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Cognitive Radio Based Enhanced Compressive Spectrum Sensing Technique for 5G Adhoc Networks

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Abstract

Spectrum sensing is a challenging issue in cognitive radio network. In particular, wideband spectrum sensing gains more attention due to emerging 5G wireless networks characterized by high data rates in the order of hundreds of Gbps. Conventional sensing techniques uses samples for its observations based on Nyquist rate. Due to hardware cost and sampling rate limitations those techniques can sense only one band at a time. Enhanced cognitive radio networks (E-CRNs) based on Spectrum Sharing (SS) and Spectrum Aggregation (SA) are proposed for the fifth Generation (5G) wireless networks. The E-CRNs jointly exploit the licensed spectrum shared with the Primary User (PU) networks and the unlicensed spectrum aggregated from the Industrial, Scientific, and Medical (ISM) bands. The PU networks include TV systems in TV White Space (TVWS) and different incumbent systems in the Long Term Evolution (LTE) Time Division Duplexing (TDD) bands. The harmful interference from the E-CRNs to the PU networks are delicately controlled. Furthermore, the coexistence between the E-CRNs and other unlicensed systems, such as WiFi is studied. In spite of this issue secondary users have to sense multiple frequency bands using frontend technologies which lead into increased cost, time and complexity. Considering the facts and issues, compressive sensing was introduced to minimize the computation time by improving the sensing process even for high dimensional resources. Holding the essential information and reduces the sample size which is related to high dimensional data acquisition is performed in compressive sensing. In the last decade various researchers paid more attention to improve the performance of compressive sensing in cognitive radio networks based on sensing matrix, sparse representation and recovery process. This survey paper provides an in-depth analysis of conventional models and its sensing strategies in cognitive radio networks along with its merits and demerits to obtain a detailed insight about compressive sensing. The ECRNs framework provides a spectrum usage prototype for 5G wireless communication networks.

Keywords: Cognitive radio network • Compressive sensing • Spectrum sensing • Channel estimation • Narrowband Sensing • Nyquist theorem

Introduction

The demand towards radio spectrum resources increases due to the advancement in wireless communications. Federal communications commission has set up regulations to access this limited spectrum resource. Using specific wireless services, the spectrum is allocated to the licensed users based on spectrum allocation policy which is defined by FCC [1]. The fifth Generation (5G) mobile communication system comes into being. Cellular network through which Internet of Things (IoT) will be the major driving force for 5G development as well as for device to device connection. The 5G network will give a platform for people of various regions not only to exchange information but also provide interconnectedness of all things begins from home utilization to industrial applications. Licensed users are allowed to transmit and receive data through allocated spectrum while, the unlicensed users are prohibited to utilize the resource. Due to this reason, some of the channels are heavily used and other channels are not used properly which leads into spectrum underutilization. The licensed users are the primary users and the unlicensed users are considered as secondary users. Primary users will not utilize the resource all the times which creates a spectrum hole [2]. These holes are not utilized and the spectrum remains unused by licensed user leads into inefficiency as the other users cannot utilize the spectrum which results into spectrum scarcity. To reduce spectrum scarcity dynamic spectrum management is introduced to utilize the unused spectrum without affecting the performance to primary users. Secondary users are allowed to utilize the spectrum if it is unused by PUs. Cognitive radio network [3] performs spectrum utilization in this manner. It detects the available channel and allocates the resources to secondary users to reduce the inefficiency in spectrum. Figure 1 gives an illustration of dynamic spectrum access in cognitive radio network (Figure 1).

Methodology

Cognitive radio network upwards 5G

Cognitive Radio gives an opportunity to reuse valuable spectrum resources without change in spectrum allocation policy which address a problem of low utilization rate. The core idea behind Cognitive Radio is to share the spectrum through dynamic spectrum access and implication of sharing is that SUs can

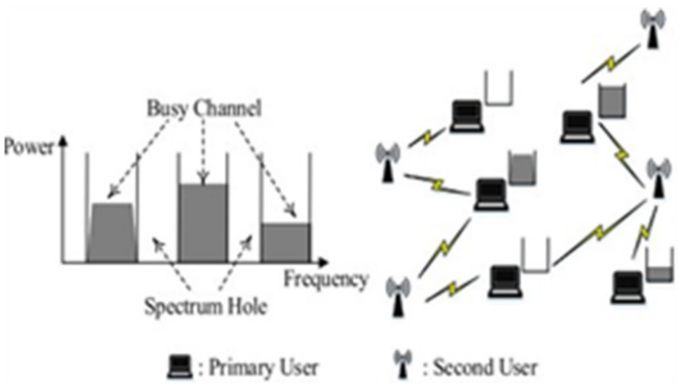

Figure 1. Spectrum sensing.

