Effective Servicing of a Busy Base Station using Queuing Models in Cognitive Radio Networks

C. Sharanya, V.Rajendran

Abstract: This paper aims the effective utilization of spectrum using queuing models in cognitive radio. The data from various service providers are obtained and considered for our analysis. Analytical mathematical models based on queuing theory are developed for effectively servicing the arrival calls and improving the service rate. Based on the following parameters, we design a model to service the calls effectively: Average number of customers in the system, Average number of customers in the queue, Average wait in the system and Average wait in queue.

**Keywords** : Arrival rate, cognitive radio, queuing models and service rate.

I. INTRODUCTION

Basically, human is a mutual being which derives mutual benefits. These benefits are derived from public infrastructures such as, airports, railways, mobile call centers, etc. If these infrastructures are not well managed, it can lead to total collapse of human lifestyle. To ensure customers optimal satisfaction there must be strict measures. Satisfaction is obtained when customers waiting time, length of queue is reduced.

Customers always wait in queues to utilize public facilities at different places and at different times. The most important task is to understand how to manage queues.

Here we consider the case of a base station in thickly populated communicating area which handles higher number of calls than usual. Calls may arrive one by one or in groups. In a mobile base station or any public infrastructures the customer arrival process can be described by inter arrival times [1]. The probability distribution can characterize the random customer arrivals. And the larger number of calls can be prioritized based on queuing theory.

Queuing theory [2] is the mathematical study of the delays in waiting line. Queuing models[3] are created to predict the queue lengths and waiting time. It has been used for research, operations and system analysis.
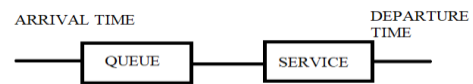
Fig.1 Basic Diagram of Queuing Theory

Queuing theory

The important point of consideration is the number of customers waiting for service. The waiting room or queue length can be considered as infinite. In telecommunication networks the realization of such queue is hard.
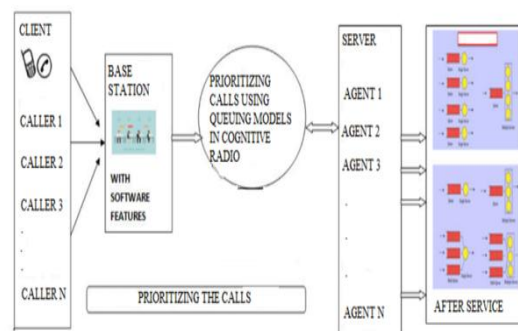
Fig.2. Basic block diagram

The main functions of queuing process include:

Arrival rate: The arrival [4] of calls in queuing system are not predetermined, they are random in nature. The probability distribution is used to describe the inter-arrival time or number of calls arriving during a time interval.

Clients: These are the individual request for service (e.g. a request by the clients by the server).

Queue: The set of callers waiting for service. The calls are served by different types; they are

1. First-In First-Out (FIFO) Or First-Come First-Served [5] (FCFS) are mostly used.
2. Last-In First-Out (LIFO)
3. Service In Random Order (SIRO) is randomly used.

Servers: These are the entities or resources that are capable of satisfying the service requests.

Service time: To specify the service time there is a need to use appropriate probability distribution. Service of calls may also be in single or groups.

Cognitive radio

The radio spectrum is divided into licensed and unlicensed frequencies.

Both the licensed and unlicensed bands of communication channels can be accessed by cognitive radio[6] using advance wideband access technology. Licensed spectrum [7] is used by primary network for operation. The presence of PU in the network has to be monitored by SU. The spectrum band can be used by SU, in the absence of PU. Hence for SU to utilize the vacant band of the PU, a complicated framework of spectrum management is developed.
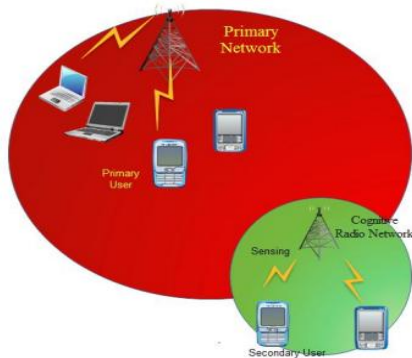

Fig.3. Basic principle behind Cognitive Radio Network

II. METHODOLOGY

An effective utilization of public infrastructural (Base station) usage is mainly focused in this research, and also the study of base station using queuing models and evaluation of queue parameters analysis. In this paper, base stations of different nodes are considered. Data on arrival calls, service time were obtained for a particular period of time. A base station in a thickly populated communication area has to handle higher number of calls. The incoming, outgoing and missed calls handled by the base station at a particular second should be prioritized. The prioritization [8] will be based on queuing theory. A queuing model is developed to analyze the data obtained. The queuing theory is predicated on First-come First-served discipline and assumed that the client arrival rate may be approximated by a Poisson distribution [9]. The length of queue can be endless, as the demand for call services is endless. Probability distribution assumes a Poisson arrival and Exponential service time, which is represented by M/M/1 and M/M/C models.

