can be found using the nearest CR node. So each CR will sense the channel for white spaces and can share the information with each other also. But the final decision will be made each CR independently based on the collected information. Advantage of this technique is its less network traffic overhead. But the corresponding disadvantage is the presence and maintenance of redundant information at each CR.

Cluster Based Sensing

Yucek and arslan in [8] expressed a technique where a cluster head is nominated for a defined region. A cluster head is one which has maximum access to channel. Different CR nodes operate under a cluster head. Each CR node will independently sense the channel and send the information to cluster head. Cluster head in turn will send the sensing data to the common hub. Common hub will collect data from different cluster heads. Finally a decision is made at common hub and free channels are allocated to the SUs by passing the knowledge available with hub to the corresponding cluster head.

The advantage of this technique is that best decision about available spectrum holes is maintained at central hub collected from different cluster heads. So this technique is combination of centralized a s well as distributed. Disadvantage of this technique is failure of cluster head or common hub and excessive communication overhead.

III. HYBRID SENSING TECHNIQUES

Rest of this paper will focus on hybrid sensing techniques proposed for sensing spectrum holes using cognitive radio.

Hang and zhang in [9] proposed a Cream-MAC protocol where each secondary user have a cognitive radio enabled multiple sensors device. These users use one common channel to share multi channel resources. Cream -MAC follows a four way handshake mechanism for control packets to solve hidden terminal problem. The disadvantage of this protocol is that more number of sensors is required for each user to improve the throughput.

Xu et al. in [10] described a Blind source separation (BSS) technology which can easily differentiate the signals from Cognitive radio users and primary users, in multiple antenna detection with little collision. If both PU and SU differ a lot, then it is very obvious that BSS will separate them very quickly. This protocol was implemented in MATLAB by taking two signals.

Chen et al. in [11] proposed a security mechanism that can be added to any sensing technique. The possible attack emulates the behavior of PU signal so it called as Primary user emulation (PUE) attack. The attacker can generate the signals whose features matches as that of PUs. As a result it becomes difficult for SUs to access the channels. The proposed scheme LocDef can distinguish whether the signal is from PU or not by determining the characteristics of signal or by tracking the location of the user. The scheme is implemented in matlab using 300 SU and then injecting this attack using single attacker and multiple attackers. Results showed that the proposed scheme is effective to find the attacks.

Sharma et al. in [12] used a trained Hidden Markov Model (HMM) that predict the interference temperature of the licensed channels in future time slots and compute the value of Channel Availability Metric (CAM).CAM is used by the wireless sensor networks with cognitive radio capability to select a licensed channel for transmission. The Disadvantage of trained HMM is the trapping of trained HMM in local maxima.

Tian in [13] discussed a collaborative distributed sensing technique. It works as a compressed wide band sensing technique. Here sensing is performed locally on wide band by each CR. This data collected locally can be adapted with the one collected globally. This technique can help overcome the problem of fading.

Zheng in [14] proposed a cooperative sensing technique for blind source. In this the information about the source is not known so it is blind. It can distinguish between noise and actual PU signal. So it overcomes the problem of energy detection technique.

Yau et al. in [15] provided a better understanding of Cognitive Radio Wireless Sensor Networks (CR-WSN) and described various open issues like sleep wake strategy, spectrum sensing algorithm, effect of quiet period, topology management, context-aware routing, and deployment of coordinators in attaining a CR-WSN .This paper also introduced a method called Reinforcement Learning (RL) method to attain context awareness and intelligence in CR-WSN.RL method is appropriate to address the open issues in CR-WSN.

Hu and Wang in [16] proposed a technique for applying energy detection technique in cooperative manner. Simulation results showed that this technique will overcome the problem of fading channels.

Akin and Gursoy in [17] analyzed the performance parameters of the cognitive channel. With QoS constraint, duration of channel sensing is observed. Based on absence and presence of PU, the information is transmitted at different levels of power. Results shows that how increase in channel sense duration will decrease the probability of false alarm.

Tu et al. in [18] proposed a spectrum sensing technique for OFDMA systems working in cognitive radio environments. A multistate sensing method will be used that will make use of received signal strength (RSSI), cyclic properties, symbol rate. With this the primary user activity can be detected so that interference can be avoided with secondary user.

