IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received February 26, 2019, accepted March 12, 2019, date of publication March 20, 2019, date of current version April 13, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2906469

Efficient Spectrum Management Techniques for Cognitive Radio Networks for Proximity Service

S. NANDAKUMAR[1], T. VELMURUGAN[1], UTTHARA THIAGARAJAN[1], MARIMUTHU KARUPPIAH[2], (Senior Member, IEEE), MOHAMMAD MEHEDI HASSAN[3,4], (Senior Member, IEEE), ABDULHAMEED ALELAIWI[3,4], AND MD. MOTAHARUL ISLAM[5]

[1]School of Electronics Engineering, Vellore Institute of Technology, Vellore 632014, India
[2]School of Computer Science and Engineering, Vellore Institute of Technology, Vellore 632014, India
[3]Research Chair of Smart Technologies, King Saud University, Riyadh 11543, Saudi Arabia
[4]College of Computer and Information Sciences, King Saud University, Riyadh 11543, Saudi Arabia
[5]Department of Computer Science and Engineering, BRAC University, Dhaka 1212, Bangladesh

Corresponding author: Mohammad Mehedi Hassan (mmhassan@ksu.edu.sa)

This work was supported by the Deanship of Scientific Research at King Saud University through Vice Deanship of Scientific Research Chairs: Chair of Smart Technologies.

ABSTRACT Cognitive radio networks improve spectrum efficiency by employing vigilant and accurate spectrum management techniques. This is done to enable an unlicensed user to use the underutilized spectrum. Spectrum sensing determines if a spectrum hole exists for the unlicensed user, this is accomplished using various techniques such as energy detection, minimum Eigen value detection, and matched filter technique. Conventional energy detection techniques do not achieve high values of detection; hence an improved adaptive energy detection technique has been proposed to improve the efficiency. The proposed methodology exhibits better numerical results than conventional techniques. Another important spectrum management procedure is spectrum handoff. The concept of multiple attributes for decision making was implemented, under which, the simple additive weights method and the technique for order preference by similarity to ideal solution method were compared based on a performance involving the triple play of services.

INDEX TERMS Adaptive energy detection, cognitive radio networks, spectrum handoff, spectrum sensing.

I. INTRODUCTION

Spectrum efficiency is a major factor when designing an ideal network. With the number of users increasing exponentially, maximum utilization of the available spectrum is the need of the hour. Cognitive radio networks address this issue by using a concept where the spectrum can be used by unlicensed users in the absence of licensed users to provide maximum spectrum efficiency [1]. To ensure the smooth operation of such a system the network must exhibit intelligence and agility to cope with rapid changes in the spectrum environment [2].

This is achieved by using dynamic spectrum access which allows users to access spectrum bands in an opportunistic manner through continuous sensing and selection [3]–[4]. Spectrum management firstly involves sensing the spectrum to determine when the licensed user is absent. It also includes spectrum handoff which is initiated when an unlicensed user has to be handed off to another band due to the arrival of the licensed user. Determination of the spectrum holes, selecting the best network for the service at play have to be executed accurately, and in a short time span to warrant efficiency [5].

Spectrum sensing is the process of sensing the spectrum and detecting the presence of a primary user, if absent, the secondary user is permitted to use the spectrum. Conventional techniques include matched filter method which exhibits high performance at low SNR but prerequisite knowledge of the primary signal is required for accurate results [6]. Another method is Eigen value detection where Eigen values are extracted from the input signal covariance matrix and are then compared to the energy of the sample received to determine the presence of the licensed user. This method is advantageous as prior knowledge of the primary user is not necessary, however computational complexities may increase the time span of sensing [7].

Energy detection is one of the most popular spectrum sensing techniques due to low cost and low computational complexities. The energy of the sensed signal is compared with the given threshold to ascertain if the secondary used can be allowed to use the spectrum [8]. Fixed threshold methods may fail to sense the spectrum

The associate editor coordinating the review of this manuscript and approving it for publication was Md Zakirul Alam Bhuiyan.

accurately due to noise uncertainties, this can be combated using adaptive thresholds for energy detection based on the signal to noise ratio [9]–[10].

Spectrum handoff follows spectrum sensing in the event of the arrival of a primary signal. When this occurs, the secondary user has to scan the available free networks and select the one that would produce optimal results for the service at play [11]. Once the selection has been made, the secondary user can shift to the new network for uninterrupted service [12]–[13]. Multiple attributes decision making is a technique where the various attributes of the available networks are validated and the best network is chosen. Algorithms such as simple additive weight, technique for order preference by similarity to ideal solution assess the networks to select the one that exhibits the characteristics best suited for the service at play [14]–[15].

This paper is organized as follows: Section 1 deals with spectrum sensing and the various techniques involved, section II consists of spectrum handoff using MADM techniques, section III comprises of results and discussions of the study, section IV concludes the paper.

II. MATERIALS AND METHODS

A. SPECTRUM SENSING

1) MATCHED FILTER

A matched filter is a linear filter which specializes in decreasing the noise component and maximizing the signal component of the signal. Thus, it improves the signal to noise ratio and is one of the best suited sensing technique in an AWGN environment.

The received signal was passed through a band pass filter that amplifies the signal and suppresses the noise component. This will ensure a definite contrast between signal and noise. It was then passed through a matched filter where, if the signal is present, the results will show a large peak. No such peak will be observed if the primary user is absent. Following this, the association between the determined sensing threshold and the output of the matched filter is used to ascertain the existence of the licensed user. Methodology for the matched filter method is given below:

a: COMPUTATION TEST STATIC FOR MATCHED FILTER

$$T_{stat} = \sum_{N} v\,(n)\,x^{*}u\,(n) \tag{1}$$

In eq. (1), v(n) is the signal that the system receives for sensing, and u(n) is the pilot that contains prerequisite knowledge of the licensed user signal used for synchronization purposes.

b: DETERMINATION OF PROBABILITIES OF ACCURATE DETECTION P(D) AND FALSE ALARM P (F)

$$\mathrm{P(d)} = \mathrm{Q}\left(\frac{\delta - E}{\sqrt{\mathrm{E}\gamma_{\mathrm{w}}^{2}}}\right) \tag{2}$$

$$P(f) = Q\left(\frac{\delta}{\sqrt{E\gamma_{w}^{2}}}\right) \tag{3}$$

In eq. (2), E is the energy of the sample from the PU signal and δ is the threshold used to compare energy levels. The probability of detection P(d) is the probability of the system identifying the presence of the licensed user accurately. Whereas, P(f) is the probability of the system stating that the channel is busy when in actuality, the channel is idle.

c: ESTIMATION OF SENSING THRESHOLD

It is given by eq. (4) as a function of PU signal energy and noise variance (γ_{w}^{2}).

$$\delta = Q^{-1}(P(f)\sqrt{E\gamma_{w}^{2}} \tag{4}$$

d: COMPARISON TO DETERMINE THE PRESENCE OF PU

The estimated threshold from eq. (4) is then compared with the test static from (1) to determine the presence of the primary user. If the test static's value is higher than that of the sensing limit then the primary user is currently occupying the spectrum hole otherwise, the channel is idle.