The arrival rate follows Poisson distribution and service rate follows exponential distribution in both the models.

It represents length of queue [10] in the system. They have single/ multi server to serve the customers. The M/M/1 model is compared with M/M/C model. In M/M/C model, C parallel servers [11] are used to serve the customer in the system (two servers). The arrival process and service process follow C distribution (Poisson distribution). If all C servers are already busy in serving customers, the primary customers within the queue are served by any of the C servers as soon as the previous customer departs from the server. From the distribution, the behavior of the base station will be observed and a cognitive engine will be designed to adapt such a

situation. Cognitive radio can automatically detect available channels in a wireless spectrum and changes transmission parameters. Cognitive engine is the brain of cognitive radio which provides intelligence to share the spectrum more efficiently.

The assumed queue parameters are as follows:

λ: Average rate of arrival. It is equal to 1/E [Inter-arrival-Time]

μ: Average service rate. It is equal to 1/E [Service-Time].

$\rho = \lambda/\mu$ for single server queues.

Pk: Probability that there are n customers in the system.

L: Average number of customers in the system.

Lq: Average number of customers in the queue.

W: Average wait in the system.

Wq: Average wait in the queue.

C: number of servers in M/M/C (2)

M/M/1 Design:

In M/M/1[12] queuing model P is the probability of subscribers in the system, which is independent of number of people in the system. If K be the type of arriving customer with probability P_k therefore

$$\sum_{K=0}^{\infty} P_K = 1 \tag{1}$$

$$L = \sum_{k=0}^{\infty} K P_K \tag{2}$$

$$L = \sum_{k=0}^{\infty} K(1-P)P^K \tag{3}$$

$$L = (1-p)\sum_{k=0}^{\infty} K P^K \tag{4}$$

$$L = (1-P)\frac{P}{(1-P)^2} \tag{5}$$

$$L = \frac{P}{1-P} \quad (P=\frac{\lambda}{\mu}) \tag{6}$$

$$L = \frac{\frac{\lambda}{\mu}}{1-\frac{\lambda}{\mu}} = \frac{\frac{\lambda}{\mu}}{\frac{\mu-\square}{\square}} \tag{7}$$

The number of customers in the system can be written as

$$L = \frac{\lambda}{\mu-\square} \tag{8}$$

From the little theory[13],

$$L=W\lambda \tag{9}$$
$$L_q=W_q\lambda \tag{10}$$

$$L_q = W_q + \frac{1}{\mu} \qquad (11)$$

$$W = \frac{L}{\lambda} = \frac{\frac{\lambda}{\mu-\square}}{\square} \qquad (12)$$

Average wait in the system can be written as

$$W = \frac{1}{\mu-\square} \qquad (13)$$

$$W_q = W - \frac{1}{\square} \qquad (14)$$

$$W_q = \frac{\mu - \square + \lambda}{\mu(\mu-\square)} \qquad (15)$$

Average wait in the queue can be written as

$$W_q = \frac{\lambda}{\mu(\mu-\square)} \qquad (16)$$

$$L_q = W_q \lambda = \frac{\lambda}{\mu(\mu-\square)}\lambda \qquad (17)$$

Average number of customers in the customers in the queue can be written as

$$L_q = \frac{\lambda^2}{\mu(\mu-\square)} \qquad (18)$$

$$L = L_S + L_q \qquad (19)$$

Average number of customers in service can be written as

$$L_S = L - L_q \qquad (20)$$

M/M/C Design:

- The arrival rate in M/M/C [14] remains as same as in M/M/1 model but the number of servers can approximate the service rate. The service rate will be nμ for n=c
- The service rate μc in the case

$$\mu_c =$$
$$\{(\square\square)\ \square < \square\ \square\square\square\ \square -1,2,\ldots..\ \square\ (\square\square)\ \square > \square\ \square\square\square\ \square = \square, \square = 1, \ldots.$$
$$\qquad (21)$$

