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# Stochastic Resource Algorithm for Effective Utilization of Bandwidth for IoT Sensor Networks in Arecanut Agriculture Applications

**Niranjan Murthy C, Sanjay Pande M B, Kotreshi S N**

***Abstract*: *Cognitive radio technology is a growing positive solution for the effective utilisation of bandwidth in IoT device networks. The fixed spectrum allocation scheme leads to insufficient spectrum utilisation. To overcome this problem, a stochastic resource allocation algorithm is proposed in the present work. This method of internet spectrum allocation considerably increases the performance of IoT sensor networks by utilising the internet spectrum through non-cognitive, inactive IoT sensors (white space/spectrum holes) via continuous spectrum sensing. In this paper, we discuss effective resource allocation for interweave and underlay conditions, as well as variable interference constraints (short-term and long-term spectrum sensing) in an IoT network. The arecanut plantation for agriculture scenario is considered in the present paper, and the sensor environment simulation is performed using MATLAB.***

***Keywords*: *Primary, Secondary Users, Resource Management, Stochastic Approximation, Imperfect Channel Information, Lagrange's Multipliers.***

## I. INTRODUCTION

Wireless communication technology is continually improving, and it has reached 5G today. As there has been continued progress in technology over the last decade, demand for internet spectrum has also grown in parallel. As internet spectrum availability is limited by international distributors, satisfying all client sensors in the IoT implemented world with available bandwidth is becoming a significant challenge in the internet networking field. Utilising the internet beyond the available spectrum, which may exceed gigahertz, can start to cause severe injury to birds and human beings. International-level auctions are conducted for purchasing internet spectrum bands for upcoming IoT framework implementations. The internet spectrum scarcity has begun as a result of the vast number of IoT client devices and sensors being connected. Therefore, managing the vast number of IoT sensors connected to IoT servers becomes a very significant research problem.

Cognitive radio technology is emerging as a solution to meet the increasing demand for IoT internet, despite the limited spectrum available from the Indian IT authority for 4G spectrum distribution. To achieve this, dynamic resource allocation has been studied, and many algorithms related to dynamic resource allocation are discussed in [1-3].

The proposed stochastic resource allocation algorithm is one of the dynamic resource allocation methods used for the effective utilisation of available IoT spectrum resources. The present paper proposes a dynamic resource allocation algorithm to sense the channel spectrum by analysing the average power and suboptimal power of the channel, considering Rayleigh power fading. The instantaneous power and sample average power of the interleave and underlay spectrums are calculated, and the results are depicted using MATLAB.

## II. RELATED WORK

Many authors have discussed different algorithms related to dynamic resource allocation. The optimisation problem has been solved by analysing the average power and suboptimal power of the channel, assuming a Rayleigh fading channel. An effort was made to reduce the power consumption by sensor nodes in the IoT communication [2] many resources are concentrating on interference management in fem to cell network.

These femto cell networks are cooperative networks with the radio network. The analysis of power allocation strategy based on the interference behavioural study (previous history) by using the two-state Markov chain model is done [3]. Several studies have been conducted on the dynamic resource allocation of subcarriers based on channel state information for orthogonal frequency division multiple access (OFDMA). Many schemes have been developed to exploit the knowledge of perfect instantaneous CSI. Paper [4] mainly concentrates on resource allocation by having perfect instantaneous CSI.

If CSI is not considered, it is referred to as a stochastic algorithm. Stochastic algorithms can dynamically sense wireless IoT sensor data channels to achieve an optimal strategy, provided prior knowledge of the channel is available. In this case, an optimal scheme can be obtained using Lagrange's dual gradient iteration [5]. The separation of wireless network design into various layers and the associated problems in each fading state are discussed in [6].

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Interference power constraint for cognitive radio to protect primary user translation is discussed in [7]. The various capacity limits achieved by primary user fading, like ergodic and outage capacity, are discussed in the paper [8].
Xiang Zhang et al. have explained the technique of spectrum sensing with a static algorithm [9]. Amar Abdul Ahamad Khadar et al. have presented a survey of CR-based IoT and mentioned some previous works. It highlights in detail the spectrum sensing stage for both narrowband and wideband [10]. Critical technical issues related to the cognitive radio-based IoT network are discussed in the paper [11].