2) MINIMUM EIGEN VALUE

Eigen values of the covariance matrix constructed using the received signal can be used to detect the presence of the primary user using the minimum Eigen value detection algorithm. The test static in this case is the relation between the least Eigen value and the power of the noise signal. This methodology has a higher Pd at low SNR when compared to other approaches like Maximum eigenvalue detection. One of the main advantages of this method is that prior information of the licensed consumer is unnecessary to obtain accurate results. The algorithm is as follows:

a: CONSTRUCTION OF COVARIANCE MATRIX X

Covariance matrix is constructed as shown in eq. (5)

$$X = \begin{bmatrix} x\,(N) & 0 & 0 \ldots & & \ldots 0 \\ x\,(N-1) & x\,(N-1) & 0 \ddots & & \ddots \vdots \\ \vdots & \vdots & \vdots \ddots & & \ddots \vdots \\ \vdots & \vdots & \vdots \ddots & & \ddots \vdots \\ \vdots & \vdots & \vdots\ \vdots & \ddots & \vdots \\ \vdots & \vdots & \vdots\ \vdots & \vdots & x\,(N-L+1) \\ \vdots & \vdots & \vdots\ \vdots & \vdots & x\,(\text{N-L}) \\ \vdots & \vdots & \vdots\ \vdots & \vdots & x\,(N-L-1) \\ \vdots & \vdots & \vdots\ \vdots & \vdots & \vdots \\ x\,(1) & x\,(1) & x\,(1) \ldots & & \ldots x\,(1) \end{bmatrix}_{NXL}^{r} \tag{5}$$

With R number of signal samples received from the receiver with (L = 4) smoothing factor and where x(n) is the sample of the signal sensed by the system.

b: CALCULATION OF SAMPLE COVARIANCE MATRIX

The sample covariance matrix of the received signal is calculated by using eq. (6).

$$Sx = \frac{1}{R}(XX^T) \tag{6}$$

c: CALCULATION OF EIGEN VALUES OF MATRIX S

Eigen values are essential in signal processing as they help ascertain the noise in the signal samples by estimating the degree of similarity between the samples. They are described as the values of γ when the determinant of the given matrix $(X - \gamma * \mathrm{I})$ is equal to zero. From this, the minimum and maximum Eigen values are calculated.

d: DECISION

If the relational value is comparatively lower than the energy received then the secondary user is not permitted to use the channel, if not, then the channel is free to be utilized.

3) ENERGY DETECTION WITH ADAPTIVE THRESHOLD

This method compares the estimated energy of the received signal to a sensing energy limit to assess the presence of the licensed user. The energy detector does not have a high implementation cost and the computational complexities are lower than that of the minimum Eigen value method. In the conventional fixed threshold method the received signal energy is equated with a theoretical fixed threshold which does not depend on the signal to noise ratio. This leads to obtaining inaccurate results as noise uncertainties are not taken into account. Hence the method implemented introduces a concept of adaptive threshold where the threshold is evaluated with the SNR at that instance taken into consideration. The adaptive threshold method is realized as follows:

a: CALCULATION OF THEORETICAL THRESHOLD

The theoretical threshold is calculated in eq. (7) using the inverse Q function of the probability of false alarm (Pf) and the number of samples (L = 1000)

$$\mathrm{E_{i}} = \left(\mathrm{Q}^{-1} * \left(\frac{\mathrm{P_f^i}}{\sqrt{\mathrm{L}}}\right)\right) \tag{7}$$

b: ESTIMATION OF ADAPTIVE THRESHOLD

The adaptive threshold is estimated using the theoretical threshold, the noise power (σn) and the SNR as shown on eq. (8).

$$\mathrm{E_{i'}} = \frac{\frac{2}{\mathrm{L}}\ln(\mathrm{Ei}) + \ln(1+\mathrm{SNR})}{\frac{\mathrm{SNR}}{\sigma_n^2(1+\mathrm{SNR})}} \tag{8}$$

$\mathrm{E_{th1}} = \mathrm{E_i}$' and $\mathrm{E_{th2}} = 25 * \mathrm{E_{th1}}$. $\mathrm{E_{th1}}$ and $\mathrm{E_{th2}}$ represent the lower and upper threshold levels respectively.

4) DETERMINING THE ENERGY OF THE RECEIVED SIGNAL

The energy of the received signal is estimated to be compared with the threshold. The received signal can either comprise of just noise in the absence of the primary user or it could contain the energy of both the noise and the primary signal.

5) COMPARISON WITH THRESHOLD TO ARRIVE AT DECISION

If energy of sampled signal, $\mathrm{E} > \mathrm{E_{th2}}$, it is concluded that the PU occupies the channel. If $\mathrm{E} < \mathrm{E_{th1}}$, the decision is that the channel is available. If $\mathrm{E_{th1}} < \mathrm{E} < \mathrm{E_{th2}}$, spectrum sensing is executed once more as this is considered as the region of indecisiveness. Once the spectrum holes are sensed, the secondary user can occupy the band that's best suited for the service at use. This can be achieved using spectrum handoff, where the attributes of the available bands are analyzed to select the best option.

B. SPECTRUM HANDOFF PROCESS

Cognitive Radio Networks (CRN) focus to enable secondary users (SU) to use unutilized primary user's (PU) spectrum bands and thereby resolve spectrum scarcity. Spectrum sensing and spectrum handoff are critical operations of CRN.

For the proper operation of the CRN, the SU nodes must be able to sense the environment, select the best channel from the available choices for utilization, coordinate handoff in case of arrival of PU and ensure uninterrupted services [16]–[17]. It is also important for the SU to maintain the Quality of Service (QoS) above the minimum threshold during all these operations. Once the SU occupies a spectrum hole, it keeps sensing the environment to detect the arrival of a PU. In case of arrival of the PU, spectrum handoff is triggered. The SU has to vacate the current band to facilitate PU occupation. Out of the other available spectrum holes, the SU chooses the optimum band for spectrum handoff, such that the QoS is satisfactory. The main principle behind spectrum handoff is that when the primary user arrives at the licensed band which is occupied by the secondary user, the secondary user has to vacate the spectrum and switch the communication link to an unoccupied channel to avoid interrupting the transmission of the primary user as well as its own. Based on the fluctuating nature of the available spectrum, the secondary user faces a number of challenges. These include sensing the available spectrum holes, evaluating them based on various attributes and finally selecting one that's best suited for the service required.

