Cost-Effective Spectrum Utilization for Futuristic Cognitive Radio based Services

Chanda V. Reddy

Abstract: ***The proliferation of various mobile users in the context of advanced wireless technologies, spectrum scarcity arises as a crucial problem. The notion of cognitive radio (CR) principle offers cost-effective spectrum reusability with intelligent mode of transmission model. It basically enables a radio-driven technology to utilize dynamic spectrum accessing to meet the quality-of-services (QoS) requirements by satisfying enormous communication and connectivity demands. To alleviate the spectrum scarcity problem the study proposes a novel analytical solution of spectrum allocation considering a simplified evolutionary learning model. The prime target of the formulated concept is to detects the spectrum holes effectively for reusability and the possibility of identification has be maximized for best possible spectrum allocation to the radios. And on the other hand also the occurrence of false positive identification has to be minimized. The outcome obtained after performing the simulation shows promising aspects in the context of effective spectrum allocation for higher priority user with better throughput performance.***

Keywords: ***Cognitive Radio, Spectrum Allocation, multi-objective optimization, Throughput performance***

I. INTRODUCTION

In the recent scenario researchers from IEEE and many other communication societies are more concerned towards improving the communication paradigm in the context of 5G wireless technologies. The underlying principle of cognitive radio (CR) technology opens up a new opportunity for effective spectrum utilization and also aroused significant attention for its wider prospects [1] [2]. CR has been introduced to tackle the issue connected with the constraints of bandwidth availability of conventional wireless communication standards which is tightly licensed and restricted by the Government policies. Thereby, it can be seen that mobile devise are restricted to utilize a certain value of frequency and hence a bottle-neck scenario arises in reality due to limited bandwidth where the number of mobile users are tremendously increasing. Thereby maintain quality of service aspects (QoS) with effective spectrum utilization has become crucial.

CR technology can easily handle this issue of spectral scarcity by meeting the growing demand of mobile user requirements and also has become a reliable solution to solve the spectral congestion problem in the modern wireless communication [3][4]. CR is utilized as an extended technology component of software defined radio (SDR) and also incorporates an intelligent system of sensing and channel management functionality. There exist various time-critical applications of CR such as into public safety networks, disaster relief and emergency networks etc. and it is highly agile for advanced intelligent communication systems considering its autonomous mode of selection of operating parameters [5][6]. The figure 1 presents and overview of the advanced paradigm in CR based radio communications.

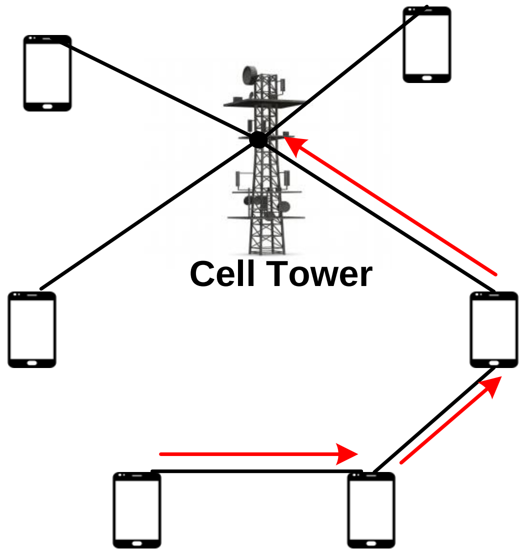

Fig 1 Radio communication in CR

Fig.1 shows that how the CR enabled communication facilitates mobile devices to communicate with each other so that communication between a mobile client and cell-tower can be established with higher throughput efficiency [7][8]. This research study addresses the spectrum allocation problem in the modern wireless communication technology and aims to formulate an energy efficient optimized transmission model based on CR to attain better end-to-end throughput performance. The system modeling of CR is designed with an objective to perform intelligent resource scheduling in variable traffic conditions in the context of advanced cellular networking operations. For this purpose the methodology aims to maximize the spectrum utilization performance considering a metaheuristics evolutionary learning model with lower complexity to attain best possible outcome. The entire manuscript is presented with respect to different sections, *section II* highlights the existing trend of research based studies on CR and outlines the gap in reality.

