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QUEUING MODEL TO RESOLVE CONTENTION IN COGNITIVE RADIO NETWORK ENVIRONMENT

OKWONG Atte Enyenihi
Department of Computer Science
University of Cross River State, Calabar, Nigeria

Abstract

This study introduces a contention resolution model within cognitive radio networks. The queuing theory model of M/G/1/K with a First Come First Serve (FCFS) algorithm was employed. Challenges associated with contention handling in cognitive radio environment includes spectrum underutilization, interference, and fairness in spectrum utilization. The model provided leverages on M/G/1/K queuing model, providing a theoretical foundation for optimizing contention resolution. Through the FCFS algorithm, the model ensures equitable access to the spectrum, prioritizing the first arriving users. To validate the efficacy of the proposed model, Matlab and Minitab software were employed for simulation and statistical analysis. The simulation results not only demonstrate the model's effectiveness in mitigating contention issues but also provide insights into system performance under various scenarios. This research contributes to the advancement of cognitive radio networks by offering a robust contention resolution model supported by empirical evidence from Matlab and Minitab simulations. The integration of these software tools enhances the reliability and practicality of the proposed solutions, making them valuable for designing efficient and fair cognitive radio communication systems. This research has explored efficient methods for managing spectrum access conflicts and enhance utilization by prioritizing access based on arrival times and utilizing queuing theory principles. More so, the model establishes a framework where secondary users contend for available spectrum resources in a first come first served manner. Above all, the model and process will contribute to helping Nigerian Communication Commission (NCC) and other Dynamic Spectrum Usage functionaries in analyzing and optimizing the contention resolution process for the effective utilization of available spectrum resources in dynamic cognitive radio environment.

Keywords: Spectrum Sensing, Spectrum management, First Come First Serve Algorithm and M/G/1/k Model.

1.0 Introduction

Cognitive Radio Networks (CRNs) have emerged as a promising solution to address the growing demand for wireless communication services while efficiently utilizing the limited and crowded radio frequency spectrum (Mitola, 2009). In the dynamic and unpredictable nature of the radio environment, contention arises when multiple cognitive radio devices seek to access the same frequency bands simultaneously. Contention resolution becomes a critical aspect of ensuring fair and efficient spectrum utilization in cognitive radio networks, Akbar, el at (2010). Contending devices must contend with each other to access available spectrum resources, and effective contention resolution models play a pivotal role in optimizing network performance. These models aim to manage the competition among cognitive radio nodes, dynamically allocating spectrum access based on priority, fairness, and overall network efficiency (Ramani & Sharma, 2017, Helen &Susan, W, 2015).

The complexity of contention resolution in cognitive radio networks is magnified by the need to coexist with primary users and adapt to the changing radio frequency environment. Traditional contention resolution mechanisms, such as Carrier Sense Multiple Access (CSMA), may not fully address the unique challenges posed by the dynamic and cognitive nature of these networks (Rahman & Karmakar, 2018, Akyildiz,el at , 2011, Uddin, & Al-Dubai, 2013),.

This introduction explores the significance of contention resolution models within the context of cognitive radio networks, highlighting the need for adaptive and intelligent mechanisms to address contention challenges. By delving into the principles, algorithms, and advancements in contention resolution, we aim to gain insights into how these models contribute to the efficient and reliable operation of cognitive radio networks in diverse and dynamic communication scenarios (Mahmoodi, el al, 2009, Digham, el at, 2007).

Contending for spectrum access in cognitive radio networks involves intricate decision-making processes, as devices must dynamically adapt to changing environmental conditions, avoid interference with primary users, and adhere to regulatory constraints. Contention resolution models play a crucial role in orchestrating these decisions, ensuring that cognitive radio devices cooperate effectively to share the spectrum efficiently (Yucek and Arslan ,2009, Khan,et al, 2015, Zang, el at., 2009).

The challenges associated with contention resolution in cognitive radio networks are manifold. Devices must contend not only with each other but also with the uncertainties introduced by varying propagation conditions, interference levels, and the presence of dynamic primary users. Traditional contention resolution mechanisms may struggle to cope with these complexities, necessitating the development of novel models that harness the cognitive capabilities of the devices.

