

# Channel access mechanism for maximizing throughput with fairness in wireless sensor networks

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## ABSTRACT

The spectrum scarcity problem of wireless sensor networks (WSNs) is improved through amalgamation of cognitive radio networks (CRNs) into WSNs. However, spectrum allocation to secondary users (SUs) is challenging in cognitive radio wireless sensor networks (CR-WSNs) as channel is already crowded and at same time should not induce interference to primary users (PUs). In designing efficient spectrum access model for CR-WSNs recent work have adopted machine-learning game theory (GT) and statistical model. However, the major limitation of existing spectrum access model they fail to assure access fairness with maximal throughput with minimal collision. This work presents a maximizing channel access fairness model to handle the research challenges. To boost CR-WSN performance, the throughput maximization using channel access fairness (TMCAF) employs shared and non-shared channel access designs. Experiment outcome shows throughput is improved and collision in network is reduced in comparison with state-of-art channel access models.

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## 1. INTRODUCTION

Wireless sensor network (WSN) is composed of large number of cheap-tiny sensor nodes connected wirelessly together for provisioning different application [1] such as target tracking of malicious object such as drones and disaster management. The wide adoption of WSNs has to growth of internet of things (IoT) environment [2]. The model application requires higher spectrum resource; however, the 2.4 GHz network already very congested [3]; thus, requires effective spectrum access design. In addressing spectrum scarcity issues, the cognitive radio networks (CRNs) have been incorporated into WSNs [4]. The architecture of cognitive radio wireless sensor networks (CR-WSNs) is shown in Figure 1. In CR-WSNs network, it is important to address energy constraint issues into spectrum access design [5].

Spectrum sharing [6], [7], opportunistic spectrum access [8], and sensing-based spectrum sharing [9] are the four broad categories under which the spectrum access mechanism in CR-WSNs is categorized. A very good performance is offered by sensing-based spectrum sharing. Even more so in a multi-user, multi-channel system, interference issues must be taken into consideration due to inadequate channel sensing measurement. When creating a new efficient channel access design, it is also necessary to take the energy constraint and access equity among secondary users (SUs) into consideration. In next section extensive survey of various spectrum access methodologies have been studied. Majority of work focused in maximizing throughput with quality of

service (QOS) constraint [10]. Further, the channel availability information is used for maximizing performance objective function [11], [12]. Shi *et al.* [13] employed reinforcement learning for addressing the mobility pattern [14] prediction of SUs and primary users (PUs) to take decision of spectrum access of large-density cognitive radio (CR) enabled WSNs [15].

ML-based [13], [14] and game theory (GT) approaches [16]–[18] are used to address the limitations of optimal channel access methods with access fairness [19], [20]. However, employing current GT-methods [17], [18] does not guarantee access fairness with regard to the performance and energy requirements of CR-enabled large-scale WSNs (LS-WSNs). The throughput maximization using channel access fairness (TMCAF) model is presented in this work to meet the research challenges. The TMCAF uses shared as well as non-shared channel access mechanisms to ensure energy efficiency while maximizing throughput with a minimum amount of collision and access fairness.

- The TMCAF uses channel access pattern information for reducing interference during allocation of channel to SUs.
- The TMCAF employing shared and non-shared channel access mechanism improves overall resource utilization with minimal interference.
- Throughput is maximized and collision in network is reduced by assuring access fairness; thus, energy efficiency is improved through reducing number of retransmission requirement.