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Section III finally extracts the cumulative research problem which is jointly addressed in this study with problem formulation aspect.
Finally section IV highlights a comprehensive discussion on proposed analytical system design for CR assisted effective spectrum resource management.

The mathematical modeling is formulated for best possible available spectrum allocation to the SDR with higher possibility of available spectrum detection and also minimizing the false positive cases. The experimental results are further demonstrated in section V. Section VI highlights the contributory remarks about the proposed concept.

II. LITERATURE REVIEW

The work of **(Zayen et al., 2008)**, presented a work where a novel approach of autonomous identification of proper radio-spectrum sub-band in the context of CR technology is introduced. The approach modeled in a way where the derivation utilizes an information diffusion oriented to identify the spectrum holes from the bands. The validation of the presented approach is carried out considering RF agile platform. The simulation outcome shows that the presented approach attain promising performance results in sensing better sub-bands [9].

The spectrum scarcity problem is also handed in the study of (**Hattab and Ibnkahla. 2014),** where better channel utilization is addressed by minimizing the hand-off frequency. The study also performed an investigational approach to extract significant information from existing trend of literatures about the advancement of multi-band spectrum sensing techniques. The key performance metrics of conventional approaches are also assessed [10]. The following table summarizes and briefs few of the significant relevant works which also focuses on cost-effective spectrum utilization and sensing in CR based advanced communication technologies.

Table 1 Existing state-of-the art studies on CR

Authors	Problem studied in the context of advanced wireless communication	Formulated Solution approach (e.g. Theoretical/Experimental/Empirical)
(Yu et al., 2011) [11]	Sensing and spectrum allocation	Experimental
(Grøndalen et al, 2010) [12]	Spectrum scarcity	Investigational
(Chakraborty and Misra, 2015) . [13]	Spectrum hand-off	Computational
(Zhu et al., 2008) [14]	Energy detection in spectrum sensing	Computational
(Mueck *et al*.,2009) [15]	Dynamic spectrum management	Investigational
(Lin *et al*., 2011)[16]	Robust and secure spectrum sensing	Empirical
Mao et al., 2018 [17]	Scarcity in spectrum sensing	Empirical (multi-objective optimization)
(Manku et al., 2017) [18]	Cost effective execution and band selection	4RX-1TX SoC Experimental design
Soltani et al., [19]	Dynamic spectrum access	Experimental approach
Imata et al., [20]	Efficient use of frequency spectrum	Theoretical approach

The study of (Akyildiz et al., 2006) also focused on dynamic spectrum access in the context of CR based wireless networks and provided significant insight theoretically [21]. Various other studies also worked on the futuristic prospects of CR enabled applications such as IoT services where 5G works as backbone of infrastructure such as (Khan et al., 2016) [22] , (Khan et al., 2017) [23] and many more. (Chanda V. Reddy and Padmaja K.V) [24] have illustrated the related based technique for improving resource allocation which is used in future cellular network. Another work done by (Chanda V. Reddy and Padmaja K.V) [25] [26] shows the performance value in the 5G networks and leveraging broadcasting performance for the OFDM by using allocation of the power. The next section further highlights the existing research gap which is specific to our research problem of interest.

III. RESEARCH PROBLEM

An investigation study of existing trend of research on CR shows that majority of the studies focused on spectrum utilization problems but the research contributions are limited to theories embedded achieves only. Very few approaches talked about complexity of execution and QoS optimization problems. The study jointly addressed the spectrum scarcity problem and Quality of Services aspects in the context of CR based wireless networking operations. Therefore the problem statement can be formulated to bridge the existing gap in the research trend of CR as: “There is an essentiality to formulate a multi-objective optimization based learning model which can jointly address the complexity of dynamic spectrum allocation and QoS aspects in CR based advanced services in futuristic backbone of 5G”.