Spectrum handoff happens quickly when a PU touches base on a channel involved by a SU is shown in Fig.1. The SU at that point moves from its present channel to an objective channel. Spectrum handoff is categorized in to five processes as follows,

1) Number of considerable channel is ch1, ch2, ch3 and ch4. Two of SUs (SU1 and SU2) users are arriving to ch3, remaining are busy in this state as shown in Fig. 1.
2) Handoff triggering is required when the PU approaches the channel. SU1 direct information to SU2.
3) Further transmission of SUs to be continued to search the available channel such as proactive and reactive handoff from ch3 to ch4.

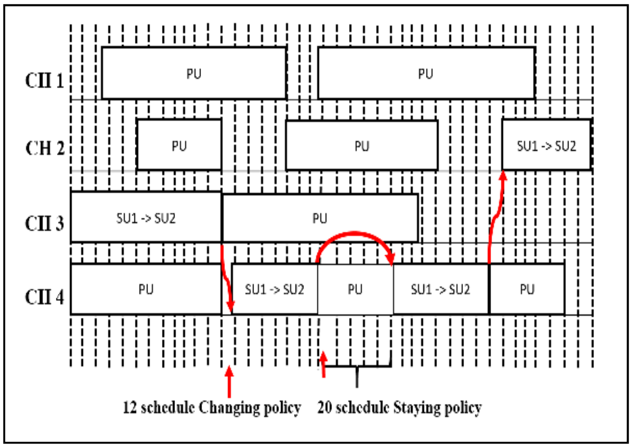

FIGURE 1. Transmission of primary and secondary users in different channels.

4) Based on staying policy after 24th slot, SU to stay in the same channel when PU transmission time is smaller than SU.
5) Process will be repeated if SU is interrupted in different time slot by PU for multiple handoff due to transmission.

These five steps determine the mechanism of spectrum handoff, as elaborated in Fig. 1.

Multiple Attribute decision making (MADM) are mathematical techniques that deal with solving decision problems based on some decision criteria. These procedures are used to select a suitable network from a finite number of alternatives offered. The alternative is selected based on characteristic attributes and the relation with other attributes.

Some of the main algorithms are SAW (Simple additive weighting), TOPSIS (Technique for order preference by similarity to ideal solution). The resulting outcome is a network ranking distribution of the alternatives to determine the ideal network. According to results, the correlation to the ideal solution is high due to the effective calculation of estimated weights. It is proved that SAW and TOPSIS method are two of the most ideal methods for MADM. In a MADM problem, each row is determined as n alternatives and each column is represented as m criteria. Subjective weights are assigned to every criterion. The multiple attributes matrix, D, which is also known as decision table is computed using eq. (9)

$$D = \begin{matrix} A1 \\ A2 \\ \vdots \\ \vdots \\ \vdots \\ Am \end{matrix} \begin{bmatrix} A11 & A12 & \vdots & \vdots & \vdots & \vdots & A1n \\ A21 & A22 & \vdots & \vdots & \vdots & \vdots & A2n \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & Aij & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ Am1 & Am2 & \vdots & \vdots & \vdots & \vdots & Amn \end{bmatrix} \tag{9}$$

For deliberation, networks such as WiMAX, Wi-Fi, Cellular and Satellite were considered. The multiple attributes for the

TABLE 1. Multiple attributes for Various CR Networks.

Networks	Attributes			
	D	DR	PLR	P
WiMAX	60	35	25	15
Wi-Fi	50	11	30	8
Cellular	30	2	50	40
Satellite	200	2	80	8

selected networks considered are the delay (milliseconds), data rate (Mbps), Packet Loss Ratio (PLR) (per10^6) and price (per unit) as shown in Table 1. These attributes are the main factors that affect the performance of a service from the user's point of view hence they play a vital role in the decision-making process.

1) SUBJECTIVE ENTROPY WEIGHTS ESTIMATION ALGORITHM

The weights for the MADM procedure are estimated using entropy method. The entropy method is selected as there are no computational complexities involved. The weights are calculated using the attributes entropy. The steps involved are:

a: ESTIMATION OF THE MULTIPLE ATTRIBUTES NORMALISED VALUE

$$v(i,j) = \left(\frac{A(i,j)}{\sqrt{\sum A(i,j)^2}} \right) \tag{10}$$

In eq. (10), i ranges from 1 to m and j ranges from 1 to n where A(i,j) is the attributes matrix from eq. (9)

b: ENTROPY ESTIMATION

The entropy of the multiple attributes is calculated as follows:

$$yj = \left[-\frac{1}{\ln(n)} \right] * \sum_{i=1}^{m} [v(i,j) * \ln(v(i,j))] \tag{11}$$

c: CALCULATION OF THE DEVIATION

The deviation from the entropy is calculated as follows:

$$ej = 1 - yj \tag{12}$$

d: COMPUTATION OF WEIGHTS COEFFICIENTS

The weights from eq. (13) are used to evaluate the attributes.

$$cj = \frac{ej}{\sum\limits_{j=1}^{n} ej} \tag{13}$$

e: SUBJECTIVE WEIGHTS

$$cj = \frac{(ejcj)}{\sum_{j=1}^{n} ej} \tag{14}$$

For subjective weights, the proffered weights are calculated keeping in mind the constraints of each service. The triple play services, as in, voice, data and video have been considered.

2) TECHNIQUE FOR ORDER PREFERENCE BY SIMILARITY TO IDEAL SOLUTION METHOD (TOPSIS)

Based on the range of attributes available for the alternatives, the preferred option should have the shortest possible distance from the positive idyllic solution and the longest possible distance from the negative idyllic solution. The methodology for the TOPSIS method is shown in Fig 2:

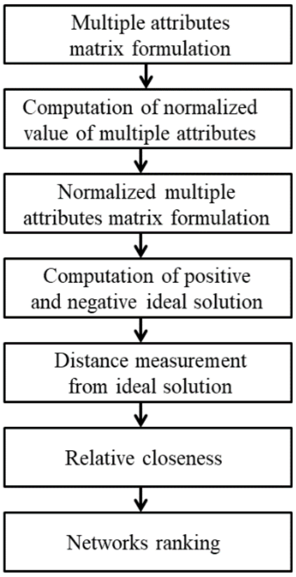

FIGURE 2. Flowchart for the TOPSIS algorithm.

a: COMPUTATION OF THE MULTIPLE ATTRIBUTES MATRIX

The multiple attributes matrix, D is formulated from eq. (9), with m alternatives and n attributes.

b: CALCULATION OF NORMALIZED VALUE OF MULTIPLE ATTRIBUTES

v(i,j) is the normalized value which is computed using eq. (15)

$$v(i,j) = \frac{A(i,j)}{\sqrt{\sum_{i=1}^{m} A(i,j)^2}} \tag{15}$$

c: CONSTRUCTION OF THE NORMALIZED MULTIPLE ATTRIBUTES MATRIX

The weighted normalized multiple attributes matrix is computed by multiplying v(i,j) values with the corresponding weight Cj from eq. (13).

