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Design of MAC Protocol Based On Cross Layer Optimization For Cognitive Radio Wireless Sensor Networks

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ABSTRACT

The purpose of this article is to recommend a model of intervention policing in emergency situations. The intervention policing model emphasizes the importance of three approaches to police intervention; participatory intervention, institutional intervention, and regulatory intervention. These three police intervention approaches become the style of policing in carrying out their duties and functions in emergency situations. Therefore, this article attempts to evaluate and criticize the democratic policing or community policing model when it is implemented in emergency situations such as the Covid-19 pandemic. This article provides an important perspective in police studies regarding the intervention policing approach in emergency situations.

Keywords: Optimization, Energy Efficiency, Duty Cycle, CRWSN.

1. INTRODUCTION

The cost of licenced spectrum rises as a result of the proliferation of wireless devices, necessitating the development of cognitive radio (CR) [1]. Wireless Sensor Networks (WSNs) can be equipped with the Cognitive radio to overcome the fixed spectrum allocation and the communication and processing resource constraints of low-end sensor nodes [2]. In the ISM band, where the radio spectrum is congested, CRWSN offers a promising direction for communication [3]. The medium access control (MAC) protocol should be created for such a network to meet the demands of the heterogeneous network [4]. In this paper, we put forth the idea of framing a MAC protocol that uses spectrum resources fairly while being energy-efficient.

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The cross-layer parameter, or the physical layer parameter and MAC layer parameter, is the foundation upon which this protocol is created. We created the MAC protocol by taking into account asynchronous time intervals having an active and sleep phase, with data transmission and sensing occurring during the active phase. Based on the findings of sensing and channel Error Vector Magnitude (EVM) values, the data transmission channels are selected. In this paper, the parameter duty cycle is assessed, and the energy efficiency of the CRWSN is optimised. The lifetime of the network can be extended and energy consumption can be greatly decreased by optimising duty cycle to maximise CRWSN energy efficiency. The remainder of this paper is structured as follows. Section II details the related works in CRWSNs and III with cross-layer concepts. The MAC protocol design is presented in section IV, simulation parameters in section V with its results and discussion in section VI. Finally, we conclude the paper in section VII.

II. RELATED WORKS

Various methods are used to maximise the energy efficiency in CRWSN in the literature. By jointly establishing the best sensing and transmission times for Cognitive Radio Networks, energy-efficient spectrum sensing and transmission were proposed in [5]. By recommending an iterative technique with low computational complexity in [6], transmission power was also optimised in addition to sensing duration in order to maximise energy efficiency. To achieve energy efficiency, [7] takes into account optimisation of the number of sensors required for Cooperative Spectrum Sensing (CSS), in addition to sensing time, transmission duration, and power. To select the subgroup with the lowest average energy consumption for CSS, a heuristic technique was applied. A less-than-optimal approach was additionally suggested to lessen the computational complexity.

Ateeq Ur Rehman (2013) put forth an Opportunistic Cognitive Medium Access Control (OC-MAC) [8] protocol that enables the CR to effectively accept the spectrum whenever it is available. Control packets RTS and CTS were also used to solve the hidden terminal issue that the CR frequently encountered. Additionally, when the channel is designated for use by SUs and vice versa, the use of RTS and CTS packets reduces interference between SUs and PUs. Amna Jamal, C.K. Tham, and W.C. Wong (2014) introduced a unique multi-channel medium access control (MAC) protocol in [9] for the cognitive radio enabled sensor network where the requirements of both the cognitive and sensor domain are needed. It is established that a spectrum-aware asynchronous duty cycled multichannel method is superior to multichannel MAC. The blind cognitive Medium Access Control (Cog MAC) protocols were developed by Omar Mehanna and Ahmed Sultan Hesham El Gamal in 2009. They encourage an unlicensed transmitter-receiver pair to connect over the downtime of a number of licenced primary user channels. Here, it is believed that the secondary user has no prior knowledge of any statistical data regarding the original user's traffic. Markov chain model [10] was applied to the system's investigation.