Moreover, contention resolution in cognitive radio networks is closely tied to the concept of spectrum sensing, where devices must accurately detect and assess the occupancy status of the spectrum. The integration of sensing information into contention resolution models adds a layer of intelligence, allowing devices to make more informed decisions about when and where to contend for spectrum access.

2.0 Material and methods

Developing a contention resolution model in a cognitive radio network involves considering various materials and methods as we shall discuss. Here are key elements:

2.1.1 Hardware Components: Describe the physical components used in the study.

Which include details about the cognitive radios, antennas, signal processing equipment, and any other relevant hardware as indicated in diagram below.

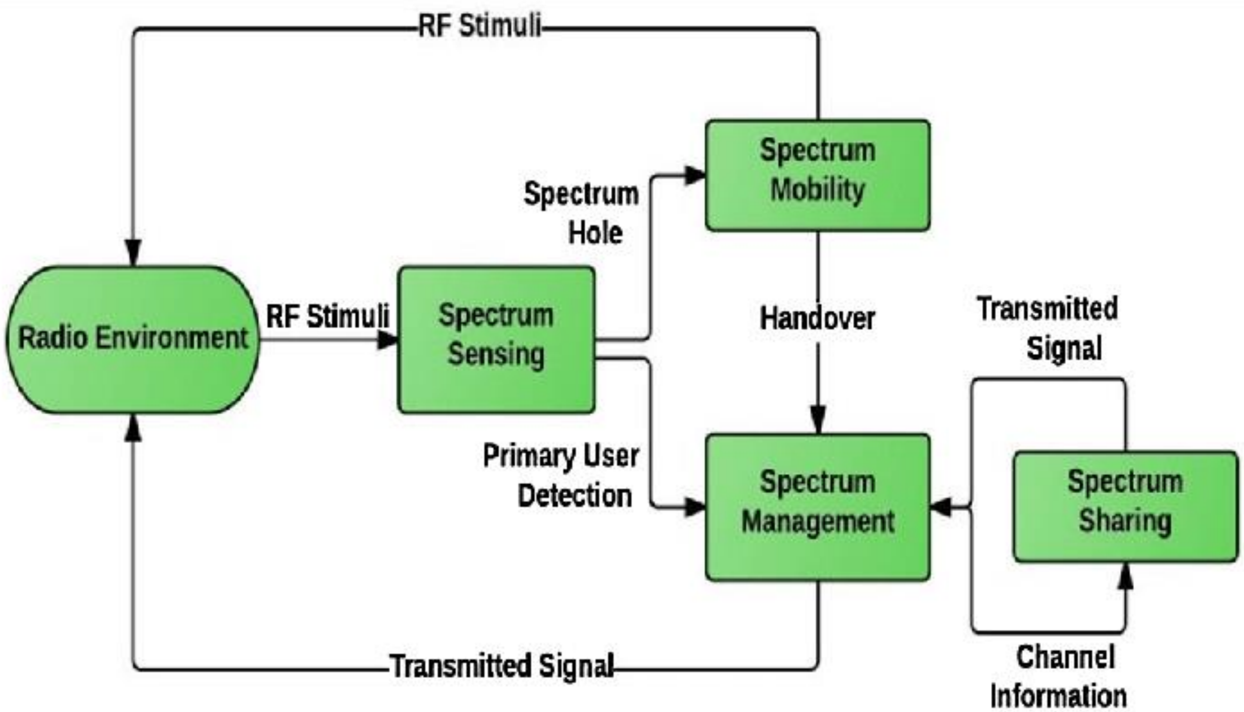

Figure 1: Design of Hardware Components used Contention Model

2.1.2. Software Tools: The software tools for simulation platforms are MATLAB and MINITAB used for implementing the contention resolution model. Cognitive radio often involves complex algorithms and simulations.

2.3 Datasets: The datasets are provided according to the displayed graph for testing and validating the contention resolution model in table 1 and 2.

2.2 Methods:

2.2.1 Algorithm: Algorithms is provided as a detailed explanation of the contention resolution in the model.

2.2.2 Experimental Design: Speculative assumption was conducted because of absent of equipment and outline the speculative variables.