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use idle spectrum of Pus but only if they cannot interfere with communication of PUs. The brief diagram of spectrum sensing is shown in Figure 1.

The goal of the sensing technique is to check for the status of the spectrum. Also to check the activity of licensed user by sensing periodically. The CR transceiver looks for an idle band i.e., spectrum holes without causing interference to the primary network. Sensing can be of centralized and distributed. First step of sensing to complete spectrum sharing to improve spectrum utilization and can be realize for various application. SUs continuously detect frequency. In digital systems, data acquisition and sampling are considered as an important aspect. Compressive sensing is an acquisition and reconstruction algorithm [4] which combines sampling and sensing. Initially it was introduced to sample the signals based on the Nyquist rate where the conventional sensing models are performed sensing using Shannon- Nyquist theorem [5]. The signal recovery in conventional models forces the receiver to change its sampling rate similar to Nyquist rate to recover the information. The limitation of Nyquist theorem-based sampling is present in its bandwidth specification. Minimum two times of signal bandwidth is required to recover a signal in Nyquist sampling which leads into numerous samples and makes the acquisition process as cost expensive in large communication networks. Instead compressive sensing recovers the signals with few samples and measurement values which is far better than conventional models [6]. Based on three process such as spare representation, encoding and decoding, compressive sensing is performed. In this sparse representation is used to identify and reconstruct the signals as much as possible. Based on measurement matrix, the sparse signals are sampled and then compressed. Using suitable recovery algorithm, the compressed signals has been recovered in the receiver end (Figures 2-4).

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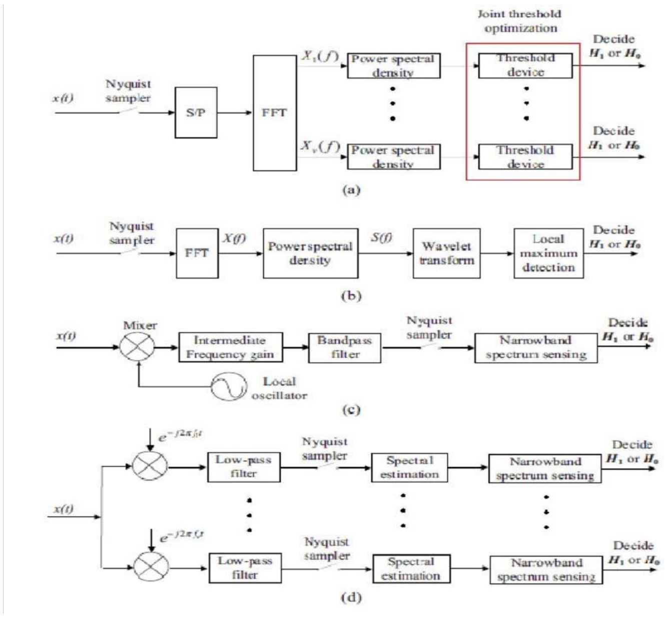

Figure 2. Block diagrams for sub-Nquist wideband sensing algorithm. **a)** Analog to informationconverter-based wideband sensing, **b)** Modulated wideband converter-based wideband sensing, **c)** Multi-coset sampling-based wideband sensing and **d)** Multi-rate sub-Nquist sampling-based wideband.

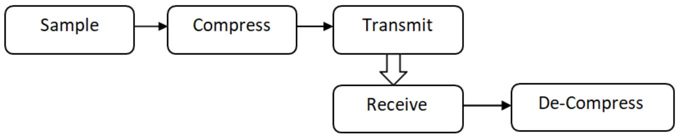

Figure 3. Conventional sampling and data compression.