Duan et al. in [19] discussed a different way of sensing the channel using multiple secondary users. As the signal level at each SU can be low, so a cooperative technique is followed. The decision can made using soft or hard fusion of information. Here the effect of false alarm and detection of missed is also analyzed.

Liu et al. in [20] proposed an index belief degree technique to sense the spectrum. This technique makes use of distributed spectrum sensing where the spectrum decision is made on the basis of matrix determined the probability result value of each cognitive user.

Min and Shin in [21] enhanced the existing cooperative sensing technique by providing the sensing scheduling to it. It takes three things in consideration:- signal strength of PU, cooperation among sensor nodes with and CR and new one is to set the time of scheduling. The results shows that sensing overhead is reduced using this technique.

Bixio et al. in [22] presented an application of surveillance using CR in WSN. A distributed design is provided to collect the data using human intervention. The results are gathered dynamically by taking final decisions. Security threats are avoided.

Ciflikli et al. in [23] presented the application of wireless regional access network (WRAN) using CR in educational purposes for remote areas. It can handle the issues like wired transmissions and improve the efficiency of the network by dynamic sensing.

Yucek and Arslan in [24] elaborated various challenges faced in wireless networks with cognitive radio. A comparison is made among all sensing techniques available. Semi-markov model is predicted to judge sensing information based on the history.

Peha in [25] described three different ways of sharing a spectrum. First is among the primary users, second is between primary and secondary user and last is among the secondary users of the spectrum. The sharing decision is either made by the central regulator or to a license holder.

Liu et al. in [26] proposed a beam forming technique to access the spectrum. In this technique the SU can access the channel without any interference with the PU. ZFBF weight factor orthogonal method is used where relays are used to pass the information till destination.

Liu et al. in [27] worked on optimization of the cooperative sensing technique using energy detection method. Here the fusion strategy using Bayesian criteria and Neyman-Pearson is performed. This technique gives a trade-off between overhead in sensing and performance in sensing.

Ghassemi et al. in [28] discussed stand alone radio and secondary radio architectures but in both the architectures transmission of smart grid time critical data is difficult because of intrinsic sensing delays and cognitive radio defined IEEE 802.22.As a solution of this problem a dual radio architecture is proposed for cognitive based transmission where one radio chain is devoted for data transmission and acceptance while the other chain is devoted for spectrum sensing.

Ramli and Grace in [29] proposed a distributed algorithm. In this technique the distance between the nodes and cluster head is reduced. Moreover, a node can contend to join a cluster network and even to become a cluster head. A node is nominated as cluster head if it has the maximum node density around it.

Tachwali et al. in [30] described the design and implementation details of CR terminals used to connect a geographically spread and incompatible set of wireless terminals with the help of small form factor SDR platforms.

Jia et al. in [31] proposed a new hardware design for cognitive radio based WSN. This design helped in resolving issues like power consumption, resource utilization as compared to conventional WSNs. A cross layer is design is used in cognitive cycle to improve energy constraints.

Feng and Zhao in [32] performed a study of cluster based CRSN which occasionally accesses the licensed spectrum unused by other networks. Both real time constant bit rate and best effort traffic is supported by cluster based CRSN. Two types of resource allocation policies that take exclusive features in CRSN are used to provide the CBR traffic with high priority. Results of mathematical model used to analyze the performance of CRSN shows that satisfactory real-time performance can be assured in the network.

Sreesha et al. in [33] proposed a modified RPL ((Routing protocol for low power and lossy networks) to improve the efficiency and reduce latency. Here the nodes that are working on battery are freed from task of spectrum sensing. A multilayered approach is used for design.

Men et al. in [34] proposed an improved WSCN using cooperatives sensing is proposed. The malicious nodes in the network are identified using the outlier, bi weight techniques. It will ultimately reduce the interference in the network

Zhang et al. in [35] discussed an Efficient Cognitive Radio Enabled Multi-channel MAC (CREAM-MAC) protocol. CREAM-MAC protocol is integrated with cooperative sequential spectrum sensing and packet scheduling over the wireless dynamic spectrum access (DSA) at physical and MAC layer respectively. In CREAM-MAC protocol each secondary user is equipped with cognitive radio enabled transceiver and multiple channel sensors that enables secondary user to utilize the unused frequency spectrum in optimal manner. The CREAM-MAC protocol avoids the collision among secondary users and between secondary users and primary users. To validate the CREAM-MAC protocol an extensive simulation was performed in this paper.