The overall idea, applications, and the need for cognitive radios in the IoT framework device applications are discussed in the paper [12]. Dina Tarek et al. have given a clear view of the spectrum sensing techniques with a survey of all available techniques for the spectrum sensing and resource allocation methods [13]. Banhammer et al. have discussed the motivations and research challenges in the implementation of cognitive radios in the IoT and highlighted the challenge of spectrum sharing in dynamic scenarios [14]. Idrees et al. have presented the basic functionalities of both CR and IoT technology and present a five-layered framework for CR-enabled IoT.

In addition to the framework, we also proposed and developed a spectrum sensing algorithm for CR-based IoT architecture, meeting the efficiency and time sensitivity requirements [15]. Alberti et al. have developed an embedded and low-cost cooperative spectrum sensing solution, which has been experimentally implemented [16].

## III. INTERFERENCE CONSTRAINTS

In our proposed system, we have considered two types of interference constraints. The first is a short-term constraint, which involves channel state information. This short-term constraint reduces the probability of exceeding the threshold interference over a very short time. Another is a long-term constraint that leverages the diversity of interfering channels to reduce the likelihood of exceeding the threshold over a prolonged period (fraction of time). In the long term, the mathematical output terms are multiplied using Lagrange's multiplier, whose values depend on the previous history of the channel/system. The proposed stochastic algorithm first estimates the probability of interference and then estimates the optimum value of Lagrange's multipliers based on these two estimates, allocating the spectrum resource accordingly.

## IV. FLOW DIAGRAM OF PROPOSED ALGORITHM

As shown in the flow diagram (Figure 1), the first step is to obtain the channel state information by estimating the average power of the channel, and then we sample it. After these steps, we get the instantaneous power using Lagrange's multipliers, and the interfering power levels are calculated to determine the threshold power level. By having this data on the threshold, we will set the threshold power level to prevent the secondary user from exceeding it.

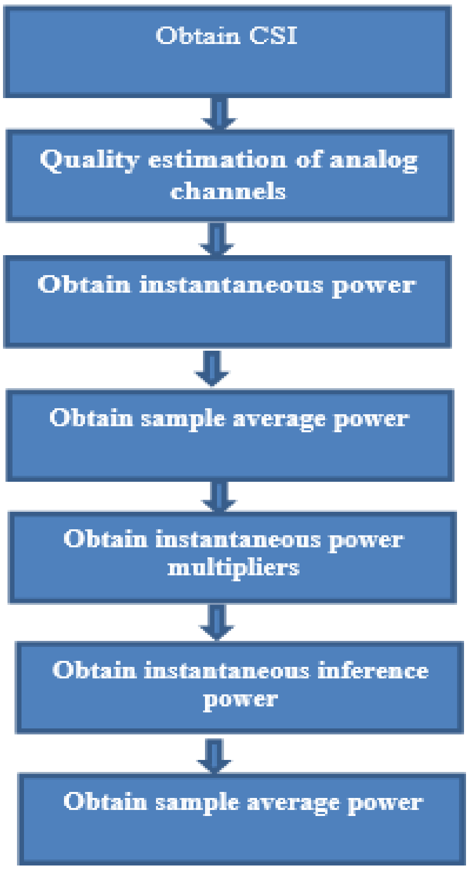


**Fig. 1: Flow of operation**

## V. MATHEMATICAL ANALYSIS

In this proposed algorithm, we consider "M" secondary users who can transmit their data over "k" different channels in an opportunistic manner.

Let h m k, 2 [n] be the instantaneous power of the channel between the mth secondary transmitter and its expected receiver on the kth band at a specific time "n". Here, the subscript two states that the channel belongs to the secondary transceivers in the IoT framework. Here, we consider the case where the licensed user transmitters are at a far distance from the SU (Secondary User) receivers. This is the fact that in IoT-CRN (Cognitive Radio Network), the CSI (Channel State Information) of a certain PU (Primary User) network can't be perfectly known because it is infeasible to sense all sensor data channels simultaneously. Therefore, there would always be probabilistic and varying information of the primary CSI (Channel State Information). Therefore, estimating CSI under interweave and underlay conditions is very crucial in IoT-CRN modelling. The discussion of CSI in the IoT framework sensor channel settings is presented in the following sections.