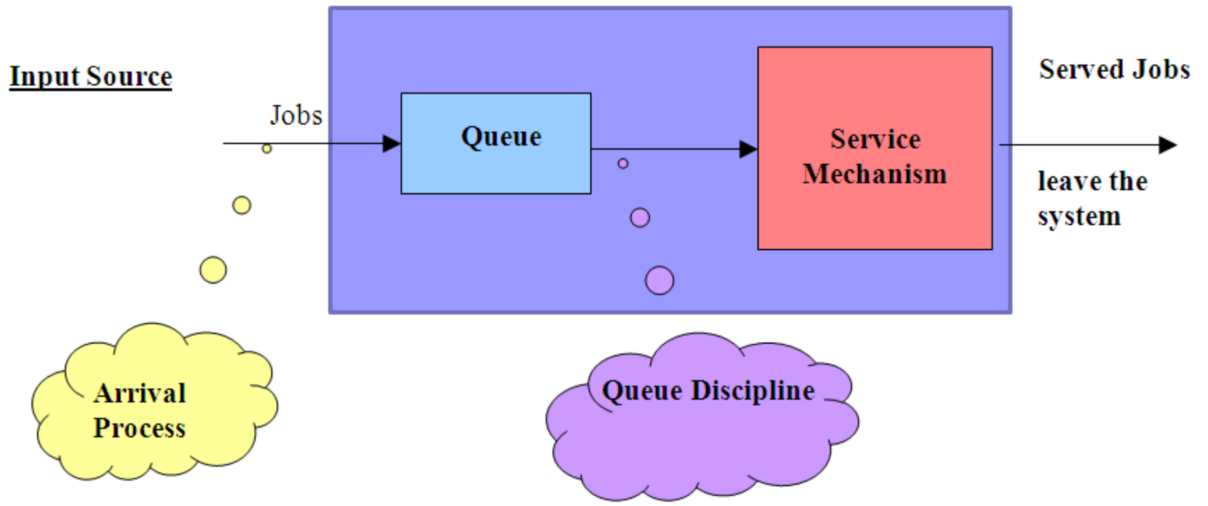

Figure 2: Queuing Model for transmission of Contention Using First Come First Serve (FCFS)

In a cognitive radio network, the contention resolution process often involves deciding which node or device gets access to a particular spectrum channel when nodeis contending for the same channel as indicated in Figure 2. Queueing theory is employed to model and analyze contention resolution as one common approach is the First Come First Serve (FCFS) algorithm. FCFS is a simple queueing discipline where the node that arrives first is served first. Here's a simplified representation of a contention resolution algorithm using FCFS in a cognitive radio network environment:

2.2.3 First come first serve (FCFS) contention resolution algorithm for transmission:

Step 1: Initialization: Maintain a queue to store the nodes that is contending for spectrum access.

Step 2: Contending Node Arrival: When a cognitive radio node wants to access the spectrum, it joins the end of the queue.

Step 3: Channel Sensing: If the channel is sensed to be idle, the node at the front of the queue gains access to the spectrum or The node is removed from the queue and begins transmission.

Step 4: Channel Busy: If the channel is sensed to be busy

The contending node remains in the queue or the node at the front of the queue will gain access once the channel becomes idle.

Step 5: Transmission Completion: Upon completing its transmission, the node releases the channel, making it available for the next contending node.

Step 6: Repeat: Steps 2-5 are repeated for each contending node in the queue.

End: 7. The process continues as long as there are contending nodes.

3.0 Result and discussion

We Consider the imbedded Markov Chain of system states at these time instants $t_i = 1, \ldots$ when the ith SU leaves from the system after transmitting. At a time instant ti , the system state n_i will be the number of SUs left behind in the system when the ith SU leaves. Note that n_i will range between 0 and $K-1$ since the departure of the job cannot leave the system completely full, i.e. with system state K.