IV. SYSTEM MODEL

The formulated concept pertaining to the research study introduces an efficient model of spectrum allocation in the context of CR.

The system considers variable multi-hop data-flows in advanced cellular networking. The network is formulated with respect to a function $\theta_1(n, l)$. Here θ_1 represents a graph of vertices and edges where n represents the number of nodes and l represents set of maximum possible links. If node (j) tries to establish communication with node (k) then the scenario can be mathematically expressed as $(j \to k) \in l$. In the context of CR transmission and network modeling each link corresponds to radio-frequency transmission within a band of spectrum channel for supporting variable flow of transmissions. Let's assume there is *m* number of spectrum channels available for licensed eligible mobile stations/user and q = $\{q_1, q_2, q_3 \ldots q_o\}$ represents multi-hop simultaneous traffic within the network.

A. Transmission System Modeling

The paradigm of CR communication defines efficient on-demand spectrum selection to support variable flow of transmission, thereby the study in this aspect realizes that spectrum sharing and reusability are two core factors which promotes better spectral efficiency in a multi-hop cognitive radio network. The following figure shows overview of the formulated system with an architectural block-based design.

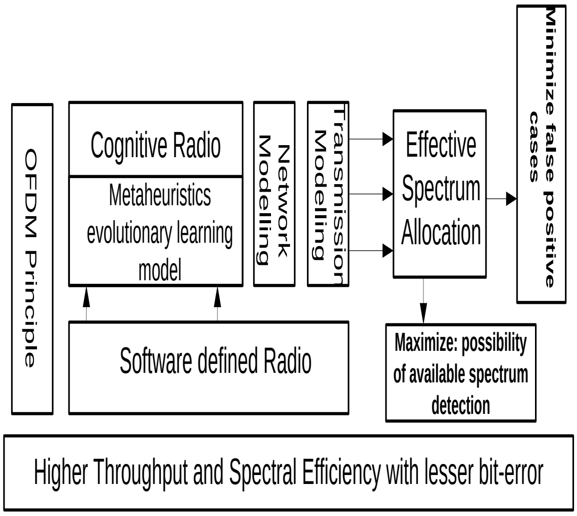

Fig.2 Formulated Methodical Overview of Optimized Spectrum Sensing in CR networks

The system modeling design in this study clearly shows that the prime objective of the system model is to maximize the spectrum allocation using a reusability approach. The optimized transmission and network modeling in aspects play a very crucial role. The system modeling is designed recognizing the fact that in the context of cognitive radio (CR) networks spectrum utilization is very less when the licensed higher prioritize users are concerned. Thereby it introduces spectrum holes during the process of communication. Thereby the study realizes that there is a need to develop an efficient method which can effectively utilize the spectrum to leverage on-demand network services with higher quality of services (QoS) aspects. The system model also considers the foundation principle of CR technique where unutilized spectrum of licensed high priority user can be used by low-prioritized user when needed. Spectrum sensing is very much essential in this aspect from a learning view-point. This means spectrum sensing can give a user better learning experience and make them adaptable into a new kind of situation when traffic modeling is concerned.

B. Optimization Modeling of Spectrum Sensing

The formulated system applies cooperative sensing modeling in order to minimize the possibility of false positive cases when it comes to unutilized spectrum, allocation and also applies time-synchronized spectrum sensing modeling to reduce the probabilistic factor associated with hidden primary user problem. It means that the if needed low-priority user have to make the spectrum slot available for high priority user on the requirement basis and it is to avoid the channel interference problems [27].