### A. Perfect and imperfect channel state information in IoT- CRN

In the case of the interweave CRN setting, the network controller requires information on whether an individual spectrum or channel is being used or not.

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To measure the spectrum occupancy, let ak be a variable representing the activity of the PUs network at a specific time instant on the kth band. Here, ak[n] = 1 means that at a particular time instant, the kth PU, ak[n] = 0, is active and utilising its resource. On the contrary, states for the idleness of the kth band at an instant. Here, we define a verification factor (2*1) represented as

F ak[n]:= [Pr {ak [n] = 0} , Pr {ak [n] = 1}]T ------------(1)

Where the probability mass depends on the previous behaviour of the system up to the last nth instant.

Consider Sk [n] to be a Boolean variable with Sk [n] = 1 representing the scenario when the kth band has been sensed at a particular instant n; otherwise, Sk [n] = 0. Furthermore, consider ak [n] to be the estimated value of the measurement at a specific time instant n, during the time of consideration. Here, in the proposed algorithm, we have considered two predominant types of imperfect CSI. They are Outdated CSI (Sk[n] = 0) and noisy CSI (the probability of noise addition during the sensing process is higher; therefore, in this case, ak [n] is not equal to ak[n].

To address outdated CSI, it is necessary to retrieve the dynamics of ak [n] throughout the defined observation time. Here, we have followed a first-order Markov process for estimating outdated CSI.

Considering Q as a transition probability matrix, and hence the entry at the i, jth instant is:

Qij = Pr{ak[n] = i} / Pr {ak [n − 1] = j} -----------(2)

To address the sensing errors, this paper considers two factors: the Probability of False Alarm (PFA) and the Probability of Miss Detection (PMD). These two are represented mathematically as

PMD = {ak [n] = 0}/ {Ak [n] = 1} and

PFA = {a^k[n] = 0}/ {ak [n] = 1}

Now, we have defined a 2x1 matrix, such that

q1 = [1 − PFA, PMD ]T

q1 = [PFA, 1 − PMD ]T

In this paper, we have utilised a Hidden Markov Model (HMM) to estimate CSI; therefore, recursive Bayesian estimation can be employed to retrieve the instantaneous verification factor, fak [n]. Thus, the verification factor can be updated as:

Fak [n] = Qfak [n − 1]

fa^k [n] = fak [n − 1]

We have optimised FAK using the Bayesian rule. If we consider the [n] to be the lth entry of the vector, hence

[fak[n-1]l] = ([q0]l[fa^k[n]l)/q0T fa^k [n]

[fak[n]]l = ([q0]l[fak[n]]l)/ q1 fa^k [n]

## VI. ESTIMATION OF LAGRANGES MULTPLIERS

The primary use of the Lagrange multipliers (LMs) is that, generally, one can observe that the most universal difficulty in integral or differential calculus concepts is discovering the maxima and minima points, also known as the extreme values of a particular function, as shown in Figure 2.