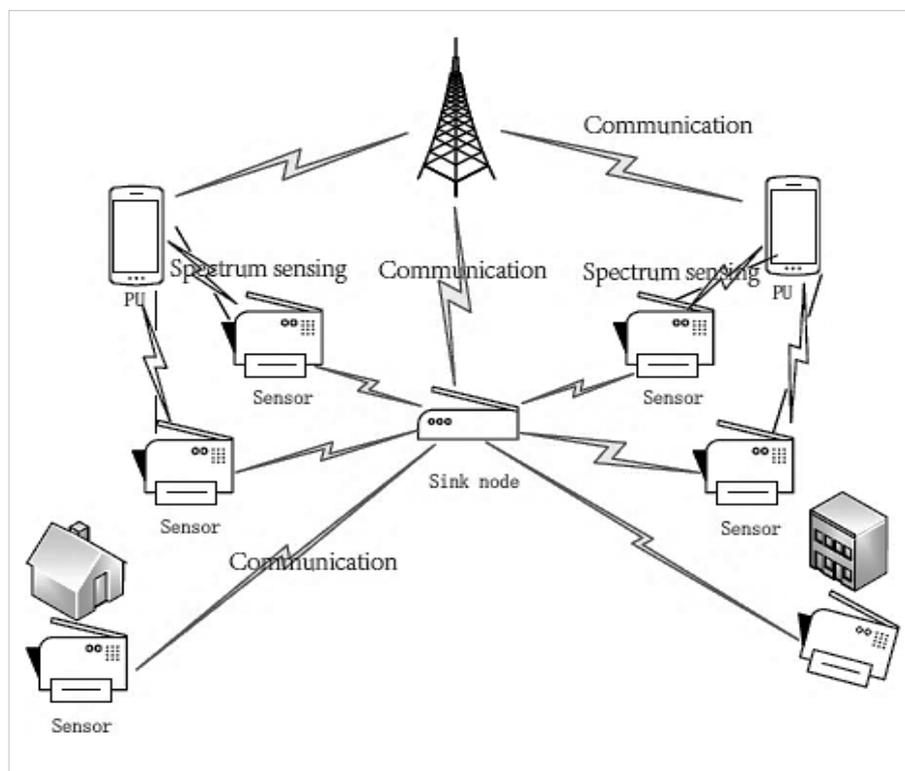


Figure 1. Architecture of CR-WSN [21]

Paper organization: in section 2 study different existing spectrum access design for CR-WSN. The suggested spectrum access paradigm is presented in section 3. Section 4 provides results obtained utilizing proposed and current spectrum access mechanisms. The research is concluded and the work scope is provided in the final part (section 5).

## 2. LITERATURE SURVEY

This section conducts survey of recent spectrum access mechanism for CR enabled WSNs. The detailed analysis of survey is described in Table 1. This table comprises of all the related survey done regarding this research.

Table 1. Survey table

Model name	Methodology	Advantages and its limitation
Sun <i>et al.</i> [22], 2022	Designed a spectrum access model by combining CR and SWIPT; alongside focused to address energy efficiency issues during spectrum access in IoT's environment.	The model allows adaptive spectrum switching mechanism to improve throughput of network; however, it induces higher interference to primary network.
Abbas <i>et al.</i> [23], 2021	In this showed how frequent access of entire channel by SUs significantly affects the energy efficiency and induces delay in CR enabled IoT network. The problem is addressed by considering multi-objective probability parameter in designing of channel access model.	The model reduces collision by optimizing the channel order according to channel prediction status. However, the model does not utilize the resource more efficiently.
Ostovar <i>et al.</i> [24], 2020	Designed channel access mechanism for CR-WSNs. Here both interference management of PUs and energy is taken into considerations. The sensing performance is improved by minimizing bandwidth wastage through minimization of power as a constraint.	The model significantly improved the throughput by considering energy constraint of CR-WSNs. However, access fairness issues is not addressed.
Xu <i>et al.</i> [25], 2020	The work addresses the resource and power allocation to SU in large-scale heterogenous network. Considered assumption of poor spectrum access with improper channel state information (CSI) information.	The model improved throughput of network and addresses access fairness through minimization of interference to PUs. However, energy efficiency nature of WSNs is not considered in designing spectrum access model.
Moayedian <i>et al.</i> [26], 2020	Employed channel access mechanism through amalgamation of both underly and overlay network. The model assures reliability to SU with presence of PUs in the network	Provides fair channel access mechanism with energy efficiency; however, induces higher collision in network as CSI is not accurate.
Xu <i>et al.</i> [27], 2021	Addressed energy constraint of multiuser heterogenous network through adoption of distributed spectrum access mechanism using CSI and QoS constraint.	The model provides robustness consider in accurate CSI; however, higher collision in network is not tolerable for WSNs.
He <i>et al.</i> [28], 2021	The model focused in maximizing the rate i.e., minimize number of sources required for packet transmission. Employed GT for optimizing the transmit power through iterative mechanism.	The model improved energy efficiency of CR-WSNs; however, access fairness issues is not addressed.
Deng <i>et al.</i> [21], 2021	Employed Q-learning for designing channel access mechanism for WSNs.	The model improved spectrum access QoS of SUs. The model also reduces packet failure; however, resource efficiency can be further improved by handling interference more efficiently.
Ning <i>et al.</i> [29], 2020	They addressed interference issues through effective channel access mechanism. The PUs optimize the US's spectrum usage using GT.	The provides good spectrum efficiency with good interference management; however, energy efficiency issues of WSNs are not considered into designs of spectrum allocation mechanism.
Latif <i>et al.</i> [30], 2022	The model addressed both spectrum and energy efficiency together through adoption of hybrid tabu search optimization mechanisms. Further, fuzzy rules are used for providing optimal performance.	Improves resource and energy efficiency of CR-IoT. However, the model failed to address the access fairness issues of spectrum allocation design.