For numerical modeling the study initially considered two different types of signal such as sig(t1) i.e. noisy signal and sig(t2) i.e. the high prioritize user real-values signal. The initial modeling also initializes the signal to noise (snr) with linear attribute along with probabilistic factor to indicate false alarm (pF). Here $\mathrm{sig}(t1) \to \mu = 0$ and $\sigma^2 = 1$. The signal which is received at the recipient unit (Rx) can be mathematically derive as follows:

Sig (Rx) = sig (t1) + sig (t2) where t1, t2 refers to time-sampled values eq. (1)

During the multi-slot spectrum sensing in CR enabled communications; the higher prioritize users (**U**p) initially allotted to higher spectrum width. However, during the process of sensing the low prioritize users (Lp) constantly checks about the spectrum availability within their communication range (Cr) and also checks whether any adjacent Up is currently allocated with the spectrum slot. When Up is found active and currently under transmission-reception mode, then the sampled received signal attributes can be represented as Sig (Rx) = sig(t1) , else it takes eq. (1) to represent the transmission of Lp generated signal. The study as considered theoretical values of threshold (Th) during the numerical computing process. However, different time slots of j → t. The power of the received signal can be computed as follows:

Pow(Sig) = Σ | Sig(Rx)|^2 eq. (2)

The computation of sensing for different range ofstatistical factors are imposed for the energy detection as the energy detection at the receiving end determine the possibility of false detection associated with spectrum sensing. If in the receiver end the power of noise signal is found greater than the theoretical value of Sth (Sensing throughput factor) that means that the Up signal is absent and it generates the probability factor associated with false positive cases. The numerical modeling is found effectively detecting false positive cases during energy spectrum allocation procedure for different signal attributes. The possibility of identification can be represented with the a cumulative distribution functional attribute which is represented with eq. (3)

Maximize I(p) = ∫ [Pow(Sig) ,Sth] dt eq. (3)

This is the way the proposed conceptualized system maximizes the identification of false positive cases and also at the same time maximizes the available spectrum to enhance the throughput efficiency.

The final functional module implemented $\theta_3(X)$ which is subjected to perform metaheuristics optimization model to enhance the throughput performance during CR communications. The next section shows the outcome obtained after simulating the concept in a numerical computation platform

V. RESULT ANALYSIS

This section basically highlights the outcome obtained after simulating the multi-objective optimization modeling computationally where different performance metrics such as energy variance, total error rate of packets at the receiver end, accumulated received energy, probability of identification of available spectrum at every epoch are demonstrated.

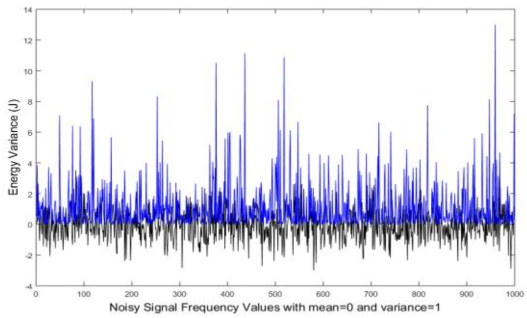

Fig 3 Statistical measurement of energy variance

Fig.3 shows the statistical measure of variance associated with both the types of signals. It also shows that the computational module attain very lesser processing time ~33.053441 Sec during the execution period.

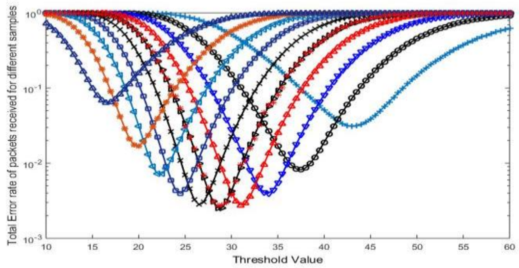

Fig.4 Statistical measurement of total rate of received packets at a given Sth

Fig.4 shows the quantified outcome associated with total error rate of packets received for different samples. It is evaluated for different types of threshold value which ranges between 10 to 60.