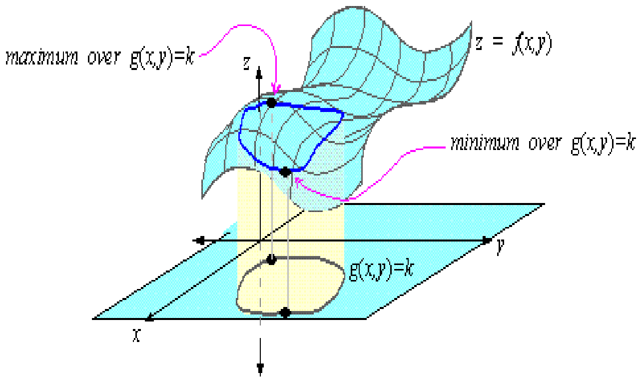


**Fig. 2: Example of Langarangian Multipliers Approach To Find Maxima and Minima**

**Pmo, θ0, ν0 are the variables used to optimise the particular function in the Lagrangian** approach. There are many methods used to estimate Lagrangian multipliers. This method uses a fixed step size multiplication; therefore, it has some limitations. The main limitation of this approach is that, at every step, it requires averaging all possible states of h (including channel imperfections). Every time, the channel statistics of users must be recomputed. Alternative approaches are used to obtain the multipliers. These approaches do not aim for optimal values but instead calculate the values that are updated at every time instant. The main advantages of this approach, especially for IoT-CRN settings, are: The computational complexity is very low; they can be compatible with non-stationary channels. Convenient when the primary user transmitters are very close to the secondary users' receivers. To overcome the limitation of the Lagrangian Multiplier approach, evolutionary computing or genetic algorithm-based Lagrangian multiplier optimisation is used in the proposed algorithm. The proposed genetic algorithm-based calculation of Lagrangian multipliers for the stochastic resource allocation of spectrum is illustrated in Figure 3.

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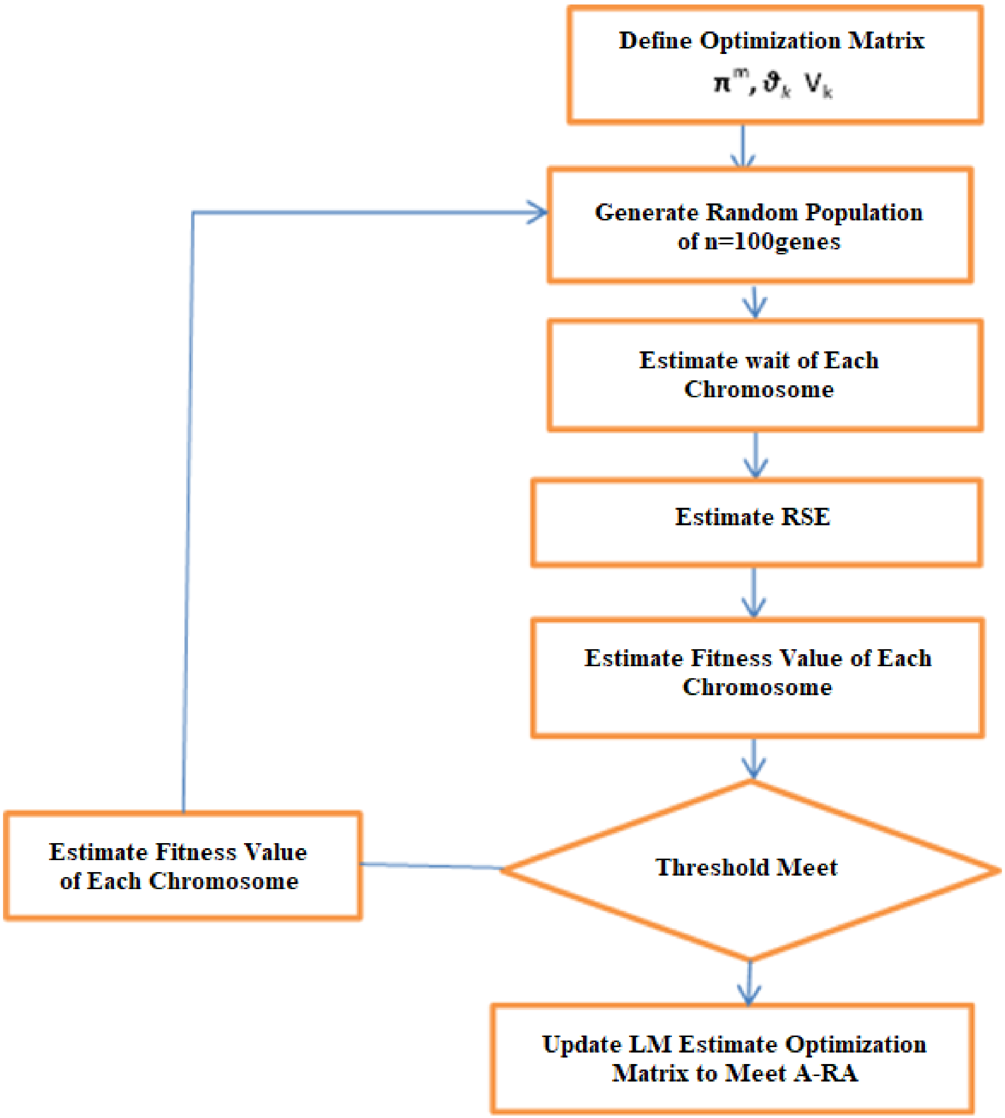