Stotas, and Nallanathan in [36] proposed a novel cooperative spectrum sensing protocol to perform opportunistic spectrum access. This protocol was analyzed and compared with various existing cooperative sensing protocol by performing extensive simulation. The results show that the improved performance of the proposed protocol in comparison with the existing ones.

Lee, and Jeon in [37] proposed a two step JCAR-update scheme for Cognitive radio based wireless mesh network (CRWMNs) to lessen the signaling overhead caused by the activation of Private user on one of the operating channels of CRWMNs. In this two step JCAR-update scheme, in first step each CR node tries to execute a simple recovery algorithm in a distributed manner to relocate channels to affected links without trading control information. In second step CRWMN re optimizes the channel allocation and routing.

Bhattacharya et al in [38] presented a sample division multiplexing technique is used to collect the randomly occurring white spaces in the network and then allot them finally for one user. The services are withdrawn from the secondary users if the higher priority primary users want to use the channel.

Wang et al. in [39] mentioned a localization estimation technique using double station cooperative tracing. The problems of hidden and exposed terminals are resolved. Ultimately the spectrum sensing efficiency will improve by finding the position of primary user that a secondary user can choose.

Fujii in [40] discussed that the primary system use the basic function for interference detection where as the secondary system uses a power control system. This paper introduces a sensing method on the basis of distance separation between primary and secondary systems.

Zheng et al. in [41] proposed a technique to optimize the throughput and energy consumption in Cognitive Radio based Industrial Wireless Sensor Network (CR-IWSN). This is a new energy efficient interference evading strategy based on collective interferences. Non linear programming is used to model the proposed scheme and distributed algorithm is used to solve the model of proposed scheme. Extensive simulation has been performed to verify the effectiveness of the proposed scheme on optimizing the total system throughput and energy consumption.

Santiago et al. in [42] proposed the viable architecture of Medical body area network (MBAN) equipped with cognitive radio features based on ultra wideband radio technology. The cognitive radio features that applied on ultra wideband MBAN helps to improve their coexistence with other electronic system by frequency agility(allow the sensor nodes to transmit in unoccupied parts of the spectrum by reducing the interference risk with other systems) and frequency-domain spectrum shaping which creates notches in the spectrum of transmitted signal.

Fanous et al. in [43] proposed two algorithm known as Cumulative summation (CUSUM) and viterbi algorithm for reliable sensing and opportunistic access on channels with stochastic traffic in batch processing system. CUSUM is used to find the idle slot on primary user channel and Viterbi algorithm is used to improve the detection capabilities by minimizing the time in detection of idle slots. Primary user spectrum is tracked by secondary user with the help of Partially Observable Markov Decision Process (POMDP) approach for maximization of throughput.

Yu et al in [44] proposed a new spectrum access model called hybrid spectrum access (HSA) that scheduled both licensed and unlicensed spectrum bands smartly for the transmission of smart grid services. Multi tiered Markov chain is used to analyze the performance of HSA under error prone spectrum sensing. Simulation result shows that the proposed scheme improved the QoS of the smart grid services and minimizes the spectrum letting cost for smart grid operators.

Elnakeeb et al in [45] discussed the importance of cognitive radio(CR) in Cooperative Multiple input Multiple output(CMIMO) WSN.CR in CMIMO WSN plays an important role in changing the traditional belief that for CMIMO WSN the most favorable transmission mode is SISO, when shorter distance communication mode is taken into consideration .Result of simulation showed that SISO is favorable only when transmission distance is small and interference threshold is relatively large but as threshold decreases inspite of considering transmission distance ,to prevent loosing the transmission of packets shifting to other transmission modes will be the favorable choice.

Liang et al in [46] observed the delay performance of random traffic with burst arrivals in the networks. Average delay for transmitting the random traffic using various channel sensing mechanism has been derived. And results are verified by doing extensive simulation. Simulation results show the improved average delay performance in CRSN as compared to conventional wireless sensor networks.

IV Conclusion

It can be concluded from the above review that different type of sensing technique can applied in cognitive radio. Out of all the clustering based cooperative sensing technique is the best one as it incorporates both the distributed as well as centralized properties in it. Various variations can be added in clustering technique to make it more energy efficient.

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