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III. CROSS-LAYER DESIGN

CRWSN can be broken down into a number of distinct layers in the layered approach to developing networks. Higher levels may benefit from some of the services provided by lower layers, and vice versa. The idea of cross-layering is to share information across many layers in order to facilitate adaptability and boost interlayer communication. The capacity of network protocols to react to modifications in channel circumstances is referred to as adaptation. It is equally crucial to comprehend this interdependency relationship and thoroughly analyse their answers since optimisation processes at different layers could improve the overall performance because the performance of neighbouring layers is interrelated. The cross-layer factors taken into account in this paper are the EVM (Error Vector Magnitude) and the Energy based sensing result.

A. Energy Sensing

Under the hypotheses H0 (PU absent) and H1 (PU present), energy detection is utilised to determine whether a Primary User (PU) is present or absent in the channel. If the calculated energy of the signal in the channel is higher than the threshold, PU is present. It is deemed to be absent if it falls below the threshold. Based on the presence or absence of PUs, the sensing outcomes of the energy detector can be configured as 0 or 1. In accordance with this output, the Secondary Users (SU) would either transmit their data when they successfully detect the PU's absence with probability H0.(1-Pf) or when they incorrectly detect it with probability H1.(1-Pd), where Pd is the probability of detection and Pf is the probability of false alarm. Otherwise, if the SU detects the presence of PU with probability H1Pd or owing to false detection with probability H0Pf, it switches to sleep mode. Figure 1[1] depicts the energy sensor block in use.

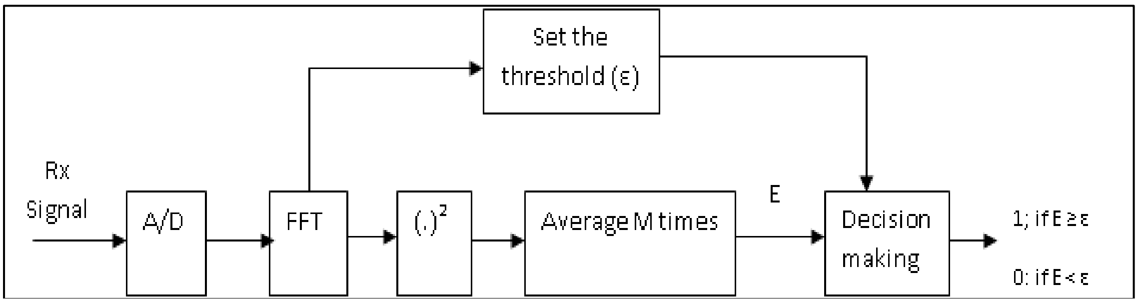

Fig. 1. Energy detector block

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B. Error Vector Magnitude

EVM is defined as the root-mean-squared (RMS) value of the difference between a collection of received symbols and transmitted/ ideal symbols [11]. The general expression for EVM is given by

$$EVM = \sqrt{\frac{\frac{1}{N}\sum_{n=1}^{N}|y(n)-I(n)|^{2}}{P_o}} \tag{1}$$

Where I (n) is the Ideal symbol and P_0 is the average power of the modulated symbols. For more number of transmitted symbols, the numerator can be rewritten as,

$$\frac{1}{N}\sum_{n=1}^{N}|y(n)-I(n)|^2 \approx |y(n)-I(n)|^2 \tag{2}$$

Hence EVM of each channel is calculated and based on those values the channel for data transmission is chosen and transmitted.

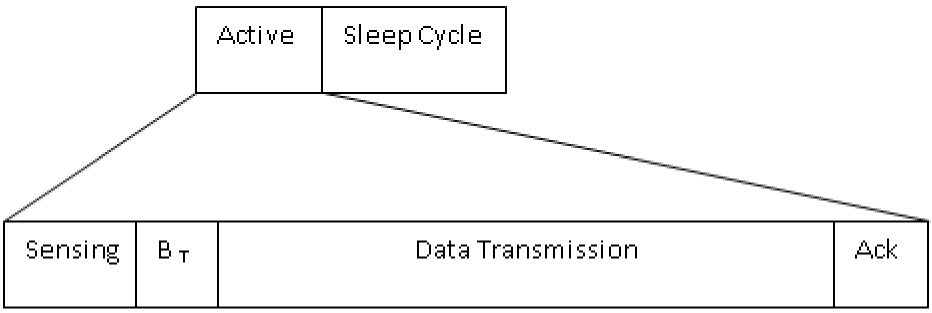

Fig. 2. Duty cycle of a node

C. Duty cycle of a node

A node's duty cycle is split into asynchronous time periods known as sleep and active cycles. The nodes will use energy detection to check for available channels during the active phase. It will emit the beacon signals (BT), followed by the data transfer and acknowledgement (Ack), depending on the outcomes of the sensing. A node's duty cycle is determined by

$$DC = \frac{T_{ON}}{T_{ON}+T_{OFF}} \tag{3}$$

The duty cycle of single SU node is given in figure 2.