**Figure 3: The Proposed Genetic Algorithm to Calculate the Lagrangian Multipliers**

An algorithm for the proposed evolutionary computational-based genetic algorithm for the calculation of Lagrangian multipliers is explained in this section:

**Step 1: Optimisation Variable Definition: In this step, the multiplier variables m[n], k[n], and vk[n] are defined, which will be used for Lagrangian** relaxation to meet A-RA objectives and interference control.

**Step 2: Population Generation - The population for optimisation variables has been generated using Equation** [7]. The retrieved values of m[n + 1], k[n + 1], and vk[n + 1] have been used as the set of chromosomes. Initially, the randomly selected chromosomes would be used to perform competition and crossover with defined genetic operators (Pc, Pm), where the initial values of Pc and Pm are 0.6 and 0.1, respectively.

**Step 3: Chromosome Weight Estimation: The weights for Πm[n], θk[n], and vk [n]** have been estimated.

$$\omega_n = \begin{cases} \dfrac{- X_{nl}+2 *10^{l-2} + X_{nl}+2 *10^{l-3} ..X_{(n+1)l}}{10^{l-2}} & \text{if } 0 < X_{nl+1} < 5 \\[2ex] \dfrac{+ X_{nl}+2 *10^{l-2} + X_{nl}+2 *10^{l-3} ..X_{(n+1)l}}{10^{l-2}} & \text{if } 5 < X_{nl+1} < 9 \end{cases}$$

Where $\omega_n$ is the weight estimated (distinct for $\Pi^m[n]$, $\theta_k[n]$, $v_k[n]$) and l is the length of the chromosomes. In the proposed algorithm, the real positive weight value has been used for multiplier weight estimation.

**Step-4** Error Estimation: The error estimated is:

$$E_j = \begin{cases} \pi^{m*} - \pi^{m}{}_{0j} = \blacktriangle\, \pi^m \\ \theta_k^* - \theta_{k0j} = \blacktriangle\, \theta_k \\ V_k^* - V_{k0j} = \blacktriangle\, V_k \end{cases}$$

Thus, the cumulative error function $E_j = \Delta\Pi^m, \Delta\theta_k, \Delta V_k$. Considering these errors as input, the fitness value has been estimated. The fitness value is predicted by subtracting the cumulative error function from the root mean square error; therefore, RMSE will become.

$$RMSE - E_j = \sqrt{\frac{\sum_{j=1}^{N} E_j}{N}}$$

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**Step 5** Fitness value estimation: $\frac{1}{RmSE} - Ej = \frac{1}{\sqrt{\frac{\sum_{j=1}^{N} E_j}{N}}}$

**Step 6**: Chromosome Ranking and Mutation. To enhance the performance of the proposed scheme with minimal computational complexity, the ranking of chromosomes is estimated in this algorithm. The chromosomes with minimal ranking are mutated.