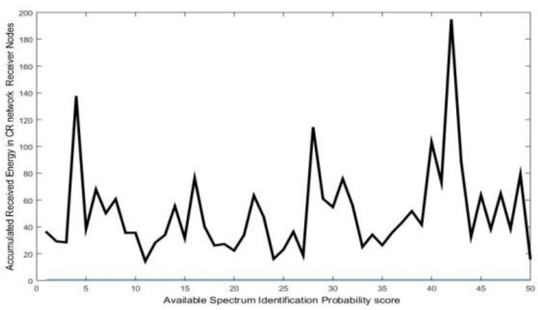

Fig.5 Visualization of quantified outcome of accumulated received energy

Fig.5 shows the accumulated received energy factor with respect to available spectrum identification probabilistic score.

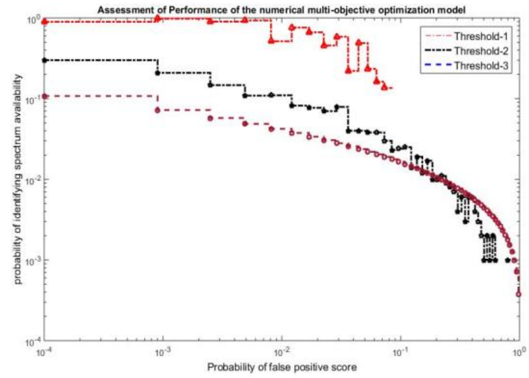

Fig.6 Visualization of quantified outcome for probability of identification of spectrum availability Vs false positive score

Fig.6 shows the quantified outcome if probability of identification of spectrum availability obtained from different threshold values. The overall outcome shows the effective performance of the proposed spectrum allocation technique where the incorporation of learning model significantly improved the throughput performance and minimized the packet error.

VI. CONCLUSION

The presented study introduces a cost-effective model to enhance the spectrum allocation in cognitive radio networks. The methodology considers efficient spectrum allocation modeling in order to maximize the throughput performance by means of detecting maximum possible available spectrum with lower rate of false positive cases. The numerical outcome shows that the system attain ~61% improvement in throughput performance and also shows that the execution model takes very lesser computation time~33.053441 as compared to the existing system.

REFERENCES

1. C. Park, S. Kim, S. Lim and M. Song, "HMM Based Channel Status Predictor for Cognitive Radio," 2007 Asia-Pacific Microwave Conference, Bangkok, 2007, pp. 1-4.
2. K. Kashiki, K. Takeuchi and A. Yamaguchi, "Research project concerning cooperative heterogenious radio networks for reliability improvements," 2009 4th International Conference on Cognitive Radio Oriented Wireless Networks and Communications, Hannover, 2009, pp. 1-5.
3. N. Chandwani, A. Jain and P. D. Vyavahare, "Throughput comparison for Cognitive Radio network under various conditions of primary user and channel noise signals," 2015 Radio and Antenna Days of the Indian Ocean (RADIO), Belle Mare, 2015, pp. 1-2.
4. A. Das, S. C. Ghosh, N. Das and A. Das Barman, "Cooperative spectrum mobility in heterogeneous opportunistic networks using cognitive radio," 2015 IEEE 40th Conference on Local Computer Networks (LCN), Clearwater Beach, FL, 2015, pp. 402-405.
5. E. Grayver, “Implementing Software Defined Radio". New York: Springer Science +Business Media, 2013.
6. J. Mitola, “Cognitive radio an integrated agent architecture for software defined radio,”Master’s thesis, Royal Institute of Technology (KTH), 2000.
7. C. R. Stevenson and G. Chouinard, “Ieee 802.22: The first cognitive radio wirelessregional area network standard,” IEEE Communications Magazine, vol. 47, pp. 130–138,2009.
8. J. Mitola and G. Q. Maguire, "Cognitive radios: making software radios more personal", IEEE Pers. Commun., vol. 6, no. 4, pp. 13-18, Aug. 1999.