$$N^n = v(i,j) * Cj \tag{16}$$

d: CALCULATION OF POSITIVE AND NEGATIVE IDEAL SOLUTIONS

The positive and negative ideal solutions can be ascertained using eq. (17).

$$N+ = (N1+, N2+, \ldots Nn+)$$
$$N- = (N1-, N2-, \ldots Nn-) \tag{17}$$

where N+ is the minimum and N- is the maximum value of the ith column of weighted normalized matrix from step3.

e: DETERMINATION OF DISTANCE FROM IDEAL SOLUTION

The Euclid alternative distance of each attribute from the positive and negative ideal solutions are measured by eq. (18)

$$N_i^{+dist} = \sqrt{\sum_{j=1}^{n} \left(N_{handoff}^{n} - Ni^{+}\right)^2}$$
$$N_i^{-dist} = \sqrt{\sum_{j=1}^{n} \left(N_{handoff}^{n} - Ni^{-}\right)^2} \tag{18}$$

f: CALCULATION OF RELATIVE CLOSENESS

Determines the relative closeness of each attribute of each network is to the ideal solution is given in eq. (19).

$$Ri = \frac{N_i^{-dist}}{N_i^{-dist} + N_i^{+dist}} \tag{19}$$

g: COMPUTATION OF NETWORKS RANKING

The networks are then systematically arranged in descending order of relative closeness values of Rj from which the best network is selected. The optimal network for spectrum handoff is the network with the highest value of relative closeness Ri from eq. (19).

3) SIMPLE ADDITIVE WEIGHTING METHOD (SAW)

SAW method also known as weighted linear combination or scoring method, is a simple and most widely used MADM method. The algorithm for SAW is shown in Fig. 3:

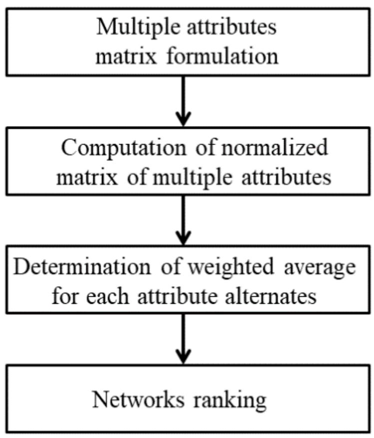

FIGURE 3. Flowchart for Simple Additive weights algorithm.

a: FORMULATION OF THE MULTIPLE ATTRIBUTES MATRIX

The multiple attributes matrix consisting of alternatives and attributes is constructed using (9).

b: COMPUTATION OF NORMALIZED MATRIX

The normalized value for positive attributes is determined where Ajmax is maximum value in each respective jth column.

$$v(i,j) = \frac{A(i,j)}{Ajmax} \tag{20}$$

c: ESTIMATION OF WEIGHTED AVERAGE

The weighted average for each alternative is calculated by multiplying v(i,j), the normalized weighted matrix with Cj, the weight determined by the entropy method as shown in eq. (21).

$$Wi = \sum v(i,j) * Cj \tag{21}$$

d: RANKING OF NETWORKS

Arranging the networks in descending order of the weighted average values from eq. (21). Thus the network with the top value of Ai is preferred as an ideal network for the spectrum handoff.

III. RESULTS AND DISCUSSION

A. MATCHED FILTER TECHNIQUE

Fig 4. Illustrates the variation in probability of detection with SNR received by SU for adaptive threshold. It is clearly observed that probability of detection increases consistently under the proposed adaptive threshold scheme. Thus, matched filter sensing achieves high performance under low SNR conditions and low sample numbers.

B. MINIMUM EIGEN VALUE ALGORITHM

The results illustrated for Minimum Eigen Value detection, in Fig. 5, show that the probability of detection is higher for the minimum Eigen value detection algorithm when compared to other conventional Eigen value techniques. This is due to the fact that maximum Eigen values vary more rapidly in comparison to minimum Eigen values for a given SNR [7]. Hence for a steady and precise sensing the minimum Eigen value is preferred.

C. ENERGY DETECTION WITH ADAPTIVE THRESHOLD RESULTS

An adaptive threshold energy detection method is executed to boost the result of spectrum sensing at low SNR region. Simulation results from Fig.6 show that the proposed system exhibits better performance than the fixed threshold system in terms of probability of detection. This process is executed for a range of SNR values from -20dB to 0dB. Over 1000 samples are taken into account. Results were generated for P(f) of 0.01 and 0.1. Pf is the probability of the technique stating that the channel is unavailable while it is actually idle. Hence reducing P(f) improves results considerably. Fig. 6 illustrates the variation in probability of detection with SNR received by SU for both fixed threshold and adaptive threshold. It is clearly observed that probability of detection under the proposed adaptive threshold scheme is nearly higher than the conventional fixed threshold based energy detection scheme at low SNR regions.

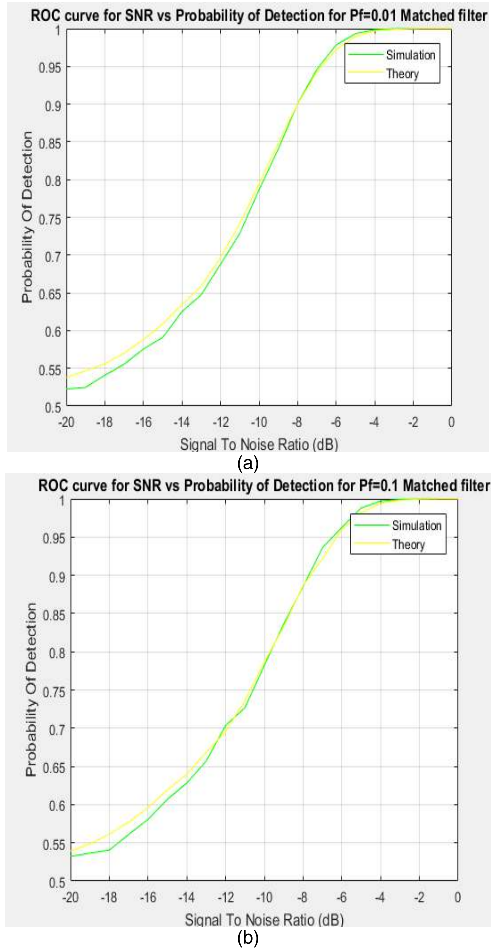

FIGURE 4. ROC curve for SNR vs. P(d) was simulated with (a) P (f) = 0.01 and (b) P (f) = 0.1.

D. SAW RESULTS

TABLE 2. Network ranking of Simple additive weights algorithm.