**Step 7** is designed to make πm, θk, and Vk approximate m[n], k, and v[k][n], respectively. Therefore, in this genetic algorithm implementation for the IoT CRN scenario, the genetic algorithm run is stopped once the errors (m, k, and k) become minimal, justifying m = m, k = k, and vK = vk. The final retrieved values of m[n], k[n], and vk[n] are used as Lagrangian multipliers, which ensure the maximisation of the weighted sum rate for the IoT spectrum resource allocation problem with assured expected interference constraints (for interweave and underlay setups). Thus, the average-power optimization can be achieved as discussed above to ensure optimal unused resource allocation to the secondary users (SUs) without introducing interference to the primary users (PUs)

## VII. SIMULATION RESULT

Simulation results for all cases and conditions are tested and simulated in MATLAB using 500 sensor nodes for the IoT framework, with k = 10, M = 5, N = 500, Pfa = 0.02, and Pmd = 0.01. The results are tested for 10 iterations of multipliers. The power achieved is tabulated and compared with the actual power to compare the accuracy of the algorithm. The instantaneous power of the data transfer channels is calculated using the proposed algorithm. The obtained result is shown in Table 1.

**Table I: Instantaneous power for Interweave condition**

| Iteration | Actual power | Estimated power |
|---|---|---|
| 1 | 0.3968 | 0.3968 |
| 2 | 0.5000 | 0.5000 |
| 3 | 0.1905 | 0.1905 |
| 4 | 0.5635 | 0.5635 |
| 5 | 0.6349 | 0.6349 |
| 6 | 0.2619 | 0.2619 |
| 7 | 0.4365 | 0.4365 |
| 8 | 0.6508 | 0.6508 |
| 9 | 0.3492 | 0.3492 |
| 10 | 0.6032 | 0.6032 |

The instantaneous power of the data transfer channels in underlay networks is calculated using the proposed algorithm. The obtained result is shown in Table 2.

**Table II Instantaneous Power for Underlay Condition**

| Iteration | Actual power | Estimated power |
|---|---|---|
| 1 | 0.2540 | 0.2540 |
| 2 | 0.1984 | 0.1984 |
| 3 | 0.1825 | 0.1825 |
| 4 | 0.1825 | 0.1825 |
| 5 | 0.2222 | 0.2222 |
| 6 | 0.2302 | 0.2302 |
| 7 | 0.2222 | 0.2222 |
| 8 | 0.2302 | 0.2302 |
| 9 | 0.1984 | 0.1984 |
| 10 | 0.1587 | 0.1587 |

The results have been tabulated considering both interview and lay conditions, and the graphs were generated by taking 500 nodes and 10 iterations. The average **powers of** channels for the interview network condition are shown in Table 3.

**Table III: The average powers of channels for the interview network**

| Iteration | Actual power | Estimated power |
|---|---|---|
| 1 | 0.1429 | 0.1667 |
| 2 | 0.8254 | 0.8333 |
| 3 | 0.6270 | 0.6190 |
| 4 | 0.5159 | 0.4921 |
| 5 | 0.2778 | 0.2540 |
| 6 | 0.4603 | 0.5079 |
| 7 | 0.3175 | 0.2619 |
| 8 | 0.6270 | 0.5714 |
| 9 | 0.5397 | 0.5159 |
| 10 | 0.3810 | 0.3571 |

**Table IV: The average powers of channels for the underlay network condition are shown in Table 4.**

| Iteration | Actual power | Estimated power |
|---|---|---|
| 1 | 0.1905 | 0.2143 |
| 2 | 0.2540 | 0.8333 |
| 3 | 0.1508 | 0.1825 |
| 4 | 0.2222 | 0.2222 |
| 5 | 0.1270 | 0.1508 |
| 6 | 0.0794 | 0.0794 |
| 7 | 0.1111 | 0.1270 |
| 8 | 0.2460 | 0.2460 |
| 9 | 0.4048 | 0.4127 |
| 10 | 0.1587 | 0.1508 |

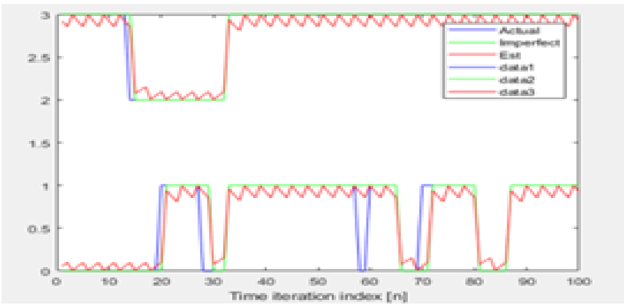


**Fig. 4. CSI estimation graph of an IoT network under imperfect conditions. The Blue line represents the actual estimation of CSI, the Green line represents the imperfect estimation, and the red line represents the estimated values of CSI for the IoT sensor network.**