### 3. THROUGHPUT MAXIMIZATION WITH CHANNEL ACCESS FAIRNESS MODEL

In CR-WSNs, a sensor node performs sensing to determine channel availability whenever it searches for a channel to carry out a specific communication. Poor channel allocation strategies may cause interference for the PUs. Therefore, effective CSI measurement is crucial for creating a channel allocation strategy that minimizes interference.

#### 3.1. Channel availability estimation

The following is an estimation of the model used to get the average channel accessible  $\omega_j$  of channel  $j$  at any given time.

$$\omega_j = (1 - \varphi_j) + \varphi_j \alpha_{i,j} = 1 - \varphi_j \alpha_{b,j}. \quad (1)$$

And, as detailed (2),  $\varphi_j$  defines the average space filled with current sensor nodes for corresponding channel  $j$ .

$$\varphi_j = \frac{4S_j^2}{M_{q,j}^2} \quad (2)$$

$\alpha_{i,j}$  represent the probability that PUs will be active in channel  $j$  under steady-state and  $\alpha_{b,j}$  represent probability that PUs will not be using channel  $j$  under steady-state. The parameter  $T_{v,j}$  defines the state when sensor node goes out of range of PUs coverage area and therefore,  $U_{v,j}$  follows an exponential distribution with transition states  $\beta_{B,j}$ .

Operative channel accessibility (OCA)  $\delta$  of channel  $j$  as the mean session period in which channel  $j$  is accessible for a sensor node to communicate can be expressed as (3):

$$\delta_j = \gamma_j \cdot U_{B,j}'' = \frac{\gamma_j}{\beta_{B,j}} \quad (3)$$

where  $\gamma_j \in (0, 1)$  is the interference factor that establishes the ideal amount of disturbance for the primary consumers. It must be remembered that a larger value of  $\gamma$  will both results in increased spectrum opportunity and increase interference to PUs. Every SU in this situation is familiar with the spatial distribution for PUs in CR-WSNs as well as temporal channel usage pattern. In this way the ideal channel accessibility i.e.,  $\beta_j, j \in \mathcal{M}$ , evaluating the pattern of dynamic mobility. The throughput maximization channel access fairness using game theory (TMCAF-GT) uses both shared as well as non-shared channel access mechanisms to provide access fairness with regard to performance goals in this work.

### 3.2. Shared channel access mechanism

The available channels have been allocated to sensor nodes in the shared channel access technique while taking the random backoff time  $u_j$  into consideration. Here, a channel is only assigned to the sensor nodes if it is free and usable for the duration of the time slots while the other SUs is in idle mode. In contrast, a random backoff window called  $u_j$  is initialized if the channel is not available. The channel is allocated to SUs as follows under the shared channel access method.

$$s(o) = 1/o \quad (4)$$

### 3.3. Non-shared channel access mechanism

Each SU senses the channel in a non-shared channel access technique with probability  $\mathcal{P}$ , and the total amount of throughput experienced by various SUs is calculated as (5):

$$pl(\mathcal{P}) = \mathcal{P}(1 - \mathcal{P})^{o-1} \quad (5)$$

by taking into account, the throughput could be maximized  $pl'(\mathcal{P}) = 0$ ; then,  $\mathcal{P} = \frac{1}{o}$  the results are as follows when employing a non-shared channel access technique.

$$g_*(o) = \frac{1}{o} \left(1 - \frac{1}{o}\right)^{o-1} \quad (6)$$

However, a new channel access technique is provided in the next section to guarantee access fairness while maximizing throughput by utilizing the advantages of both shared as well as non-shared channel access.