D. Energy efficiency optimization

Based on sensing duration (t_S) and transmission duration ($t_T = t_B + t_t + t_{ACK}$), which combines the duration for beacon (t_B) and data transmission duration(t_t) followed by acknowledgement time (t_{ACK}), CR-WSN with optimised duty cycle can maximise energy efficiency. The formula for calculating a node's overall energy consumption is

$$E_{total} = P_S.t_S + P_T.t_T.(H_0.(1-P_f) + H_1.(1-P_d)) + P_{OFF}.(T-t_T-t_S) \quad (4)$$

Where P_S and P_T are the power consumed in sensing and transmission durations. Energy consumed during active period is calculated as

$$E_t = P_S.t_S + P_T.t_T.(H_0.(1-P_f) + H_1.(1-P_d)) \quad (5)$$

The total throughput that can be achieved by the SU during transmission is given as

$$R = H_1.(1-(\delta+1).P_f).t_T.\log_2(1+P_T.\gamma) \quad (6)$$

Where γ is the Signal to Noise Ratio (SNR) and δ is the weight factor to measure the waste of potential throughput due to falsely detecting PU and SU does not transmit. The Energy Efficiency (S) is determined by the ratio of the total throughput (R) to the total energy consumption (E_{total}).

$$S = \frac{R}{E_{total}} \quad (7)$$

Where, the active period is calculated as the combination of sensing duration (t_s) and transmission duration (t_T). That is given as

$$T_{ON} = t_s + t_T \quad (8)$$

The energy constraint problem can be modeled as

$$\begin{aligned} &\text{maximize} && S(t_t, P_t) \\ &\text{subject to:} && 0 \leq Dc \leq 1 \\ & && 2mW \leq P_t \leq 20mW \end{aligned} \quad (9)$$

An half interval and iterative heuristic search based method is used to optimize the energy efficiency. The energy efficiency for each duty cycle value is computed as

$$S(x) < S(x + \Delta)\,|_{\Delta \to 0} \quad (10)$$

Where, Δ is the duty cycle interval. The optimized duty cycle for maximum energy efficiency is obtained when the first order condition, $S'(x) = 0$ satisfied.

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The optimum Duty Cycle (DC_{OPT}) that maximizes the Energy Efficiency is given by

$$DC_{OPT} = \max_{DC\ \varepsilon\ T} S = \max_{DC\ \varepsilon\ T} f(P_T, t_T) \tag{11}$$

IV. MAC PROTOCOL DESIGN

E. Algorithm

The following figure 3 shows the MAC protocol design for CRWSN.

Step 1: Verify at the secondary node that the data is ready for transmission. If so, proceed to step 2, otherwise enter sleep mode.

Step 2: Use energy detection to check whether there are any free channels available, then make a list of available free channels. If free channels are available, move on to step 5

Step 3: If during the initial phase of the sensing process there are no free channels available, increase the retry counter and repeat step 2 until the retry reaches the maximum sense, which is (max sense = 3).

Step 4: If there is no free channel available even after the counter reaches its max sense the node will wait for a random backoff time in sleep mode and then proceed to step 2.

Step 5: Send the RTS signal to the next hop node using all available free channel.

Step 6: Using equation (1) as a guide, the receiving node computes the EVM values for each channel. In response, it will construct a CTS signal and transmit it to the source node using the computed EVM values.

Step 7: Using 5 channels that are sorted according to their minimum EVM values, the source node will send the data with an optimised duty cycle.

Step 8: The source node will get acknowledgement following data transmission and go into sleep mode.