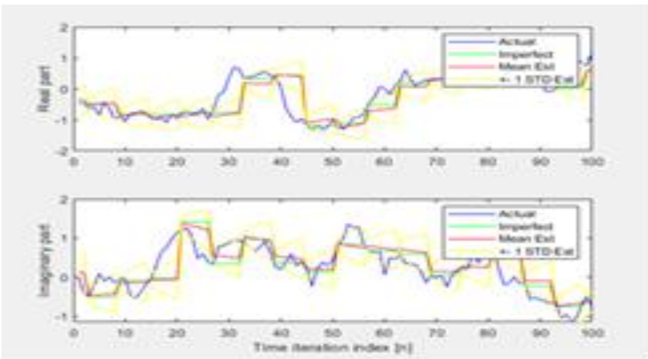


**Fig. 5. Quality estimation graph under Interweave IoT Network condition.**


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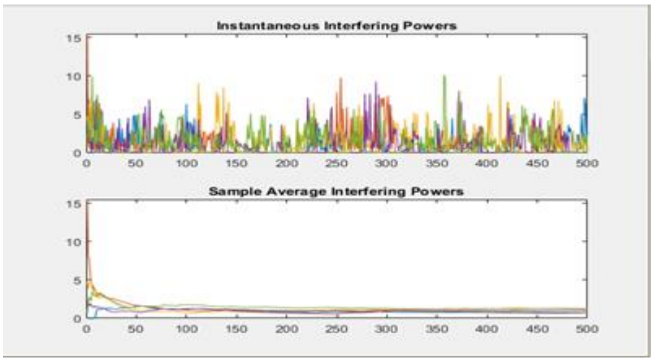


**Fig 6. Instantaneous power, sample average power, instantaneous power multipliers, Estimation at primary under Interweave network condition**