Let a_i be the number of arrivals (from the Poisson arrival process) in the ith service time. The equations for the corresponding Markov Chain can then be written as

$$\left.\begin{aligned} n_{t+1} &= \min\{a_{i+1}, K-1\} && for \quad n_i = 0 \\ &= \min\{n_i - 1 + a_{i+1}, K-1\} && for \quad n_i = 1,\ldots,(K-1) \end{aligned}\right\} \qquad (1)$$

The transition probabilities of the imbedded Markov Chain at equilibrium are defined to be

$$p_{d,jk} = P\{n_{i+1} = j\}; \quad 0 \le j, k \le K-1 \qquad (2)$$

Let α_k be the probability of k SU arrivals to the queue during a service time.

$$\alpha_k = \int_{t=0}^{\infty} \frac{(\lambda t)^k}{k!} e^{\lambda t} b(t) dt \qquad (3)$$

where the pdf of the service time is given as b(t).

The transition probability pd,jk for the two cases $j=0$ and $j=1,\ldots,K-1$ will be found separately using the values of α_k found in (3). The expressions for these are given in (4) and (5), respectively, based on the observation that the final state k cannot exceed K-1.

$$p_{d,jk} = \begin{cases} \alpha_k; & 0 \le k \le K-2 \\ \sum_{m=K-1}^{\infty} \alpha_m & k = K-1 \end{cases} \qquad j=0 \quad (4)$$

$$p_{d,jk} = \begin{cases} \alpha_{k-j+1}; & j-1 \le k \le K-2 \\ \sum_{m=K-j}^{\infty} \alpha_m & k = K-1 \end{cases} \qquad j=0 \quad (5)$$

The equilibrium state probabilities pd,k k=0,1....,K-1 at the departure instants may be calculated Using the transition probabilities of (4) and (5), along with the normalization condition as follows.

$$p_{d,k} = \sum_{j=0}^{K-1} p_{d,j}\, p_{d,jk} \qquad k = 0,1,\ldots,K-1 \qquad (6)$$

$$\sum_{k=0}^{K-1} p_{d,k} = 1 \qquad (Normalizaton\ condition) \qquad (7)$$

The transition probabilities pd,jk of (4) and (5) may now be substituted in (5) and (6), giving a set of linear equations that may be solved to get the corresponding state probabilities. Note that only K independent equations are needed, as there are only K unknowns (i.e. pd,k k=0,1,......,K-1) to be found. This set of K-1 equations is summarized in (8).

$$\begin{cases} p_{d,k} = p_{d,0}\alpha_k + \sum_{j=1}^{K+1} p_{d,j}\alpha_{k-j+1} & k = 0,1,\dots,K-2 \\ \sum_{k=0}^{K-1} p_{d,k} = 1 \end{cases} \qquad (8)$$

Alternatively, one can solve first for the normalized variables (pd,k /pd,0) using

$$\frac{p_{d,k+1}}{p_{d,0}} = \frac{1}{\alpha_0}\left[\frac{p_{d,k}}{p_{d,0}} + \sum_{j=1}^{k}\frac{p_{d,j}}{p_{d,0}}\alpha_{k-j+1} - \alpha_k\right] \quad k = 0,\dots K-2 \qquad (9)$$

and then solve for pd,0 using the normalisation condition to get

$$p_{d,0} = \frac{1}{\sum_{k=0}^{K-1}\frac{p_{d,k}}{p_{d,0}}} \qquad (10)$$

We use this and the values obtained earlier for (pd,k /pd,0), to obtain the actual state probabilities pd,k k=1,......, K-1 at the SU transmission instants.

Considering a system at equilibrium, let pa,k k=0,1,.....,K be the probability that a newly arriving SU, irrespective of whether it finally joins the queue or not, finds k SUs waiting in the queue. For this system, let pk k = 0,1,.....,K be the probability that the queue has k SUs in it at an arbitrarily chosen instant of time. We will have that

$$p_k = p_{a,k} \qquad k = 0, 1, \dots, K \qquad (11)$$

We can also define pac, k k=0,1,.....K-1 as the equilibrium probability of the system state k as seen by an arrival which does actually enter the queue. Based on the fact, that the state of the queue can change by at most ±1 because of these arrivals and the departures from it, we can claim that

$$p_{d,k} = p_{ac,k} \qquad k = 0, \dots, K-1 \qquad (12)$$

Using P_B as the equilibrium probability that an arrival is blocked (because the queue is full, i.e.

$$p_k = p_{a,k} = (1 - p_B) p_{ac,k} = (1 - p_B) p_{d,k} \quad k = 0, \ldots K - 1 \qquad (13)$$