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Table 1. Simulation Parameters

Parameter	Value
Channel	Rayleigh channel
Beacon size	1000 bits
Data size	10000 bits
Data rate	250 kbps
Sensing time	5 ms
Beacon transmission	5 ms
Data transmission	20 - 90ms
Total time/slot	100 ms
Modulation order	BPSK
Sensing power	2 mW
Transmit power	8 - 16 mW
Sleep power	5 µW
Number of channels used for data transmission	5
Data through each channel	2000 bits

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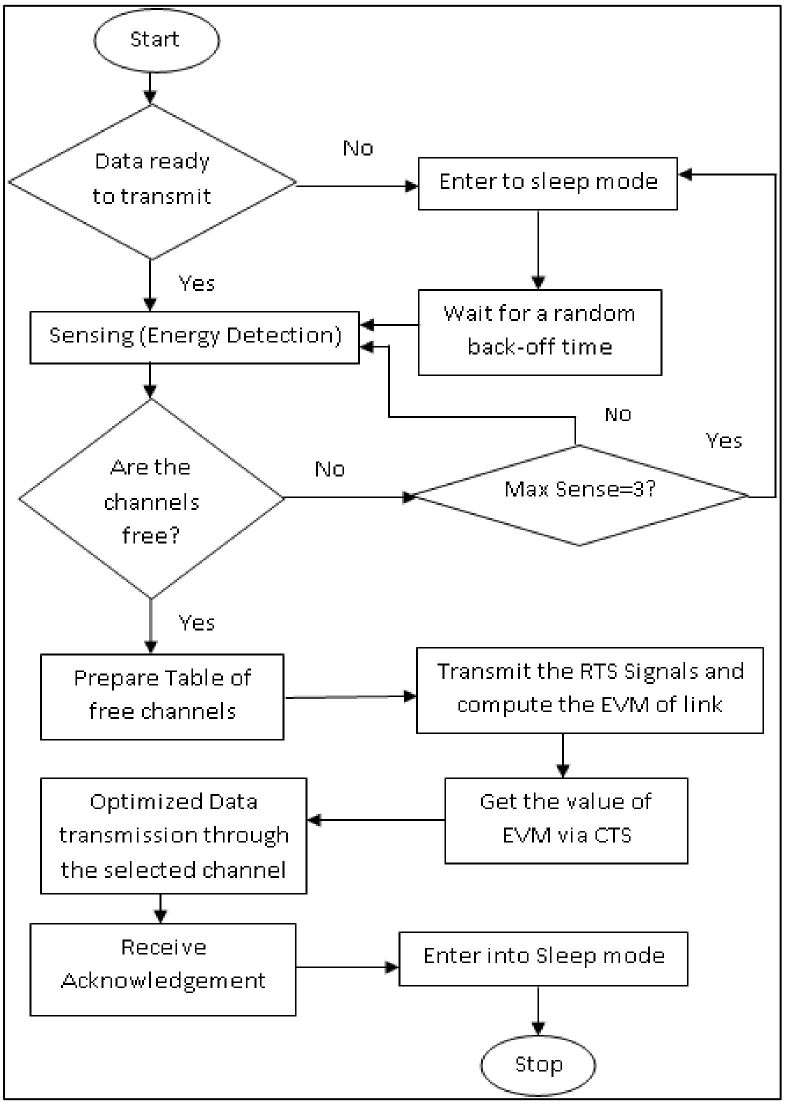

Fig. 3. OMAC Flow diagram of CRWSN

V. RESULTS AND DISCUSSIONS

The MATLAB simulator is used to simulate the proposed technique. The MAC method begins with the initial presumption that each node is aware of the other nodes time slot. The probability that the primary user is absent is assumed to be 0.3 (H_0) and the probability that the primary user is presumed to be 0.7 (H_1). We have selected a maximum data rate of 250 kbps for sensor networks, whose data rates vary from 25 to 250 kbps. The time for their transmission is also determined by the beacon and the quantity of the transmitted data. Due to energy consumption criteria, the active phase makes up 20% to 80% of the overall time slot according to the node cycle design. It takes 5ms of its active phase to sense the channel availability.