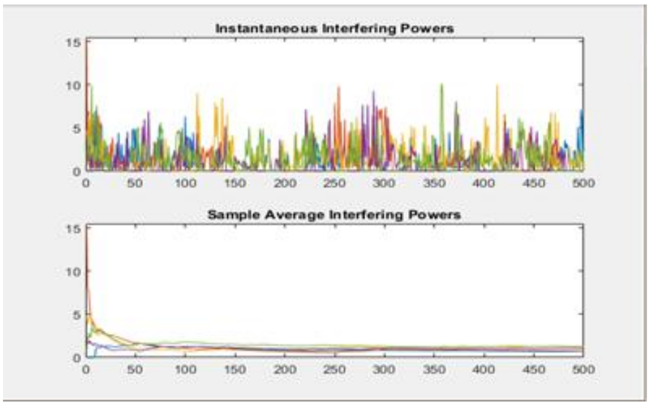


**Fig 7. Instantaneous interfering power average Interference power for an interweave network for underlay conditions.**

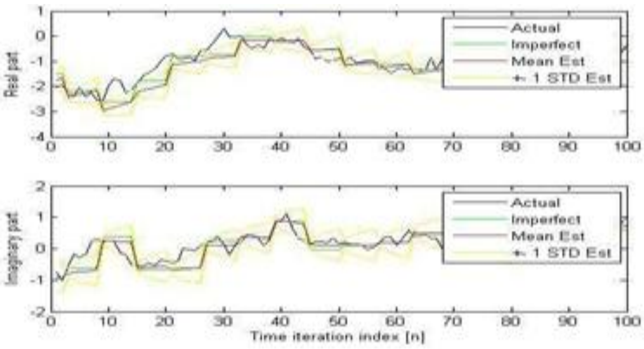


**Fig 8. CSI estimation graph for actual, imperfect, and estimated situations in an Underlay Network.**

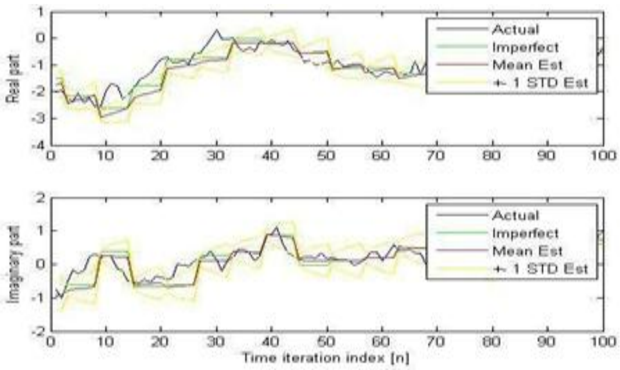


**Fig 9. Quality estimation graph for Underlay Network**

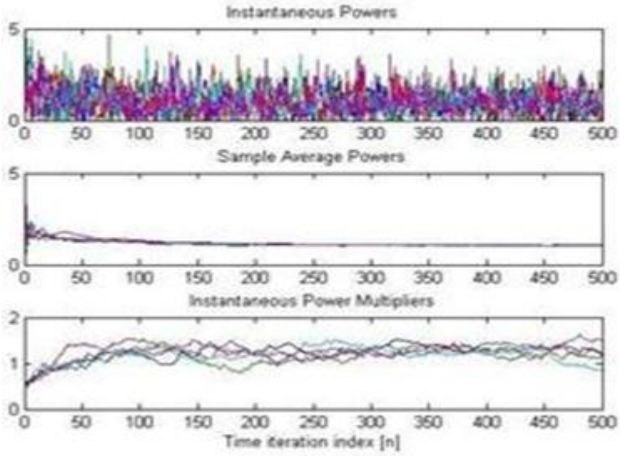


**Fig 10. Instantaneous power, sample average power, and instantaneous power multiplier estimation at the primary user for underlay networks.**

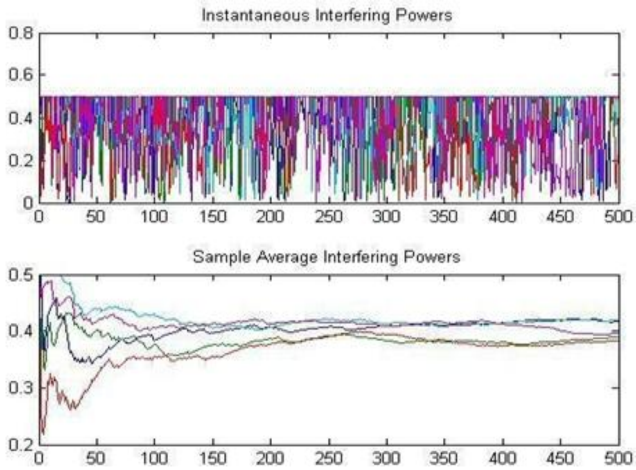


**Fig 11. Instantaneous interfering powers and sample average interference power for the Underlay Network.**

## VIII. CONCLUSION

A stochastic resource allocation algorithm is one of the significant solutions for underutilised spectrum in IoT. This algorithm is subject to two parameters: the probability of interference and the average power. In this paper, we discuss two types of interference constraints: short-term constraints, where channel state information is imperfect, and long-term constraints, where the probability of interfering at any instant does not exceed a given threshold. Another constraint is the long-term constraint, where we considered the diversity of interfering channels to confirm that the instant of time during interference does not exceed the threshold. Finally, these terms were multiplied by Lagrange's multipliers based on their previous channel history, and ultimately, genuine spectrum management is performed using cognitive radio technology for users involved in wireless communication.

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## DECLARATION

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| Ethical Approval and Consent to Participate | No, the article does not require ethical approval or consent to participate, as it presents evidence that is not subject to interpretation. |
| Availability of Data and Material/ Data Access Statement | Not relevant. |
| Authors Contributions | First author: data analysis process and practical implementation done.<br>Second author: literature survey modelling.<br>Third author: mathematical concept analysis. |

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