Note that this may also be confirmed by observing that

$$\sum_{k=0}^{K-1} p_{a,k} = 1 - p_B = \sum_{k=0}^{K-1} (1 - p_B) p_{ac,k}$$

since $\sum_{k=0}^{K} p_{a,k} = 1$ and $\sum_{k=0}^{K-1} p_{ac,k} = 1$

Let $\overline{X}$ be the mean service time of a SU in the queue. The traffic load ρ offered to the queue will then be given by $\rho = \lambda \overline{X}$. Since the average arrival rate of SUs actually entering the queue (also the average departure rate of SUs leaving the queue) is $\lambda_c = \lambda(1 - p_B)$, the actual traffic throughput of the queue will be $\rho_c = \rho(1 - p_B)$.

This implies that the probability p_0 of finding the queue empty at an arbitrary time will be

$p_0 = 1 - \rho_c$

Using (13) for the case k=0, we can then write

$$1 - \rho(1 - p_B) = (1 - p_B) p_{d,0} \qquad (14)$$

The blocking probability PB (or p_K) can be found using (14) as

$$P_B = 1 - \frac{1}{p_{d,0} + \rho} \qquad (15)$$

Using the values of $p_{d,k}$ and the results of (13) and (15), the equilibrium state distribution p_k, k=0,1,....(K-1) of the queue at arbitrary time instants may then be shown to be

$$p_k = \frac{1}{p_{d,0} + \rho} p_{d,k} \quad k = 0, \ldots K - 1 \qquad (16)$$

The equilibrium state distribution may now be used to find the mean number N in the system as

$$N = \sum_{k=0}^{K} k p_k = \frac{1}{p_{d,0} + \rho} \sum_{k=0}^{K-1} p_{d,k} + K\left(1 - \frac{1}{(p_{d,0} + \rho)}\right) \qquad (17)$$

Note that the effective arrival rate λ_c to the queue will be given by

$$\lambda_c = \lambda(1 - P_B) = \frac{\lambda}{p_{d,0} + \rho} \qquad (18)$$

Using this and Little's result, the mean total time spent in system by a SU actually entering the queue will be

$$W = \frac{N}{\lambda_c} = \frac{\sum_{k=0}^{K-1} p_{d,k} + K[(p_{d,0} + \rho) - 1]}{\lambda} \qquad (19)$$

This may be used to get the mean time spent waiting in the queue Wq as

$$W_q = W - \overline{X} = \frac{1}{\lambda}\sum_{k=0}^{K-1} p_{d,k} + \frac{K}{\lambda}(p_{d,0} + \rho - 1) - \overline{X} \qquad (20)$$

where $\overline{X}$ is the mean service time. The second moment of the time spent waiting in queue is given by

$$\overline{W_q^2} = (K-1)\left[(K-2)(\overline{X})^2 + \overline{X^2} - \frac{K\overline{X}p_{d,0}}{\lambda} - \frac{2\overline{X}}{\lambda}\sum_{k=1}^{K-1} kp_{d,K-k}\right] + \frac{1}{\lambda^2}\sum_{k=1}^{K-1} k(k+1)p_{d,K-k}$$

where $\overline{X^2}$ is the second moment of the service time

Table 1 shows the analysis of results obtained from the simulation of contention

resolution model of the speculation of the server transmission

Table 1: Result of Analysis in Contention Model

S/N	Arrival Time (λ)	Service Rate (μ)	Traffic Intensity (P)	Number of SUs (Lq)	Meantime in the Queue (Wq)per Secs
1	0.100	0.111	0.901	8.19	81.90
2	0.067	0.071	0.944	15.81	235.92

3.1.1 Implementation Requirement

Here, we employ Testing and Simulation to thoroughly test and simulate the scenario which validate the performance and reliability of the contention resolution model as shown in table 1 above.