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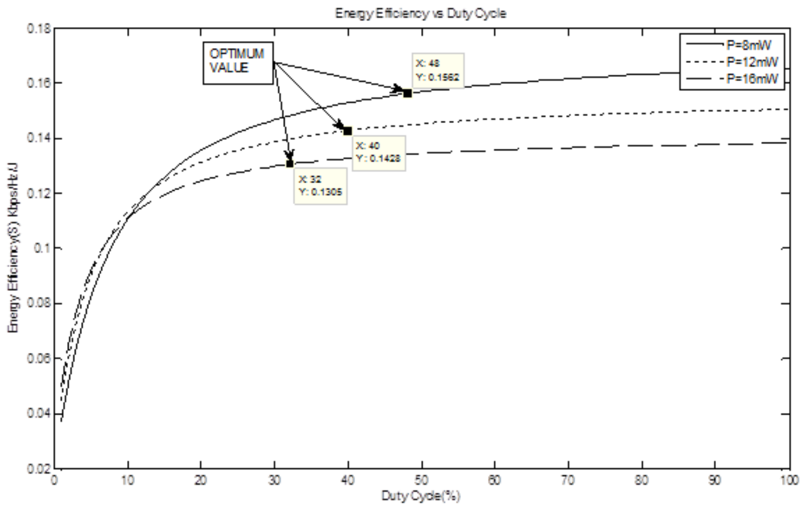

Fig. 4. Energy efficiency vs duty cycle for varying transmission powers

The relationship between Energy Efficiency and Duty cycle of SU is depicted in Figure 4. The graph clearly shows that the Energy efficiency curve increases as the duty cycle increases. For varied transmission powers (16mW, 12mW, and 8mW), the optimised duty cycle value (32%, 40%, and 48%) was determined based on the MAC optimisation that was suggested. This value is depicted in figure 4 above.

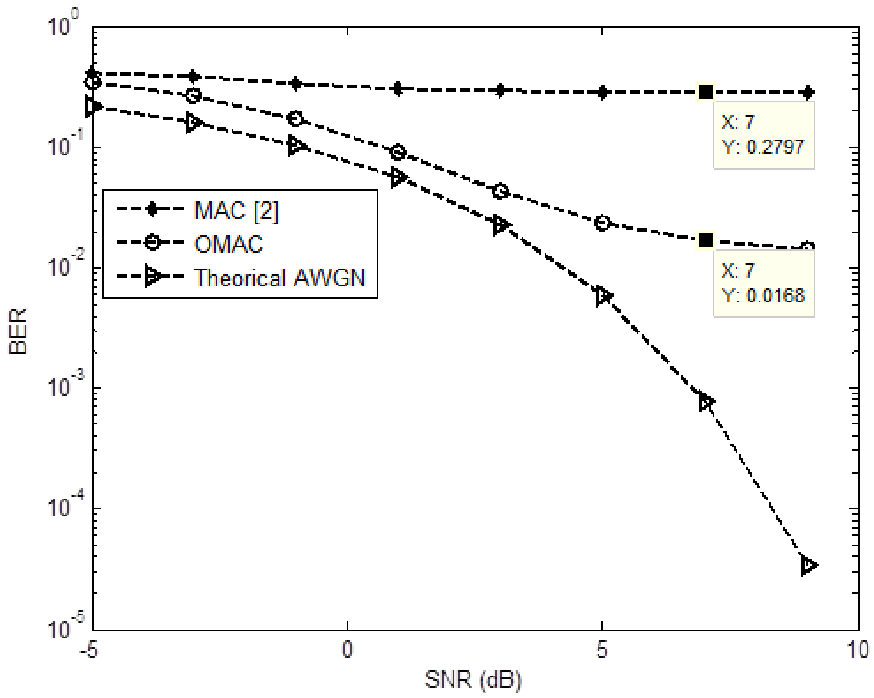

Fig. 5. Plot of BER Vs SNR

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We evaluate the performance of CRWSN based on the duty cycle that has been optimised for optimal energy efficiency. Figure 5 makes it obvious that the BER curve lowers as SNR rises. The suggested Optimised MAC (OMAC) offers a 26% improvement in error performance over the conventional MAC protocol without optimisation, which underutilizes chances and fails to locate the optimum channel for transmission, leading to high BER. The performance of the optimised MAC is satisfactory because it is close to the theoretical curve.

VI. CONCLUSION

In order to allow secondary users to access the primary users' spectrum when they are not present and to select the optimum link for data transmission, a cross-layered MAC protocol was developed for the CRWSN. The method was structured in accordance with the spectrum efficiency and energy consumption, and it was then simulated using MATLAB. According to the simulation results, the cross-layered optimised MAC offers a 26% improvement in error performance and a 5% gain in energy efficiency over the conventional MAC protocol.

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