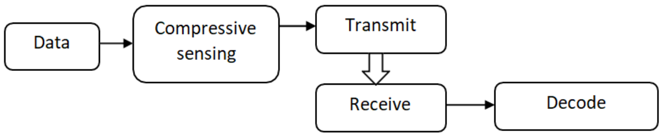

Figure 4. Compressive sensing scheme.

Spectrum allocation: It is based on the availability of spectrum holes and distributes the unused spectrum to secondary users. The numbers of holes were not fixed and the secondary users need to compete while QoS are different for different users. Therefore spectrum holes need to be used fairly and efficiently. The basic need of spectrum allocation is to design an efficient spectrum allocation algorithms and protocols through which spectrum utilization efficiency can be increased, conflict-free and preferably close to optimal target as possible.

Spectrum management: The licensed, unlicensed and unused spectrum bands are spread over a large number of frequencies in the cognitive radio networks. These unused spectrum bands show different properties according to the time varying radio environment. The Cognitive radio has to decide the best available spectrum band, such that it fulfills the QoS requirements. The collective information obtained from spectrum sensing is to plan and schedule the spectrum access by users which do not have licensed to access the spectrum. The basic component of spectrum management is: spectrum access and spectrum analysis.

Spectrum analysis: In this the data obtained from sensing is analyzed first to collect information about the spectrum holes and the decision is made by optimizing the system performance on given desired objective and constraints.

Spectrum access: After taking decision on spectrum access which is based on spectrum analysis, the unlicensed users can access the spectrum holes. Mainly it is carried out on a cognitive access protocol call MAC protocol through which collision can be avoided between primary users and also with others secondary users. In order to access the frequency band the first priority is given to primary users whereas secondary user subordinate relation to access it. It require efficient algorithm to coordinate multiple secondary users to access spectrum holes and avoid the conflicts between primary and secondary users while spectrum band.

Compressive sensing: Compressive sensing in cognitive radio networks is increased in last decade and numerous research works are evolved to improve the sensing performance and other parameters. This section provides a detailed analysis of existing research models in detail to obtain the issues in compressive sensing methods. On view of analysing the compressive sensing, adetailed classification is presented in Figure 4. Generally compressive sensing is classified into distributed sensing and jointly compressive sensing [8]. In distributed compressive sensing the sampling is performed in separate manner where the recovery is performed in joint manner. In this data acquired from each node and sampling is performed based on sensing matrix to obtain signal measurements. Also, the same reconstruction is used jointly to recover the signal. Reduced data storage and measurement rates are the advantages of this distributed compressive sensing. Using the same sensing matrix, the measurements and reconstruction of the signals are performed in jointly compressive sensing process. Wide band compressive spectrum sensing is used to realize wideband spectrum based on sampling frequency. In particular it is classified based on the Nyquist [8] and sub Nyquist [9] approaches. In this Nyquist based approach, Nyquist sampling rate is used to obtain the desired spectrum. It is a cost-efficient model which easily identifies the spectrum state. In Nyquist based approach the unused spectrums are identified using conventional digital signal processors followed by analog to digital converter.

In this, the sampling spectrum follows the Shannon sampling theorem which reduces the aliasing effect which makes the sensing process is suitable for multiband sensing operations. Edge detection [10] is a simple approach which progress based on this model, it differentiates the spectrum status as occupied or unused spectrum through its simple sampling rate. The performance of edge detection lags in its increased sensing time and complexity. To reduce the limitations in Nyquist sampling-based models, Sub-Nyquist approaches are evolved (Figure 5).

Results and Discussion

Classification of different sensing techniques

The sensing technique can be broadly divided into two categories such as: narrow band spectrum sensing and wideband spectrum sensing. The classification is shown in Figure 3.

Narrow band spectrum sensing: is technique which includes energy detection, cyclostationary detection, matched filtering detection, covariance-based detection and ML based sensing.

Wideband spectrum sensing: use two detection technique nyquist based and compressive sensing detection. Basically in Nyquist based the wideband signals get sampled by ADC at high sampling rate and low power consumption. It includes wavelet detection and filter bank based sensing. Secondly in Compressive sensing

Narrowband sensing techniques

In this technique the secondary users allowed to decide about their presence or absence of primary users over a channel of interest. Consequently this algorithm needs to able to determine accurate spectrum hole and it can be expressed as two element hypothesis detection model:

H_0: (t) = 5(t)

{H_1: (t) = (t) + 5(t)....... (i)

The above mentioned equation indicate two hypothesis of non-existence or existence of s(t). Here η(t) indicate additive white Gaussian noise and s(t) is the signal of primary user for target channel. The state H0 corresponds primary user absence and state H1 correspond primary user presence. Basically these techniques are often evaluated using probabilities of detection. These two probabilities can be defined as follow.