TABLE 2

Result of Analysis in Contention Model using MANITAB Software to validate transmission

S/N	Threshold (T)	Arrival Time (λ)	Service Rate (μ)	Traffic Intensity (P)	Number of Sus (Lq)	Meantime in the Queue (Wq)
1.	0.39	0.10000	0.11100	0.9010	8.190	81.90

2.	0.58	0.06700	0.07100	0.9440	15.810	235.92

where $0 \leq \text{Threshold} < 1$. That is, the threshold value lies between zero (with zero inclusive) and one (with one exclusive). With this in mind, we have randomly assigned threshold values to each level of the five variables: arrival time (λ), service rate (μ), Traffic Intensity (P), Number of Sus (Lq), and Meantime in the Queue (Wq).

We seek a specific multiple linear regression model whose general form assumes:

$$\hat{T} = \hat{\beta}_0 + \hat{\beta}_1\lambda + \hat{\beta}_2\mu + \hat{\beta}_3 P + \hat{\beta}_4(Lq) + \hat{\beta}_5(Wq) \quad (A)$$

where: $\hat{\beta}_0,\ \hat{\beta}_1,\ \hat{\beta}_2,\ \hat{\beta}_3,\ \hat{\beta}_4,\ \hat{\beta}_5$ are parameter estimates of the model.

In order to develop this model, the data in the Table 4.1(b) is used in MINITAB Software (version 17) to obtain a specific multiple linear regression model which assumed the general form in equation (A), and which describes the Contention Model. The result of this analyses is presented below, alongside the developed model given as equation (B).

Regression Equation

Threshold (T) = 9.7 + 38 Arrival Time (λ) - 47 Service Rate (μ) - 8.6 Traffic Intensity (P) - 0.0096 Number of Sus (Lq) + 0.000000 Meantime in the Queue (Wq)

3.1.2 Regression Analysis: Threshold (T versus Arrival Time, Service Rate, Traffic Intensity.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	0.162128	0.032426	0.30	0.890
Arrival Time (λ)	1	0.000742	0.000742	0.01	0.938
Service Rate (μ)	1	0.001287	0.001287	0.01	0.918
Traffic Intensity (P)	1	0.002395	0.002395	0.02	0.889
Number of Sus (Lq)	1	0.003344	0.003344	0.03	0.869
Meantime in the Queue (Wq)	1	0.000001	0.000001	0.00	0.998
Error	4	0.432122	0.108031		
Total	9	0.594250			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.328680	27.28%	0.00%	0.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	9.7	54.4	0.18	0.867	

Arrival Time (λ)	38	464	0.08	0.938	11982.77
Service Rate (μ)	-47	435	-0.11	0.918	13505.73
Traffic Intensity (P)	-8.6	58.0	-0.15	0.889	177.90
Number of Sus (Lq)	-0.0096	0.0544	-0.18	0.869	56.37
Meantime in the Queue (Wq)	0.000000	0.000060	0.00	0.998	12.56

Fits and Diagnostics for Unusual Observations

Obs	Threshold (T)	Fit	Resid	Std Resid	
1	0.390	0.390	0.000	0.01	X
7	0.780	0.779	0.001	0.64	X

X Unusual X

3.2 Discussion

Since the work is speculative, it does not provide table for initial testing. The result is tested with table 1 and validated with table 2. The system is speculative without experiment being carried out because of absent of equipment within the scenario of this work. However, the above mathematical equations are used to justify and validate the work.

Figure 1 Graph showing Traffic Intensity versus Service Rate and Arrival Time (mins)

The graph in Figure 2 above depicts traffic intensity showing that both service rate and arrival time are decreasing as the throughput is less than 1 (< 1).

4.0 Discussion of findings:

The graphs above are plotted using MATLAB from the implementation of our contention resolution model.

Considering Figure 1, the graph shows the pictorial relationship of the arrival time (Lq) and the Mean time spent in the queue, Arrival time and service rate. It shows the comparative analysis of Lq vs Arrival rate and Lq vs service rate. Arrival time (Lq) reduces as the server rate increases and remain almost constant about 0.053 mins while Arrival Time (Lq) reduces steadily with increase in arrival rate and almost constant 0.052 mins. We can deduce that at lower arrival rate and service rate of less than or equal to 0.053 mins, there is no significance difference in the mean time spent by the server unit in the queue.