- The probability of having n customers in the service system can be written as

$$P_n = \left(\frac{\lambda}{\mu c}\right)^n \times P_0 \qquad (22)$$

Or

$$P_n =$$
$$\left\{\left(\frac{\lambda\square}{\square(2\mu)(3\mu)\ldots\ldots(n\mu)}\right)\ \square 0\ \square\square\ \square < \right.$$
$$\square \left(\frac{\lambda\square}{\square(2\mu)(3\mu)\ldots\ldots(c\mu)(\square\square)\square-\square}\right)\ \square 0\ \square\square\ \square \geq \square$$
$$\qquad (23)$$

$$P_n =$$

$$\left\{\left(\left(\frac{1}{n!}\left(\frac{\square}{\square}\right)\square\right)\square 0\ \square\square\ \square \leq \square\ \left(\frac{1}{c!}\left(\frac{\lambda}{\mu}\right)\ \square\ \left(\frac{\square}{c\mu}\right)\square -\right.\right.\right.$$
$$\left.\square\ \right)\ \square 0\ \square\square\ \square > \square$$
$$\qquad (24)$$

$$L_q = \sum_{n=c}^{\infty} (n-c)P_n \qquad (25)$$

$$L_q = \sum_{j=0}^{\infty} jP_{c+j} \qquad (26)$$

P_{c+j} can be written as

$$P_{c+j} = \left(\frac{\lambda}{\mu} + \frac{\lambda}{2\mu} + \cdots + \frac{\lambda}{c\mu}\right)\left(\frac{\lambda}{c\mu}\right)^j P_0$$

$$\text{Or } P_{c+j} = \frac{(\rho)}{c!\square\square}\rho^j P_0 \qquad (27)$$

$$\text{Hence, } L_q = \sum_{j=0}^{\infty} j\left(\frac{\rho}{c}\right)^{j-1} \qquad (28)$$

which can be written as

$$L_q = \left(\frac{\rho\square+i}{\square\square}\right)\times P_0 \times \left(\frac{\delta\left(\sum_{j=0}^{\infty}\left(\left(\frac{\rho}{c}\right)\square\right)\right)}{\delta\left(\frac{\square}{c}\right)}\right) \qquad (29)$$

$$L_q = \left(\frac{\rho\square+i}{\square\square}\right)\times P_0 \times \left(\frac{\delta\left(\frac{1}{1-\frac{\rho}{c}}\right)}{\delta\left(\frac{\square}{c}\right)}\right) \qquad (30)$$

$$L_q = \left(\frac{\rho\square+i}{(\square-i)!(\square-\square)2}\right)P_0 \qquad (31)$$

$$W_q = \frac{\square\square}{\square} \qquad (32)$$

$$W = W_q + \frac{1}{\mu} \qquad (33)$$

The number of customers in the service system,

$$L = \lambda W \text{ (using little's law)}$$

$$L = \lambda W_q + \frac{\lambda}{\mu} \qquad (34)$$

III. RESULT AND DISCUSSION

From equation (20) the average number of customers (L_s) is determined. The average number of customers (L_q) in a queue is determined from equation (18). The average waiting time of customers in the queue (W_q) is determined from equation(16). The mean waiting time of customers in the system (W) is determined by equation (13). The values are tabulated and compared.

Table I: Queue parameters from one agent for M/M/1 and M/M/C

S/no	Networks	Avg no of arrival rate (busy hr)	Avg no. of customers arriving at one agent	Avg service time (min) for M/M/1	Avg service time (min) for M/M/C
1	NETWORK 1	55	5	14.8	5.8
2	NETWORK 2	74	4	12.5	4.9
3	NETWORK 3	63	3	9	4
4	NETWORK 4	78	6	15	7.5