$p_f = p\,(H^0)$ & $p_d = p\,(H^0)$...... (ii)

Compressive sensing is further analysed based on the following factors

Sparsity Model

Acquisition Model

Reconstruction model

Sparsity-based models

In this, sparsity-based models use its sparsity order to define the signal with number of non-zero elements by measuring the compressibility degree. Since sparsity plays an important role in compressive sensing, it helps to identify the necessary measurements which is required to perform recovery of the signal. Based on these numerous research models are evolved. Depends upon the recovery error and sampling rate the sparsity is estimated in nonblind compressive spectrum sensing. Where as in blind spectrum sensing the complexity of sensing process is reduced as it doesn't need prior knowledge about the sparsity level. Based on these two categories researchers introduced various implementation [11].

Two step compressive spectrum sensing for wideband cognitive radio network is reported in to estimate the sparsity order and the number of samples. Using small number of samples, the first step is used to estimate the unknown spectrum where as in second step the number of samples which requires is added and then used in network. Based on the two steps and the sample values the spectrum is reconstructed and sensing decision is taken in the network. Under blind compressive spectrum sensing, residual correlation matrix detection is proposed in literature which effectively obtains the non-zero elements location over a multiband signal without any signal parameter knowledge. Based on the adjacent frequency's energy ratios and sub Nyquist sampling values the sensing process is formulated [12]. Later discrete cosine transform based compressive spectrum sensing is evolved to estimate the sparsity of the primary user signal. Based on energy concentration the performance is compared with discrete Fourier transform which greatly improves the signal detection in cognitive radio network. The advantages of non-blind compressive sensing model are present in its utilization of reduced number of measurements to estimate the signal sparsity and minimized recovery error. The estimation process makes the sparsity into more complex is considered as the limitation. In blind compressive spectrum sensing, estimation of sparsity level is not required which greatly reduces the computation complexity and accelerates the detection process. The limitation of blind compressive spectrum sensing is present in its reduced quality of signal reconstruction. Detailed analysis of sparsity models is listed in Table 1 (Table 1).

Acquisition-based models

In the acquisition-based models, the received signal is first subsampled and then it is compressed for further process. Using various acquisition techniques like Random convolution, Random demodulator, Random filtering and compressive multiplexer this operation are performed in acquisition models. To improve the performance of sub Nyquist spectrum sensing sequence architecture-based application is developed. In few research works are summarized in literature for spectrum acquisition in which continuous to finite block is replaced with pseudo inversion process which reduces the complexity in computation. Later using Bayesian learning based recovery algorithms are implemented using sparse which further reduces the computation complexity. Similarly, various methodologies are introduced in the same line by focussing

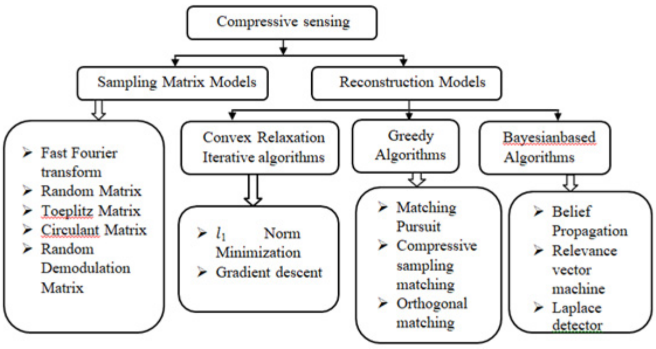

Figure 5. Classification of compressive sensing.

Table 1. Merits and demerits of existing sparsity models.