Networks	SAW Networks Ranking
WiMAX	0.4732
Wi-Fi	0.543
Cellular	0.6244
Satellite	0.7845
Ideal for Handoff	Satellite

E. TOPSIS RESULTS

Results obtained include optimal networks for both systems with preference (subjective weights) and systems without preference. Networks such as WiMAX, Wi-Fi, Cellular and Satellite were considered for evaluation. Fig 7and Fig 8 illustrate the SAW and TOPSIS ranking for networks using objective weights with no preference. The SAW method prefers the satellite network based on additive weights and the TOPSIS algorithm prefers the WiMAX network based on relative proximity to the ideal solution. WiMAX network is best suited for handoff for TOPSIS.

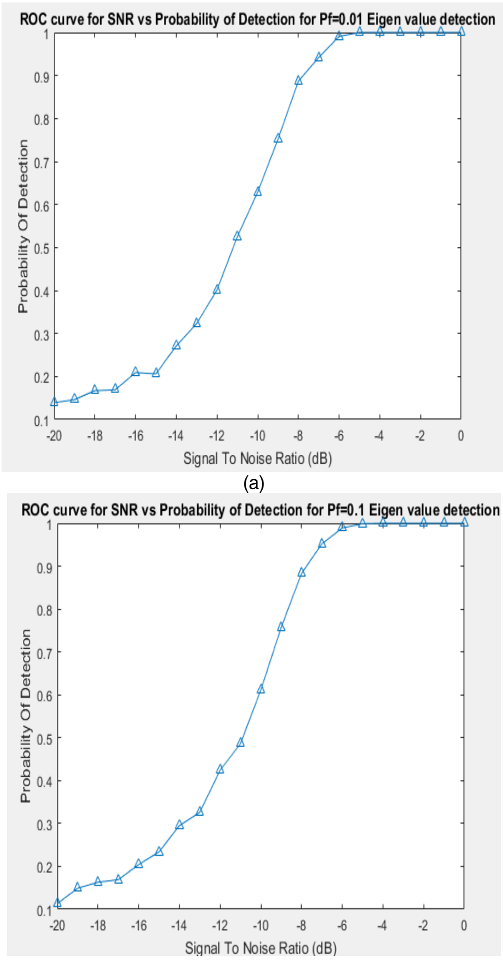

FIGURE 5. ROC curve for SNR vs. P (d) was plotted with (a) P(f) = 0.01 and (b) P(f) = 0.1.

TABLE 3. Network ranking for optimal spectrum handoff using TOPSIS algorithm in CR Networks.

Networks	TOPSIS Networks Ranking
WiMAX	0.6011
Wi-Fi	0.5830
Cellular	0.5830
Satellite	0.5123
Ideal for Handoff	WiMAX

F. TESTING OF SAW AND TOPSIS FOR TRIPLE PLAY OF SERVICES

Triple Play Services fundamentally provides 3 services over the same Internet pipe

1. High Speed Internet
2. Voice Calling

For high speed internet services, bandwidth is a major factor however, for voice services; the network with low latency is preferred. Keeping these factors in mind the subjective weights have to be calculated using the entropy method.

TABLE 4. Multiple attributes subjective weights selected for triple play services.

Services	Normalized Multiple Attributes			
	Delay	Data Rate	PLR	Price
Voice Service	0.7472	0.1131	0.0435	0.0962
Video Service	0.2069	0.6578	0.0421	0.0932
Data Service	0.2486	0.1519	0.2635	0.3360

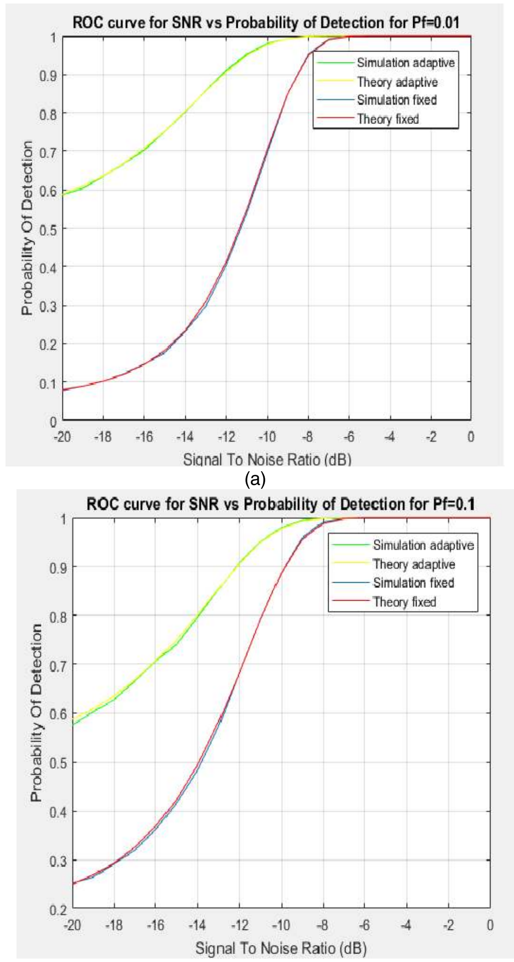

FIGURE 6. Pd vs. SNR (-20 to 0dB) for (a) P (f) = 0.01 and (b) P(f) = 0.1 (Comparison between fixed threshold method and adaptive threshold method).

The proffered weights are assigned such that the constraint with the higher priority for a particular service gets a higher weightage whereas an attribute with lower priority gets a comparatively lower weightage is shown in Fig. 9.

1) Case 1: Voice Service

The most common triple play service is voice service. Delay is considered to be the foremost factor affecting performance. The real time constraint for different weights of multiple attributes particularly for voice service is very high delay, very low bandwidth, very low PLR and very low price.

TOPSIS ranking for voice services using relative closeness to ideal solution. Fig 10 and Fig 11 provide a graphical

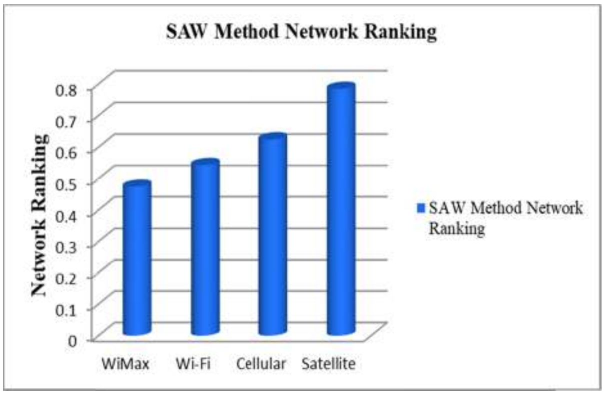

FIGURE 7. Representation of SAW network ranking for system with no preference.