Table 2: Derived parameters for M/M/1 and M/M/C models

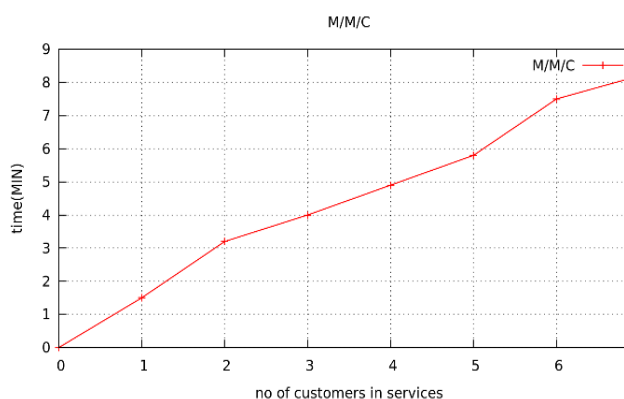| MODELS	Customers in queue (Lq)	Customers in service (Ls)	Wait in queue (Wq)	Wait in system (W)
M/M/1	6.1	1	10.5	17.8
M/MC	3.8	2	6	10

Table 3: Comparison of total time taken by customers in M/M/1 and M/M/C models.

Networks	Total no of customers	Total Time M/M/1 (min)	Total Time M/M/C (min)
Network 1	55	137.511	82.490
Network 2	74	185.052	111.163
Network 3	63	157.543	094.551
Network 4	78	195.214	117.005

In M/M/1 model the number of customers in service is compared with time in minutes as shown in fig4.
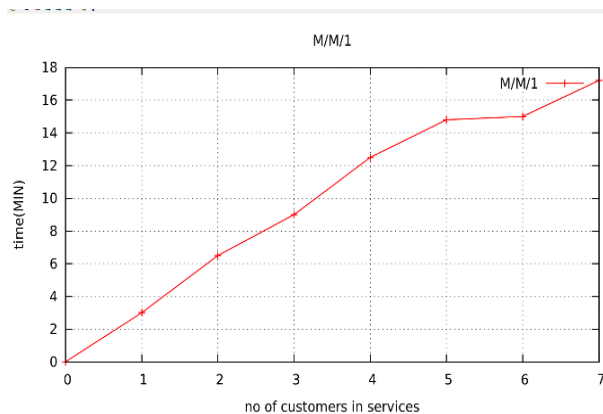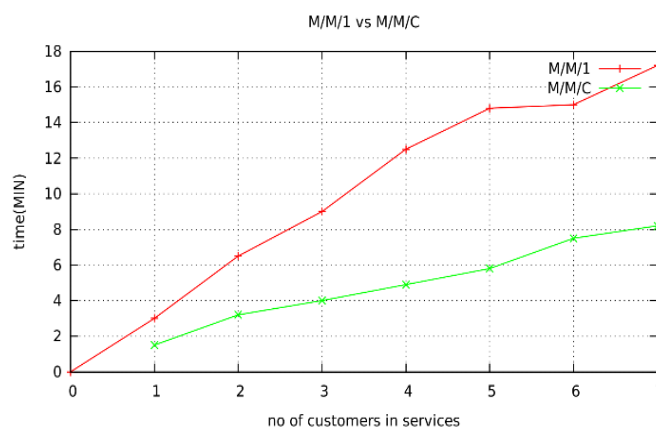

Fig.4. No of customers in service vs time in min (M/M/1)

Fig.5. No of customers in service vs time in min (M/M/C)

In M/M/C model the number of customers in service is compared with time in minutes is shown in fig.5. The service is done using C-Servers (2 servers). Considering an average of 7 users serviced in both the models, it was found that use of multiple servers (M/M/C) notably decreased the service time.

Fig.6: Comparison of M/M/1 and M/M/C

The comparison of M/M/1 and M/M/1 is shown in fig.6. Where x axis is time in minutes and Y-axis is number of customers in service.
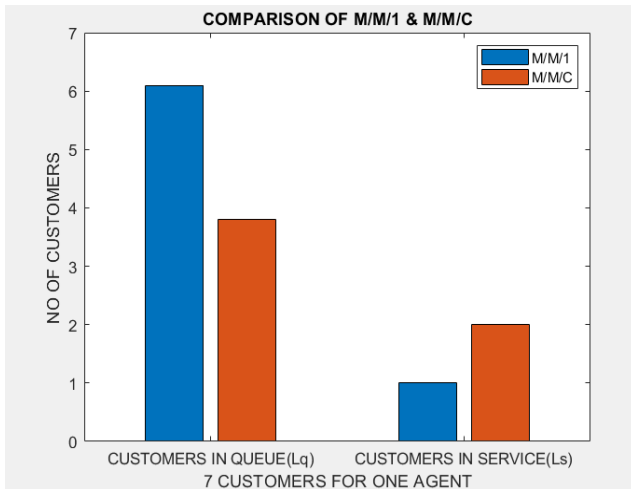
Fig.7:Comparison of L_q and L_s vs no of customers