### 3.4. Throughput maximization with channel access fairness design

Figure 2 depicts the block diagram of the fair channel access throughput maximization architecture. Each sensor node chooses a random backoff period, as shown in Figure 2, and waits for it to finish before starting the communication that will maximize it  $\mathcal{O}$ . Once they have the channel, sensor nodes  $\mathcal{O}$  transmit it to other nodes. In this work, a random backoff is taken into consideration to ensure a fair channel access mechanism, and at the same time, TMCAF can ensure good performance, which is demonstrated by a simulation analysis in the next section.

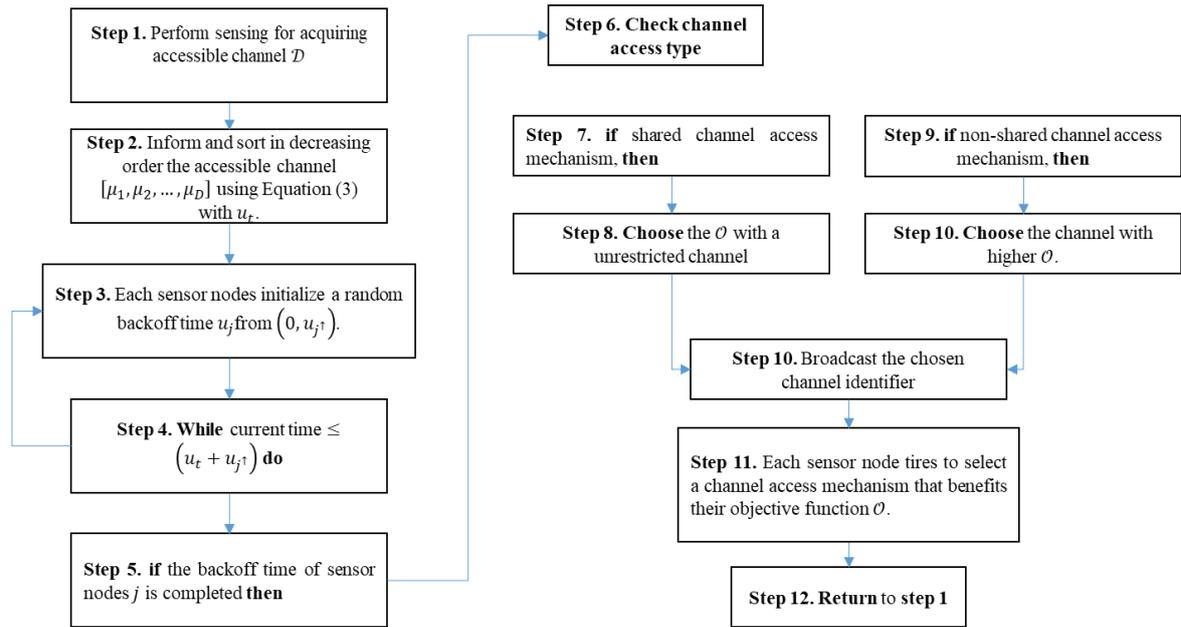


Figure 2. Block diagram of proposed TMCAF design for CR-WSN

#### 4. RESULT AND DISCUSSION

This section outlines the results obtained by combining the proposed TMCAF model with the current channel access mechanism [28], [30]. When evaluating channel access frameworks for CR-WSNs, performance measures like throughput as well as collision are taken into account. Table 2 gives a description of the simulation parameter utilized to explore the model.

Table 2. Simulation parameter

Network parameter	Value
Network size	100 m x 100 m
Number of sensor nodes	50, 100, 200
Initial energy of sensor node	1.0 joules
Modulation scheme	16-QAM
Mobility of sensor nodes	3, 6, 9 cycle per frame
Coding rate	3/4
Bandwidth	18 Mbps
Number of frequency channels	5
Time slots	12 $\mu$ s
Message information size	27 bytes
MAC used	TMCAF

##### 4.1. Throughput

This section examines how TMCAF and ECA perform in terms of throughput while taking into account various sensor speeds and devices. The size of the gadget can range from 50 to 200, and the frame rates can be anywhere from 3 and 9. Graphically depicted in Figure 3 is the throughput achieved with various device sizes. In a similar manner, Figure 4 visually displays the throughput attained under varying speed. In every instance, the TMCAF yields superior results; under various sensor device along with speed conditions, TMCAF outperforms ECA on average in terms of throughput by 19.52% and 13.12%, respectively.