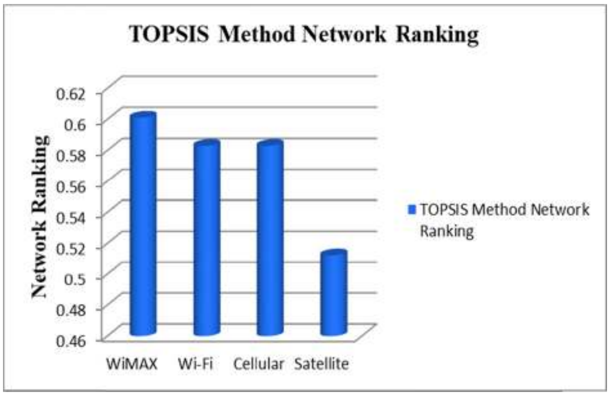

FIGURE 8. Representation of TOPSIS network ranking for system with no preference.

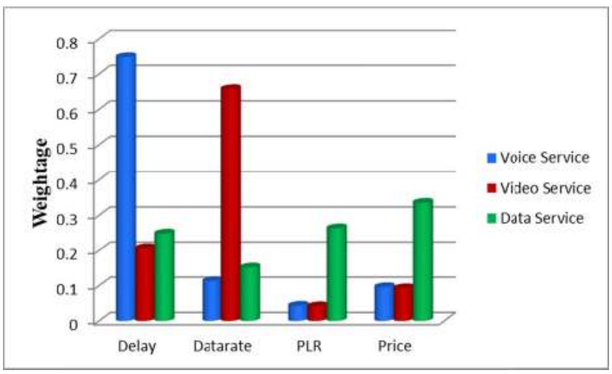

FIGURE 9. Bar graph elucidating the subjective weights assigned to each service based on constraints.

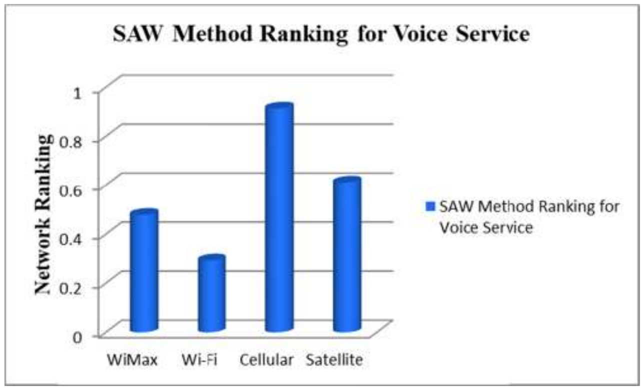

FIGURE 10. Representation of SAW Network ranking for Voice Services.

TABLE 5. SAW network ranking for delay dominant voice service.

Networks	SAW Method Ranking for Voice Service
WiMAX	0.4789
Wi-Fi	0.2931
Cellular	0.9134
Satellite	0.6113
Ideal for Handoff	Cellular

TABLE 6. TOPSIS ranking for voice services.

Networks	TOPSIS Method Ranking for Voice Service
WiMAX	0.7989
Wi-Fi	0.1563
Cellular	0.8124
Satellite	0.6203
Ideal for Handoff	Cellular

TABLE 7. Simple additive weights Algorithm ranking for video service.

Networks	SAW Method Ranking for Video Service
WiMAX	0.8567
Wi-Fi	0.8101
Cellular	0.8312
Satellite	0.8439
Ideal for Handoff	WiMax

representation of the SAW and TOPSIS ranking for voice service respectively. As delay is a dominant attribute both algorithms accurately choose cellular as the ideal network for handoff.

2) Case 2: Video Service

Video services require high speed connectivity for an efficient CR network operation. In this case, data rate is considered to be the main attribute. The real time constraint for subjective weights of multiple attributes particularly for video service are low delay, high bandwidth, very low PLR and very low price. For video services data rate has been a key factor, the results in Fig 12 and Fig 13 illustrate that the WiMAX network will appropriately cater to the user's needs according to the SAW method and TOPSIS.

Testing of TOPSIS algorithm for Video services

3) Case 3: Data Service

Data services are used to cater to mobile applications, streaming services and more. The real time constraints for different weights of subjective attributes particularly for video service are low delay, low bandwidth, medium PLR and medium price.

Testing of TOPSIS algorithm for Data services

TABLE 8. TOPSIS network ranking for Video services.

Networks	TOPSIS Method Ranking for Video Service
WiMAX	0.6241
Wi-Fi	0.2794
Cellular	0.6197
Satellite	0.4591
Ideal for Handoff	WiMAX

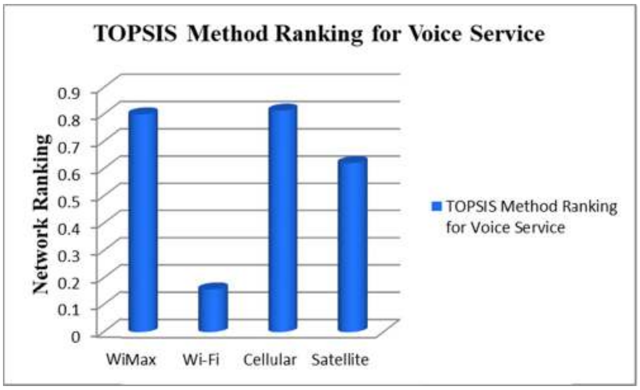

FIGURE 11. Representation of TOPSIS Network ranking for Voice Services.

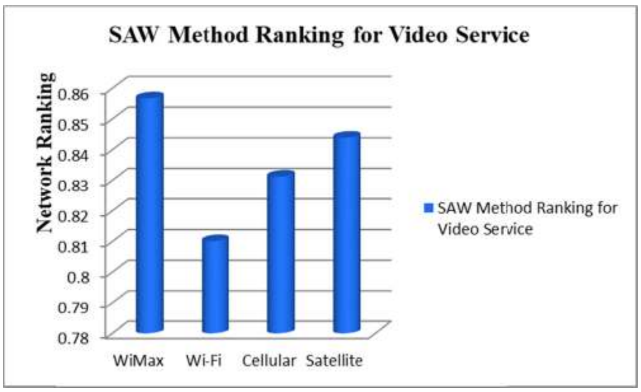

FIGURE 12. Representation of SAW Network ranking for Video Services with data rate constraint.

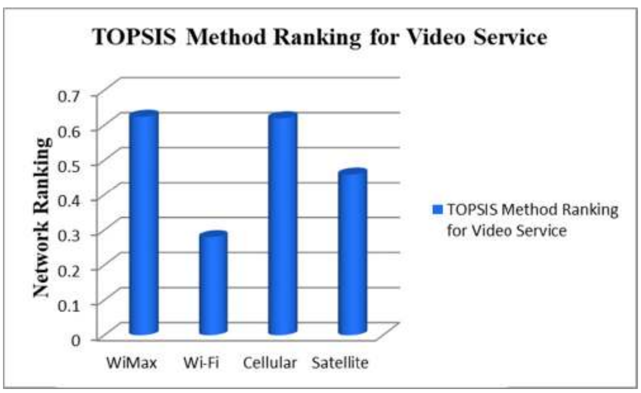

FIGURE 13. Representation of TOPSIS Network ranking for Video Services.