S. No	Algorithms	Merits	Demerits
1	Wavelet model	Reduced latency	High energy consumption High complexity
2	Two step compressive sensing	Better estimation of wideband signal sparsity Minimum number of samples	Complex due to estimation characteristics
3	Adaptive compressive sensing	Predefined number of samples Controlled recovery error	High computationcomplexity
4	DCT without recovery	Reduced complexity Sparsity estimation not required Measurement based direct recovery	Reduced performance in detection probability Increased false alarm rate
5	One-bit compressive sensing	Robust to noise Low complexity andcomputation cost Fast sampling	Less reliable

compression in the acquisition process. This helps to improve the compression parameter but lags in other cost functions of the network [13].

Regular parity check matrix is used in compressive spectrum sensing to improve the sensing performance. It uses basic RPC matrix to evaluate the functions related to sensing process in the network. Though, the performance metrics are noteworthy, modified regular parity checker matrix is introduced by replacing basic matrix into semi orthogonal matrix which improves the sensing process in cognitive radio network. The advantages of acquisition-based models are reduced sensing time, low complexity, secure and easy implementation. The limitation of acquisition-based models is, low detection probability and reduced detection performance. Table 2 gives a comparison of few acquisition models with its merits and demerits in detail [14].

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Acquisition-based models

In the acquisition-based models, the received signal is first subsampled and then it is compressed for further process. Using various acquisition techniques like Random convolution, Random demodulator, Random filtering and compressive multiplexer this operation are performed in acquisition models. To improve the performance of sub Nyquist spectrum sensing sequence architecture-based application is developed. In few research works are summarized in literature for spectrum acquisition in which continuous to finite block is replaced with pseudo inversion process which reduces the complexity in computation. Later using Bayesian learning based recovery algorithms are implemented using sparse which further reduces the computation complexity.

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Table 3. Merits and demerits of existing acquisition models.

S. No	Algorithms	Merits	Demerits
1	Random Filtering	Applicable to various compressive signal applications Efficient measurement operator Simple and easy implementation	Nonlinear reconstruction algorithm Prior knowledge about filters
2	Random Convolution	Implicit algorithm basedon fast Fourier transform Suitable for variousphysical systems	Unknown pulse structure which makes the application not suitablefor sparse signals
3	Random Demodulator	High rate ADC is not required Reduced noise and quantization errors	Slow reconstruction of signals High sampling delay (iii) Suitable for finite set of signals
4	Modulated Wideband Converter	Suitable for Analog Multiband signals Flexible sampling rate control Insensitive to parameter choice	Needs low pass filter for effectivereconstruction Applicable for limited number ofbands and bandwidth Inadequacy of non-ideal low passfilter

Similarly, various methodologies are introduced in the same line by focussing compression in the acquisition process. This helps to improve the compression parameter but lags in other cost functions of the network [17].

Regular parity check matrix is used in compressive spectrum sensing to improve the sensing performance. It uses basic RPC matrix to evaluate the functions related to sensing process in the network. Though, the performance metrics are noteworthy, modified regular parity checker matrix is introduced by replacing basic matrix into semi orthogonal matrix which improves the sensing process in cognitive radio network. The advantages of acquisition-based models are reduced sensing time, low complexity, secure and easy implementation. The limitation of acquisition-based models is, low detection probability and reduced detection performance [18-23]. Table 2 gives a comparison of few acquisition models with its merits and demerits in detail (Table 3).

Conclusion

Fully automated and independent spectrum conditioners can oversee the use of spectrum in an area, and regulate the use than a static stringent manual regulation of air waves. The new network architecture that merges network routing into wireless link and RF design can create a dynamic "fluid wireless network" without predetermined topology and spectrum allocation. Cognitive radio technology has the potential to address challenges associated with spectrum access. The key enabling technologies that may be closely related to the study of 5G in the near future are presented, particularly in terms of full-duplex spectrum sensing, spectrum-database based spectrum sensing, compressive spectrum sensing, carrier aggregation based spectrum allocation.

Acknowledgment

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Conflict of Interest

None.

References

1. Zhang, Lin, Ming Xiao, Gang Wu and Muhammad Alam, et al. "A survey of

advanced techniques for spectrum sharing in 5G networks." *IEEE Wirel Commun* 24 (2017): 44-51.

