Published: 27 May 2017

From Sensing to Predictions and Database Technique: A Review of TV White Space Information Acquisition in Cognitive Radio Networks

Hilary K. Anabi, Rosdiadee Nordin, Omar B. Abdulghafoor, Aduwati Sali, Ahmed Mohamedou, Abdulmajid Almqdshi & Nor Fadzillah Abdullah

Wireless Personal Communications volume 96, pages6473–6502(2017)Cite this article

Abstract

Strategies to acquire white space information is the single most significant functionality in cognitive radio networks (CRNs) and as such, it has gone some evolution to enhance information accuracy. The evolution trends are spectrum sensing, prediction algorithm and recently, geo-location database technique. Previously, spectrum sensing was the main technique for detecting the presence/absence of a primary user (PU) signal in a given radio frequency (RF) spectrum. However, this expectation could not materialized as a result of numerous technical challenges ranging from hardware imperfections to RF signal impairments. To convey the evolutionary trends in the development of white space information, we present a survey of the contemporary advancements in PU detection with emphasis on the practical deployment of CRNs i.e. Television white space (TVWS) networks. It is found that geo-location database is the most reliable technique to acquire TVWS information although, it is financially driven. Finally, using financially driven database model, this study compared the data-rate and spectral efficiency of FCC and Ofcom TV channelization. It was discovered that Ofcom TV channelization outperforms FCC TV channelization as a result of having higher spectrum bandwidth. We proposed the adoption of an all-inclusive TVWS information acquisition model as the future research direction for TVWS information acquisition techniques.

References

1.

Bedogni, L., et al. (2017). Indoor use of gray and white spaces: Another look at wireless indoor communication. IEEE Vehicular Technology Magazine, 12(1), 63–71.

Article

Google Scholar

2.

Şeflek, İ., & Yaldız, E. (2017). Spectrum occupancy measurements at university campus in Turkey. International Journal of Electronics and Electrical Engineering, 5(1), 1–6.

Google Scholar

3.

Martian, A., et al. (2016). Access to RF white spaces in Romania: Present and future. Wireless Personal Communications, 87(3), 693–712.

Article

Google Scholar

4.

Oh, S. W., et al. (2016). TV white space: The first step towards better utilization of frequency spectrum. Hoboken: Wiley.

Google Scholar

5.

FCC. (2008). Second report and order and memorandum opinion and order, in the matter of unlicensed operation in the TV broadcast bands (ET Docket No. 04-186) and additional spectrum for unlicensed devices below 900 MHz and in the 3 GHz band (ET Docket No. 02-380), FCC 08-260.

6.

Chen, R., et al. (2016). Spectrum sensing based on nonparametric autocorrelation in wireless communication systems under alpha stable noise. Mobile Information Systems, 2016, 1–6.

Google Scholar

7.

Anabi, K. H., Nordin, R., & Abdullah, N. F. (2016). Database-assisted television white space technology: Challenges, trends and future research directions. IEEE Access, 4, 8162–8183.

Article

Google Scholar

8.

Ning, G., & Nintanavongsa, P. (2012). Time prediction based spectrum usage detection in centralized cognitive radio networks. In Wireless communications and networking conference (WCNC), 2012 IEEE (pp. 300–305).

9.

Kishore, R., Ramesha, C., & Anupama, K. (2016). Bayesian detector based superior selective reporting mechanism for cooperative spectrum sensing in cognitive radio networks. Procedia Computer Science, 93, 207–216.

Article

Google Scholar

10.

Ali, A., & Hamouda, W. (2016). Advances on spectrum sensing for cognitive radio networks: Theory and applications. IEEE Communications Surveys & Tutorials, 98, 1–29.

Google Scholar

11.

Boyd, S. P., & Vandenberghe, L. (2004). Convex optimization. Cambridge: Cambridge University Press.

Google Scholar

12.

Akyildiz, I. F., et al. (2006). NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey. Computer Networks, 50(13), 2127–2159.

Article

MATH

Google Scholar

13.

Yucek, T., & Arslan, H. (2009). A survey of spectrum sensing algorithms for cognitive radio applications. IEEE Communications Surveys & Tutorials, 11(1), 116–130.

Article

Google Scholar

14.

Shellhammer, S. J., Sadek, A. K., & Zhang, W. (2009). Technical challenges for cognitive radio in the TV white space spectrum. In Information theory and applications workshop (pp. 1–11).

15.

He, A., et al. (2010). A survey of artificial intelligence for cognitive radios. IEEE Transactions on Vehicular Technology, 59(1–4), 1578–1592.

Article

Google Scholar

16.

Baykas, T., et al. (2010). Overview of TV white spaces: Current regulations, standards and coexistence between secondary users. In 2010 IEEE 21st international symposium on personal, indoor and mobile radio communications workshops (PIMRC workshops) (pp. 38–43).

17.

Noguet, D., Gautier, M., & Berg, V. (2011). Advances in opportunistic radio technologies for TVWS. EURASIP Journal on Wireless Communications and Networking, 2011(1), 1–12.

Article

Google Scholar

18.

Ghosh, C., Roy, S., & Rao, M. B. (2012). Modeling and validation of channel idleness and spectrum availability for cognitive networks. IEEE Journal on Selected Areas in Communications, 30(10), 2029–2039.

Article

Google Scholar

19.

Shellhammer, S. J. (2009). A comparison of geo-location and spectrum sensing in cognitive radio. In Proceedings of 18th international conference on computer communications and networks, 2009, ICCCN 2009 (pp. 1–6).

20.

Shellhammer, S. J. (2008). Spectrum sensing in IEEE 802.22. IAPR workshop cognitive information processing (pp. 9–10).