In fig.7. The graph shows the comparison of M/M/1 & M/M/C. The X -axis shows the customers in queue (Lq) and customers in service (L_s) and Y axis shows no of customers.
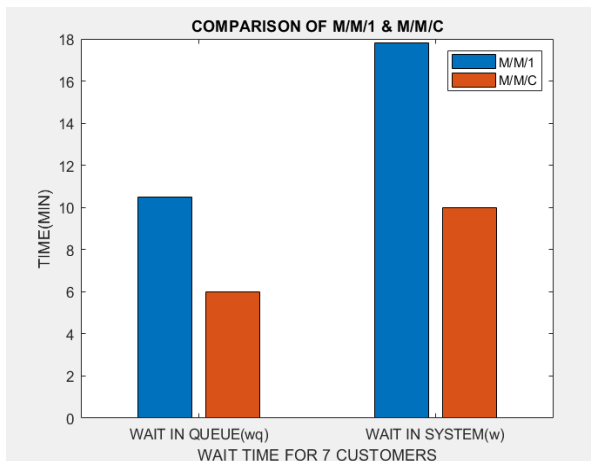

Fig.8: Comparison of W_q & W vs time (min)

In Fig.8. the graph shows comparison of M/M/1 & M/M/C. The X-axis shows the wait in queue (Wq) and wait in system (W) and Y-axis shows the time in mins. M/M/C exhibited considerably low values in both the parameters.
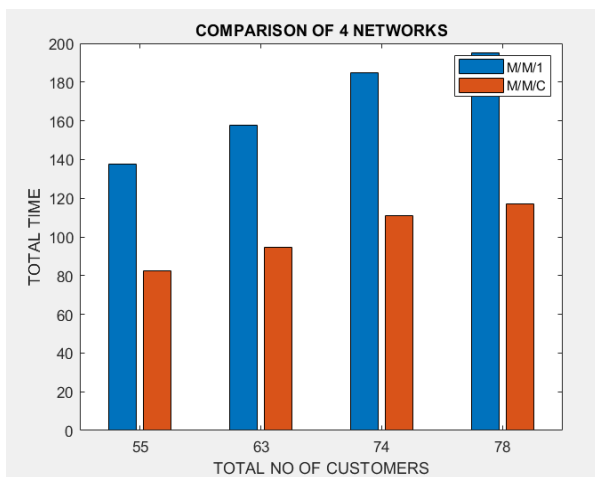

Fig.9. Total no of customers vs total time in mins

The above fig 9 shows total time taken by different number of customers in four different networks by M/M/1 models.
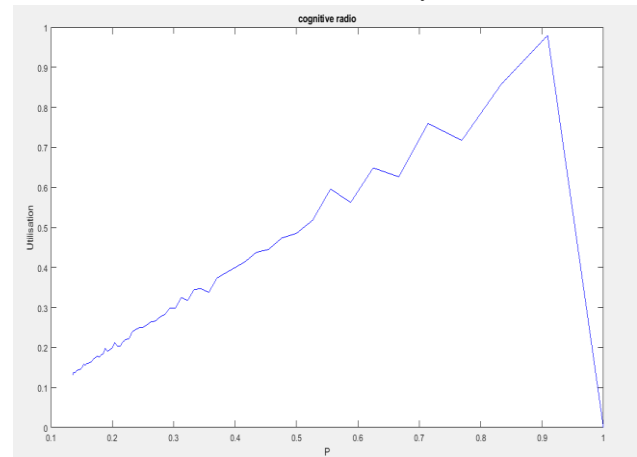

Fig.10. Probability of spectrum detection vs utilization of spectrum

The above fig.10. is a plot of probability of spectrum detection vs utilization of spectrum. From the plot it is found that the probability for effective utilization of the spectrum gradually increases except for a few values. But the probability that spectrum will be utilized fully is too low and hence the slope for probability value of 1.

IV. CONCLUSION

After analyzing the data obtained from different service providers, the samples were implement in a cognitive radio based queuing models. The two models taken into consideration were M/M/1 and M/M/C. After thorough analyzation and estimation of different parametric values of both M/M/1 and M/M/C models, we obtained various results which were discussed in the previous sections. It was found that M/M/1 model has a single server so it takes more time to serve the customers than M/M/C because of C- parallel servers(2 servers). The results of the waiting time of the customers are marginally reduced in the multi channels rather than the single channels, so the traffic is reduced. But M/M/C is little bit costlier because of multiservers. Therefore depending on the type of application in which we implement the cognitive radio networks (CRN) based queuing models, we can choose the M/M/1 or M/M/C or any other of the type appropriately.