9. B. Zayen, A. M. Hayar and D. Nussbaum, "Blind Spectrum Sensing for Cognitive Radio Based on Model Selection," 2008 3rd International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom 2008), Singapore, 2008, pp. 1-4.
10. G. Hattab and M. Ibnkahla, "Multiband Spectrum Access: Great Promises for Future Cognitive Radio Networks," in Proceedings of the IEEE, vol. 102, no. 3, pp. 282-306, March 2014
11. T. Chakraborty and I. S. Misra, "Designing a real-time spectrum handoff algorithm for VoIP based Cognitive Radio Networks," 2015 Radio and Antenna Days of the Indian Ocean (RADIO), Belle Mare, 2015, pp. 1-2.
12. J. Zhu, Z. Xu, F. Wang, B. Huang and B. Zhang, "Double Threshold Energy Detection of Cooperative Spectrum Sensing in Cognitive Radio," 2008 3rd International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom 2008), Singapore, 2008, pp. 1-5.
13. M. Mueck et al., "ETSI Reconfigurable Radio Systems — Software Defined Radio and Cognitive Radio standards," 2009 IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications, Tokyo, 2009, pp. 1-5.
14. F. Lin et al., "Cognitive radio network as wireless sensor network (II): Security consideration," Proceedings of the 2011 IEEE National Aerospace and Electronics Conference (NAECON), Dayton, OH, 2011, pp. 324-328.
15. D. Mao, W. Shao, Z. Qian, H. Xue, X. Lu and H. Wu, "Constructing accurate Radio Environment Maps with Kriging Interpolation in Cognitive Radio Networks," 2018 Cross Strait Quad-Regional Radio Science and Wireless Technology Conference (CSQRWC), Xuzhou, 2018, pp. 1-3.
16. T. Manku et al., "A 680MHz to 4GHz 4RX-1TX SoC for cognitive radio applications," 2017 IEEE MTT-S International Microwave Symposium (IMS), Honolulu, HI, 2017, pp. 586-589. [19] S. Soltani, Y. E. Sagduyu, J. H. Li, J. Feldman and J. Matyjas, "Demonstration of plug-and-play cognitive radio network emulation testbed," 2014 IEEE International Symposium on Dynamic Spectrum Access Networks (DYSPAN), McLean, VA, 2014, pp. 376-377.
17. S. Imata, M. Nohara and K. Kashiki, "Study of inter-base station beam switching considering asymmetric broadband transmission in cognitive radio," 2008 IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications, Cannes, 2008, pp. 1-6.
18. I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, ``NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey," Comput. Netw., vol. 50, no. 13, pp. 2127_2159, 2006.
19. A. A. Khan, M. H. Rehmani, and A. Rachedi, ``When cognitive radio meets the Internet of Things?" in Proc. Int. Wireless Commun. Mobile Comput. Conf. (IWCMC), 2016, pp. 469_474.
20. A. A. Khan, M. H. Rehmani, and A. Rachedi, ``Cognitive-radio-based Internet of Things: Applications, architectures, spectrum related functionalities, and future research directions," IEEE Wireless Commun., vol. 24, no. 3, pp. 17_25, 2017.
21. Reddy, Chanda V., and K. V. Padmaja. "Relaxed Greedy-Based Approach for Enhancing of Resource Allocation for Future Cellular Network." In Computer Science On-line Conference, pp. 364-373. Springer, Cham, 2018.
22. Reddy, Chanda V., and K. V. Padmaja. "Novel Framework for Enhancing Communication Performance Quality in 5G Networks.", International Journal of Engineering and Technology, Vol. 9, 2017
23. Reddy, Chanda V., and K. V. Padmaja. "Leveraging communication performance for OFDMA using novel bit loading and allocation of power." In 2016 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), pp. 1606-1610. IEEE, 2016.
24. T. Yucek and H. Arslan, "A survey of spectrum sensing algorithms for cognitive radio applications", IEEE Communications Survey & Tutorial, vol. 11, no. 1, pp. 116-127, 2009.

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