For data service, price and PLR are considered as the main traits. Fig 14 and Fig 15 represent the handoff decision of SAW and TOPSIS respectively. Both algorithms selected the

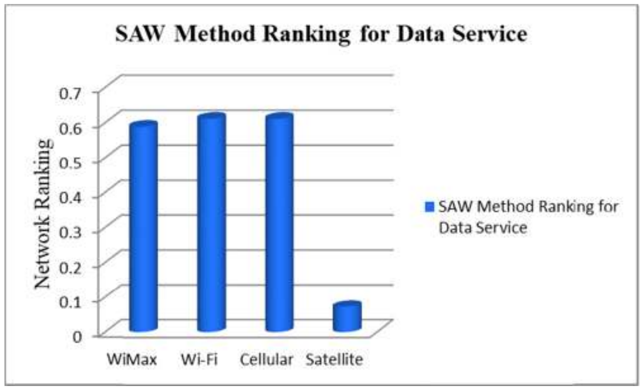

FIGURE 14. Graphical representation of SAW Ranking for Data Services.

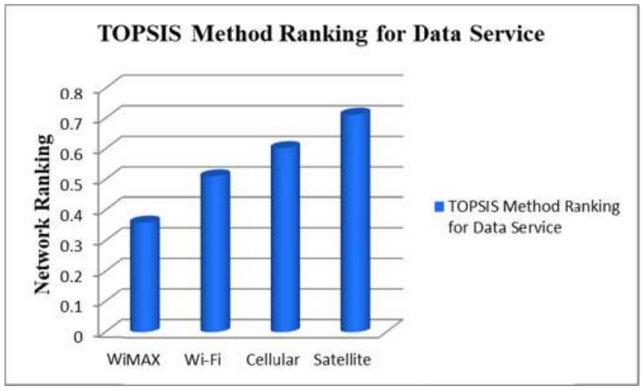

FIGURE 15. Representation of ranking when price and data rate as constraints using TOPSIS.

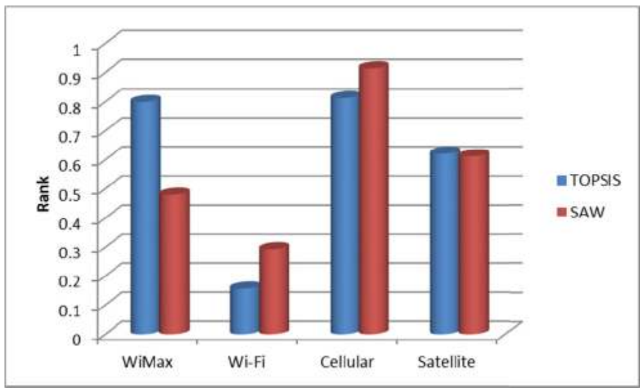

FIGURE 16. Network Rank based on SAW and TOPSIS for voice services.

TABLE 9. SAW ranking for data services.

Networks	SAW Method Ranking for Data Service
WiMAX	0.5873
Wi-Fi	0.6101
Cellular	0.6101
Satellite	0.0721
Ideal for Handoff	Satellite

satellite network that is apt for data services according to its attributes.

Fig. 16 shows that both SAW and TOPSIS accurately choose cellular as the ideal network rank based handoff for voice services.

TABLE 10. Data service ranking based on TOPSIS.

Networks	TOPSIS Method Ranking for Data Service
WiMAX	0.3578
Wi-Fi	0.5101
Cellular	0.6022
Satellite	0.7114
Ideal for Handoff	Satellite

IV. CONCLUSION

Cognitive radio networks are a breakthrough in the field of wireless communication as they address the issue of spectrum inefficiency. Accurate spectrum sensing is the first step towards an optimal network. The matched filter technique calls for prior knowledge of the primary signal which can cause issues with synchronization however, it boasts a low implementation cost. The minimum Eigen value technique overcomes the synchronization problems found in the matched filter technique but the computational complexities involved increase the execution time. Hence the adaptive energy detection technique proves to be advantageous as no prior knowledge is required and the computations are fairly simple. The high values of Pd and the consideration of the noise factor all add to the accuracy of this technique.

Spectrum handoff can be best tackled with the multiple attributes decision making algorithm as it evaluates all the available networks before recommending the most suited one. Both SAW and TOPSIS serve the purpose effectively. SAW is a commonly used method as it is not tedious to implement. Whereas TOPSIS though computationally complex exhibits highly precise results when compared to SAW. For instance when voice service is taken into account both algorithms picked the Cellular network to be ideal. And according to the attributes matrix Cellular indeed has the lowest delay, which is a key factor for voice services. This proves that the MADM algorithm is a reliable method to attain the best possible network according to user's needs.

Further work can involve implementing these schemes for particular wireless networks such as network mobility (NEMO) CR vehicular networks. Other MADM techniques such as Grey relational analysis method and cost function method can be applied to various networks to compare their performance to SAW and TOPSIS.

REFERENCES

[1] T. Yucek and H. Arslan, "A survey of spectrum sensing algorithms for cognitive radio applications," *IEEE Commun. Surveys Tuts.*, vol. 11, no. 1, pp. 116–130, 1st Quart., 2009.

[2] D. Maldonado, B. Le, A. Hugine, T. W. Rondeau, and C. W. Bostian, "Cognitive radio applications to dynamic spectrum allocation: A discussion and an illustrative example," in *Proc. IEEE NFDSAN*, Nov. 2005, pp. 597–600.

[3] M. Song, C. Xin, Y. Zhao, and X. Cheng, "Dynamic spectrum access: From cognitive radio to network radio," *IEEE Wireless Commun.*, vol. 19, no. 1, pp. 23–29, Feb. 2012.

[4] A. Ghasemi and E. S. Sousa, "Spectrum sensing in cognitive radio networks: Requirements, challenges and design trade-offs," *IEEE Commun. Mag.*, vol. 46, no. 4, pp. 32–39, Apr. 2008.

[5] I. F. Akyildiz, W. Lee, M. C. Vuran, and S. Mohanty, "A survey on spectrum management in cognitive radio networks," *IEEE Commun. Mag.*, vol. 46, no. 4, pp. 40–48, Apr. 2008.

[6] B. A. Odhavjibhai and S. Rana, "Analysis of Matched filter based spectrum sensing in cognitive radio," *Intl. Res. J. Eng. Technol.*, vol. 4, no. 4, pp. 578–581, 2017.