REFERENCES

1. Wei Li, A.S.Alfa, "A PCS network with correlated arrival process and splitted-rating channels", IEEE Journal on selected areas in communications.,vol.17, issue.7, year.1999.
2. L.Tadj, "Waiting in line[queuing theory]", IEEEPotentials.,vol.14,issue.5, year.1996.
3. W. D. Ray and B. D. Bunday, 'Basic Queueing Theory.', *J. R. Stat. Soc. Ser. A (Statistics Soc.*, vol. 151, no. 3, p. 550, 2006.
4. Thomas R.Robbins, D.J.Medeiros, Paul Dum , "Evaluating Arrival Rate Uncertainity in Call Centers", Proceedings of the 2006 winter simulation conference.,year.2006.
5. U.Loher, "Efficiency of first-come first-served algorithms", Proceedings. 1998 IEEE International Symposium on information

theory(Cat.No.98CH36252)., year.1998.

6. A.Wyglinski, "Cognitive radio communications and networks [guest editorial]", *IEEE Commun. Mag.*, vol. 46, no. 4, pp. 30–31, 2008.

7. Zhong Chen, Feifei Gao, "Cooperative-Generalized-Sensing-Based Spectrum Sharing Approach for Centralized Cognitive Radio Networks",IEEE Transactions on Vehicular Technology., vol.65, issue.5, year.2016.

8. T.I.Aliev, I.Y.Nikulsky, V.O.Pyattaev, "Modeling of packet switching network with relative prioritization for different traffic types", 2008 10th International Conference on Advanced Communication Technology.,vol.3, year.2008.

9. Kayvan Atefi, Saadiah Yahya, Amirali Rezaei, Alireza Erfanian, "Traffic behaviour of Local Area Network based on M/M/1 queuing model using poisson and exponential distribution", 2016 IEEE Region 10 Symposium(TENSYMP).,year.2016.

10. Nourin Kadir, "Observation of the common phenomena from a MATLAB model for M/M/1 queuing system", 2015 International Conference on Advances in Electrical Engineering (ICAEE)., year.2015.

11. Yu-Bo Wang, Cheng Qian, Jin-De Cao, "Optimized M/M/C model and simulation for bank queuing system", 2010 IEEE International Conference on Software Engineering and Service Sciences., year.2010.

12. O. O. A. and O. O. F., 'Effective Utilization of Mobile Call Center Using Queuing Models', *Int. J. Eng. Technol.*, vol. 8, no. 2, pp. –111, 2015.

13. P.Gao, S.Wittevrongel, K.Laevens ,D.De Vleeschauwer, H.Bruneel, "Distributional little's law for queues with heterogeneous server interruptions", Electronics Letters., vol.46, issue.11,year.2010.

14. C. E. Chuka, C. D. Ezeliora, U. P. Okoye, and O. J. Obiafudo, 'Analysis of a queuing system in an organization (a case study of First Bank Plc, Nigeria)', *Am. J. Eng. Res.*, vol. 3, no. 2, pp. 67–72, 2014.

AUTHORS PROFILE

Sharanya C received M.E. degree in Embedded Systems from Sathyabama University, Chennai. She is currently working as an Assistant Professor and is a part time PhD research scholar in Vels Institute of Science, Technology and Advanced Studies, Chennai. Her research interests include Wireless Networking, Spectrum Analysis, and Software Defined Radio etc. She is currently the Member of IEEE, Member of Institution of Electronics and Telecommunication Engineering (IETE), India and also has several memberships in electronics society and she has published several papers in national and international journals.

Rajendran V finished his UG degree from Madurai Kamaraj University, and then received M. Tech. degree from IISC Bangalore, and completed his Ph.D. degree from Chiba University, Japan, in 1993. He was closely associated with different organizations and institutions such as National Institute of Ocean Technology (Chennai), Indian Institute of Technology (Chennai), IIS (Bangalore), SSN College of Engineering (Chennai) etc. He currently serves as the director of ECE department in Vels Institute of Science, Technology and Advanced Studies, Pallavarm, Chennai.