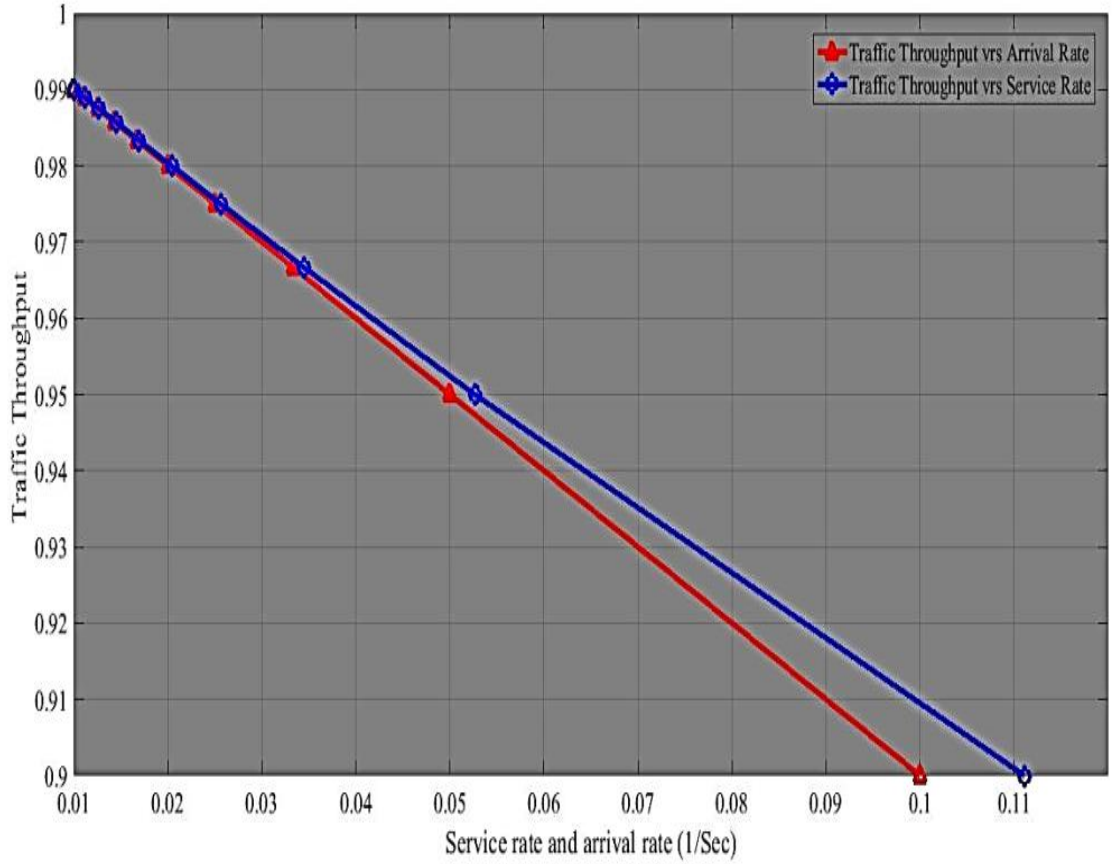

Figure 1: Traffic Throughput versus Service and Arrival Rate (mins)

Traffic Throughput decrease with an increase in service rate and arrival rate, meaning that the server is highly utilized for slower service rate and arrival rate. This show that the server is less congested and optimally used without contention and the traffic throughput is less than 1 for all conditions.