[7] S. S. Ali, C. Liu, and M. Jin, "Minimum eigenvalue detection for spectrum sensing in cognitive radio," *Intl. J. Elect. Comput. Eng.*, vol. 4, no. 4, pp. 623–630, 2014.

[8] S. Atapattu, C. Tellambura, and H. Jiang, *Energy Detection for Spectrum Sensing in Cognitive Radio* (Springer Briefs in Computer Science). New York, NY, USA: Springer, 2014.

[9] I. F. Akyildiz, W. Y. Lee, and K. R. Chowdhury, "Spectrum management in cognitive radio ad hoc networks," *IEEE Netw.*, vol. 23, no. 4, pp. 6–12, Jul. 2009.

[10] M. Jaiswal, A. K. Sharma, and V. Singh, "A survey on spectrum sensing techniques for cognitive radio," in *Proc. Conf. ACCS*, 2013, pp. 1–14.

[11] K. Kumar, A. Prakash, and R. Tripathi, "Spectrum handoff in cognitive radio networks: A classification and comprehensive survey," *J. Netw. Comput. Appl.*, vol. 61, pp. 161–188, Feb. 2016.

[12] I. Christian, S. Moh, I. Chung, and J. Lee, "Spectrum mobility in cognitive radio networks," *IEEE Commun. Mag.*, vol. 50, no. 6, pp. 114–121, Jun. 2012.

[13] J. D. Martinez-Morales, U. Pineda-Rico, and E. Stevens-Navarro, "Performance comparison between MADM algorithms for vertical handoff in 4G networks," in *Proc. 7th ICEEECSAC*, Sep. 2010, pp. 309–314.

[14] S. Huang, X. Liu, and Z. Ding, "Opportunistic spectrum access in cognitive radio networks," in *Proc. 27th Coff. Comput. Commun.*, Apr. 2008, pp. 1427–1435.

[15] A. O. Bicen, E. B. Pehlivanoglu, S. Games, and O. B. Akan, "Dedicated radio utilization for spectrum handoff and efficiency in cognitive radio networks," *IEEE Trans. Wireless Commun.*, vol. 14, no. 9, pp. 5251–5259, Sep. 2015.

[16] M. A. Rahman, A. T. Asyhari, M. Z. A. Bhuiyan, Q. M. Salih, and K. Z. B. Zamli, "L-CAQ: Joint link-oriented channel-availability and channel-quality based channel selection for mobile cognitive radio networks," *J. Netw. Comput. Appl.*, vol. 113, pp. 26–35, Jul. 2018.

[17] K. Tang, R. Shi, M. Z. A. Bhuiyan, H. Shi, and E. Luo, "Secure beamforming for cognitive cyber-physical systems based on cognitive radio with wireless energy harvesting," *Ad Hoc Netw.*, vol. 81, pp. 174–182, Dec. 2018.

S. NANDAKUMAR received the B.Tech. degree in electronics and communication engineering, the master's degree in computer and communication, and the Ph.D. degree in heterogeneous wireless networks from the Vellore Institute of Technology, Vellore, India, where he is currently an Associate Professor. His research interests include next generation heterogeneous networks, cognitive radio networks, and device to device communication. He has teaching experience of 13 years.

T. VELMURUGAN received the B.Tech. degree in electronics and communication engineering in 2000, the M.Tech. degree in advanced communication systems from SASTRA University, Thanjavur, India, in 2002, and the Ph.D. degree from the Vellore Institute of Technology, Vellore, India, where he is currently serving as a Faculty with the School of Electronics Engineering. He has published several papers in reputed journals. His research interests include handoff in wireless networks, cognitive radio networks, and the IoT.

UTTHARA THIAGARAJAN received the B.Tech. degree in electronics and communication engineering from the Vellore Institute of Technology, India, in 2018. Her current research interests include cognitive radio networks and cellular resource allocation.

MARIMUTHU KARUPPIAH (SM'18) received the B.E. degree in computer science and engineering from Madurai Kamaraj University, Madurai, India, in 2003, the M.E. degree in computer science and engineering from Anna University, Chennai, India, in 2005, and the Ph.D. degree in computer science and engineering from the Vellore Institute of Technology, Vellore, India, in 2015, where he is currently an Associate Professor with the School of Computing Science and Engineering. He has authored or coauthored more than 15 research papers in SCI indexed journals and more than 20 research papers in SCOPUS indexed journals and international conferences. His research interests include cryptography and wireless network security, in particular, authentication, and encryption schemes. He is a Life Member of the Cryptology Research Society of India and the Computer Society of India.

MOHAMMAD MEHEDI HASSAN (SM'18) received the Ph.D. degree in computer engineering from Kyung Hee University, South Korea, in 2011. He is currently an Associate Professor with the Information Systems Department, College of Computer and Information Sciences (CCIS), King Saud University (KSU), Riyadh, Saudi Arabia. He has published more than 130 research papers in the journals and conferences of international repute. His research interest include cloud computing, the Internet of Things, cognitive computing, sensor networks, big data, mobile cloud, and publish/subscribe systems. He received the Best Journal Paper Award from the IEEE Systems Journal, in 2018. He also received the Best Paper Award from CloudComp Conference at China, in 2014. He received Excellence in Research Award from CCIS, KSU, in 2015 and 2016, respectively. He has played role of the guest editor of several international ISI-indexed journals.

ABDULHAMEED ALELAIWI received the Ph.D. degree in software engineering from the College of Engineering, Florida Institute of Technology, Melbourne, USA, in 2002. He is currently serving as the Vice Dean of the Research Chairs Program with KSU. He is also an Associate Professor with the Software Engineering Department, College of Computer and Information Sciences (CCIS), King Saud University (KSU), Riyadh, Saudi Arabia. He has authored and coauthored many publications. He has published more than 70 research papers in the ISI-Indexed journals of international repute. His research interests include software testing analysis and design, cloud computing, multimedia, the Internet of things, big data, and mobile cloud. He has served as a Technical Program Committee Member in numerous reputed international conferences/workshops.

MD. MOTAHARUL ISLAM received the Ph.D. degree in computer engineering from Kyung Hee University, South Korea, with the specialization in the smart Internet of Things, in 2013. He has been an Assistant Professor with the Computer Science and Engineering Department, Islamic University of Technology, Gazipur, Bangladesh. He was serving as an Assistant Professor with the Department of Computer Science, Faculty of Computer and Information Systems, Islamic University of Madinah, Saudi Arabia. He has been leading the OBE Team for BAETE and supervising the Cloud Computing Research Lab, BRACU, since 2018. He is currently an Associate Professor with the Department of Computer Science and Engineering, BRAC University. He has published more than 50 research articles in the reputed international journal and conference. His research interests include the smart Internet of Things, IP-WSN, routing protocol, cloud computing, network virtualization, and network security. For the last two years, he had been actively engaged in outcome based education (OBE) for ABET.