2. Gandotra, Pimmy, Rakesh Kumar Jha and Sanjeev Jain. "Green communication in next generation cellular networks: A survey." *IEEE Access* 5 (2017): 11727-11758.
3. Sharma, V and S. Joshi. "Design of hybrid blind detection based spectrum sensing technique." *J Sci Res* 12 (2020).
4. Moon, Thomas, Hyun Woo Choi, Nicholas Tzou and Abhijit Chatterjee. "Wideband sparse signal acquisition with dual-rate time-interleaved undersampling hardware and multicoset signal reconstruction algorithms." *IEEE Trans Signal Process* 63 (2015): 6486-6497.
5. Zhang, Zhicheng, Xiaokun Liang, Xu Dong and Yaoqin Xie, et al. "A sparse-view CT reconstruction method based on combination of DenseNet and deconvolution." *IEEE Trans Med Imaging* 37 (2018): 1407-1417.
6. Austin, Christian D., Randolph L. Moses, Joshua N. Ash and Emre Ertin. "On the relation between sparse reconstruction and parameter estimation with model order selection." *IEEE J Sel Top Signal Process* 4 (2010): 560-570.
7. Kaarthik, K., A. Sridevi and C. Vivek. "Image processing based intelligent parking system." *IEEE* (2017): 1-4.
8. P Sivagurunathan. “A new nonlinear companding scheme for reducing OFDM signals.” *J Chem Pharm Sci* (2017): 154-157.
9. T. Sivagurunathan. “An Overview: Fiber optic communication.” *J Chem Pharm Sci* (2017): 163-167.
10. Sharma, Vatsala and Sunil Joshi. "A literature review on spectrum sensing in cognitive radio applications *IEEE* (2018) 883-893.
11. Docket, F. C. C. E. T. "Docket 10-174: Second Memorandum Opinion and Order in the Matter of unlicensed operation in the TV broadcast bands." (2012).
12. Caleffi, Marcello and Angela Sara Cacciapuoti. "Database access strategy for TV white space cognitive radio networks." *IEEE Secon* (2014): 34-38.
13. Ebian, Ahmed, Bassant Abdelhamid and Salwa El-Ramly. "New measurement matrix for compressive sensing in cognitive radio networks *IET Commun* 12 (2018): 1297-1306.
14. Huang, Xiaoge, Baltasar Beferull-Lozano and Carmen Botella. "Quasi-nash equilibria for non-convex distributed power allocation games in cognitive radios." *IEEE Trans Wirel Commun* 12 (2013): 3326-3337.
15. Palanivel Rajan, S. "Review and investigations on future research directions of mobile based telecare system for cardiac surveillance." *JART* 13 (2015): 454-460.
16. Mahendran, N., P. T. Sivagurunathan and P. Ramakrishnan. "Optimization in wireless body area sensor networks using meta-heuristic chemical reaction algorithm." *Curr Trend Biomed Comm Telemed* (2018): 50.
17. Kishore, Rajalekshmi, C. K. Ramesha and K. R. Anupama. "Bayesian detector based superior selective reporting mechanism for cooperative spectrum sensing in cognitive radio networks." *Procedia Comput Sci* 93 (2016): 207-216.
18. Sharma, Vatsala and Sunil Joshi. "Real-time implementation of enhanced energy-based detection technique." *Springer Singapore* (2021): 3-11.
19. Sharma, Shree Krishna, Symeon Chatzinotas and Björn Ottersten. "Compressive sparsity order estimation for wideband cognitive radio receiver." *IEEE Trans Signal Process* 62 (2014): 4984-4996.
20. Wang, Yue, Zhi Tian and Chunyan Feng. "Sparsity order estimation and its application in compressive spectrum sensing for cognitive radios." *IEEE Trans Wirel Commun* 11 (2012): 2116-2125.
21. Sharma, Vatsala and Sunil Joshi. "Design of energy detection based multistage sensing technique." *J Sci Res* 64 (2020).
22. Jiang, Jing, Hongjian Sun, David Baglee and H. Vincent Poor. "Achieving autonomous compressive spectrum sensing for cognitive radios." *IEEE Trans Veh Technol* 65 (2015): 1281-1291.
23. Karatalay, Onur, Serhat Erküçük and Tunçer Baykaş. "Busy tone based coexistence algorithm for WRAN and WLAN systems in TV white space." *IET Commun* 12 (2018): 1630-1637.

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