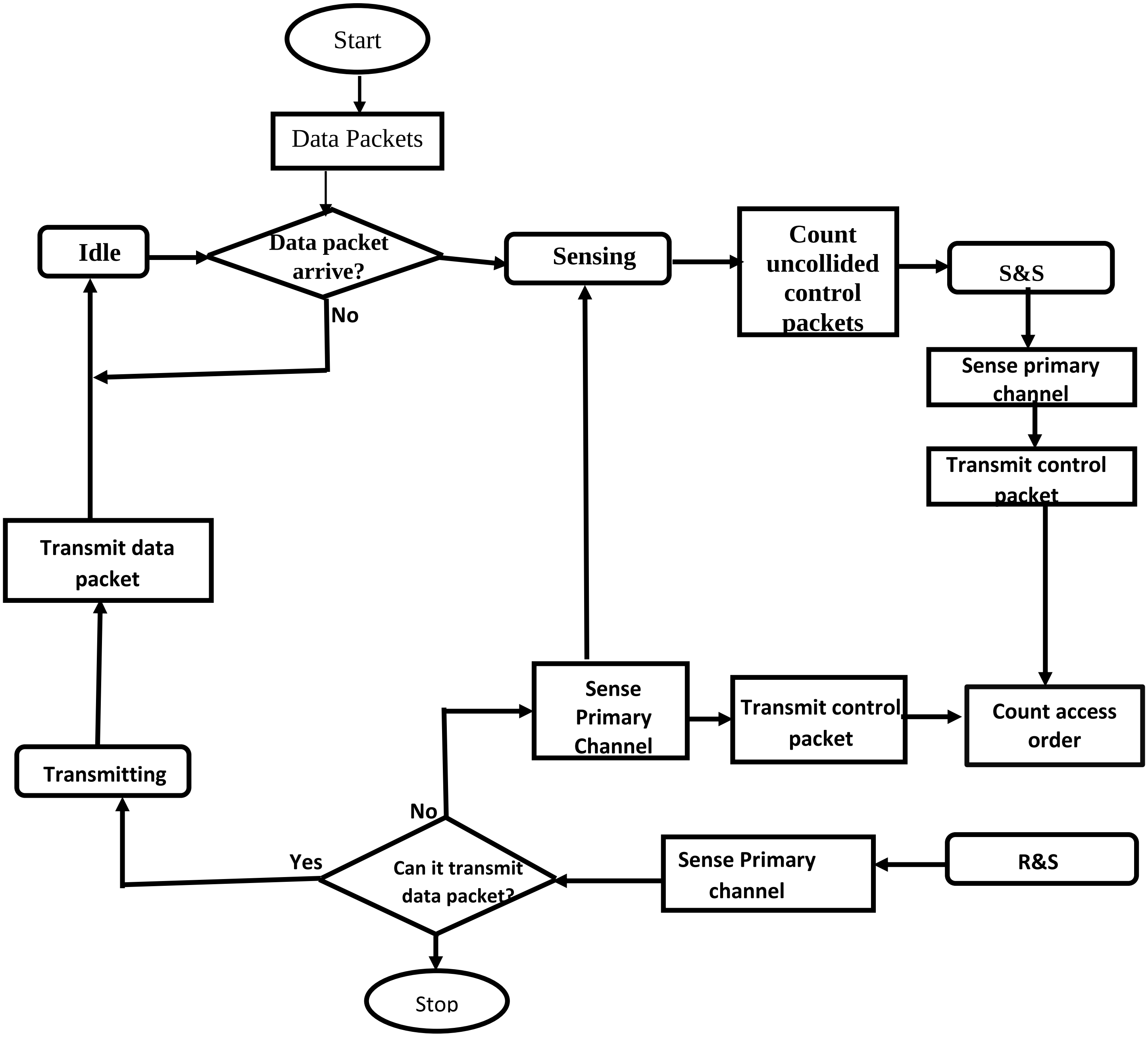

Figure 1: Logical flowchart for transmission of Cognitive Radio Spectrum Networks Environment

5.0 Summary and conclusion

5.1 Summary

Wireless spectrum is the most demanding entity in today's modern communication technology. Wireless spectrum is a highly scare resource, if properly not managed can cause severe communication constraints. This study reveals that most of the time the spectrum is idle and free which is the main problem to spectrum scarcity. In this work First come first serve is used to investigate the issues involved in spectrum management. Using queuing theory in a contention resolution model in cognitive radio networks is a valuable approach to manage and optimize the utilization of available spectrum resources efficiently

5.2 Conclusion

Queuing theory can be a valuable tool in solving sensing and contention resolution challenges in cognitive radio networks. In a cognitive radio, secondary users oppurtunically access the available spectrum, which often leads to contention for some resources. Sensing and contention are critical aspects of efficiently managing spectrum access in such networks. Employing MDP-based models for contention resolution in CRNs empowers cognitive radios to make informed, adaptive decisions in a dynamic spectrum environment. This approach optimizes spectrum usage, reduces contention, and improves the overall efficiency and reliability of communication in cognitive radio networks.

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