##### 4.2. Collision

This section examines how TMCAF and ECA function when colliding with varying sensor devices and speeds. Device sizes range from 50 to 200, and frame rates range from 3 to 9 cycles per second. The collision achieved with different device sizes is depicted visually in Figure 5. Similar to this, Figure 6 illustrates the collision achieved at various speeds. An average collision reduction of 24.5% and 128.27% are achieved with TMCAF in comparison to ECA under varying sensor device and speed, respectively. The TMCAF yields better results in all circumstances.

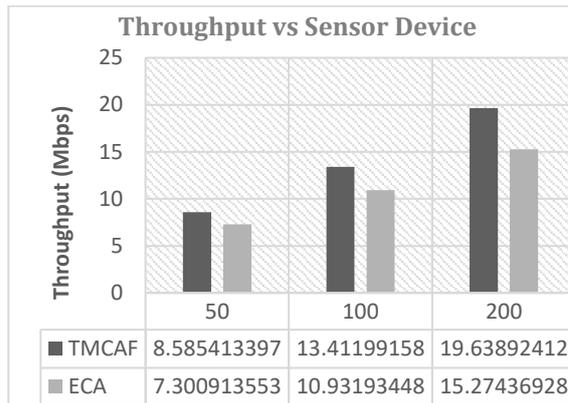


Figure 3. Throughput vs sensor device

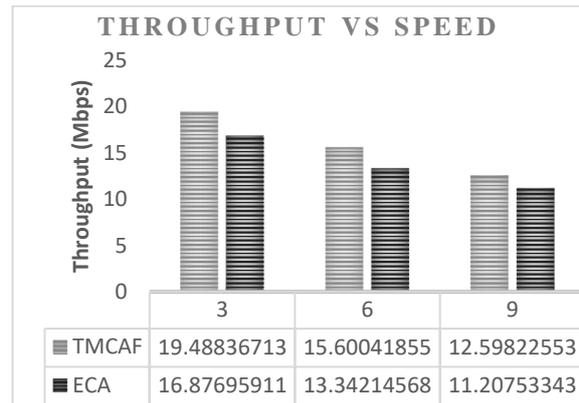


Figure 4. Throughput vs speed

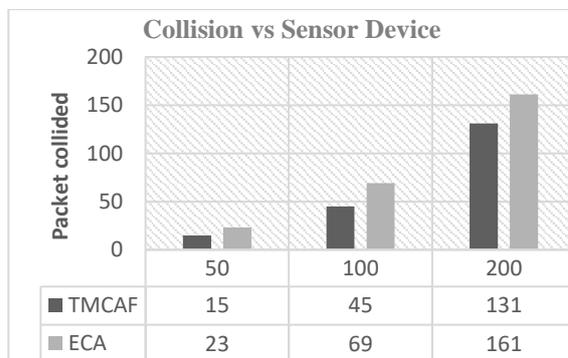


Figure 5. Collision vs sensor device

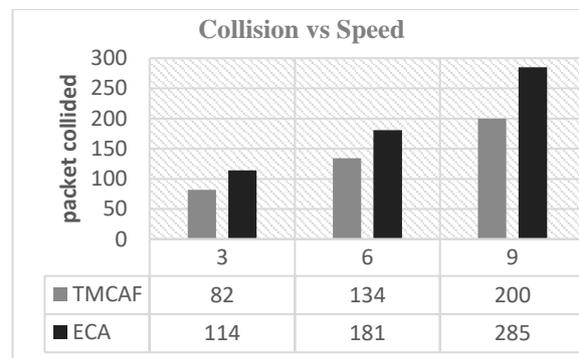


Figure 6. Collision vs speed

## 5. CONCLUSION

The TMCAF, a new channel access mechanism that was designed in this work, was created using a channel access pattern and both shared as well as non-shared channel access mechanisms. The results of the experiment reveal that TMCAF produces extremely strong throughput performance with little collision. Less interference is guaranteed thanks to the network's reduced collision rate, and energy efficiency is increased. However, the TMCAF performance can be further improved through incorporation of game-theory model into channel access mechanism; further optimizing the backoff time will further provide in reduction of interference and thereby reducing collision.

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