21.

Iliya, S., et al. (2015). Application of artificial neural network and support vector regression in cognitive radio networks for RF power prediction using compact differential evolution algorithm. In 2015 federated conference on computer science and information systems (FedCSIS) (Vol. 5, pp. 55–66).

22.

Leu, A. E., et al. (2005). Ultra sensitive TV detector measurements. In 2005 first IEEE international symposium on new frontiers in dynamic spectrum access networks, 2005. DySPAN 2005 (pp. 30–36).

23.

Eltom, H., et al. (2015). Spectrum occupancy prediction using a hidden markov model. In 2015 9th international conference on signal processing and communication systems (ICSPCS) (pp. 1–8).

24.

Mwangoka, J. W., Marques, P., & Rodriguez, J. (2011). Exploiting TV white spaces in Europe: The COGEU approach. In 2011 IEEE symposium on new frontiers in dynamic spectrum access networks (DySPAN) (pp. 608–612).

25.

Vakil, M., & Nagamani, K. (2017). Cognitive radio spectrum sensing—A survey. International Journal of Recent Trends in Engineering & Research (IJRTER), 3(02), 45–50.

Article

Google Scholar

26.

Guo, H., et al. (2017). Soft combination for cooperative spectrum sensing in fading channels. IEEE Access, 5, 975–986.

Article

Google Scholar

27.

Jiao, Y., Yin, P., & Joe, I. (2016). Clustering scheme for cooperative spectrum sensing in cognitive radio networks. IET Communications, 10(13), 1590–1595.

Article

Google Scholar

28.

Reyes, H., et al. (2016). A spectrum sensing technique based on autocorrelation and Euclidean distance and its comparison with energy detection for cognitive radio networks. Computers & Electrical Engineering, 52, 319–327.

Article

Google Scholar

29.

Ma, Y., et al. (2016). Reliable and efficient sub-nyquist wideband spectrum sensing in cooperative cognitive radio networks. IEEE Journal on Selected Areas in Communications, 34(10), 2750–2762.

Article

Google Scholar

30.

Nekovee, M. (2009). A survey of cognitive radio access to TV white spaces. In International conference on ultra modern telecommunications & workshops, 2009, ICUMT'09 (pp. 1–11).

31.

Baykas, T., et al. (2012). Developing a standard for TV white space coexistence: Technical challenges and solution approaches. IEEE Wireless Communications, 19(1), 10–22.

Article

Google Scholar

32.

Arianandа, D. D., Lakshmanan, M., & Nikookar, H. (2009). A survey on spectrum sensing techniques for cognitive radio. In Second international workshop on cognitive radio and advanced spectrum management, 2009, CogART 2009 (pp. 74–79).

33.

Sun, H., et al. (2013). Wideband spectrum sensing for cognitive radio networks: A survey. IEEE Wireless Communications, 20(2), 74–81.

Article

Google Scholar

34.

Wang, L., et al. (2011). A survey of cluster-based cooperative spectrum sensing in cognitive radio networks. In Cross strait quad-regional radio science and wireless technology conference (CSQRWC) (pp. 247–251).

35.

802.22, l. (2011). Introduction to IEEE Std. 802.22-2011 and its amendment PAR for P802.22b: Broadband extension and monitoring. doc.: IEEE 802.22-11/0132r03 (pp. 1–65).

36.

Xing, X., et al. (2013). Spectrum prediction in cognitive radio networks. IEEE Wireless Communications, 20(2), 90–96.

Article

Google Scholar

37.

Feng, X., Zhang, J., & Zhang, Q. (2011). Database-assisted multi-ap network on tv white spaces: Architecture, spectrum allocation and ap discovery. In 2011 IEEE symposium on new frontiers in dynamic spectrum access networks (DySPAN) (pp. 265–276).

38.

Gurney, D., et al. (2008). Geo-location database techniques for incumbent protection in the TV white space (pp. 1–9).

39.

Ishizu, K., Murakami, H., & Harada, H. (2012). TV white space database for coexistence of primary-secondary and secondary-secondary systems in mesh networking. In 2012 15th international symposium on wireless personal multimedia communications (WPMC) (pp. 118–122).

40.

Saleem, Y., & Rehmani, M. H. (2014). Primary radio user activity models for cognitive radio networks: A survey. Journal of Network and Computer Applications, 43, 1–16.

Article

Google Scholar

41.

Chen, Y., & Oh, H.-S. (2014). A survey of measurement-based spectrum occupancy modeling for cognitive radios. IEEE Communications Surveys & Tutorials, 4(1), 848–859.

Google Scholar

42.

An, C., et al. (2011). Spectrum sensing sequence prediction in cognitive radio networks. High Technology Letters, 17(4), 371–376.

Google Scholar

43.

Jaglan, R. R., et al. (2016). Performance evaluation of energy detection based cooperative spectrum sensing in cognitive radio network. Proceedings of First International Conference on Information and Communication Technology for Intelligent Systems, 2, 585–593.

Google Scholar

44.

Kishore, R., et al. (2014). Performance evaluation of energy based spectrum sensing in multipath fading channel for cognitive radio system. In 2014 national conference on communication, signal processing and networking (NCCSN) (pp. 1–6).

45.

Maity, S. P., Chatterjee, S., & Acharya, T. (2016). On optimal fuzzy c-means clustering for energy efficient cooperative spectrum sensing in cognitive radio networks. Digital Signal Processing, 49, 104–115.

Article

Google Scholar

46.

Ma, J., Zhao, G., & Li, Y. (2008). Soft combination and detection for cooperative spectrum sensing in cognitive radio networks. IEEE Transactions on Wireless Communications, 7(11), 4502–4507.

Article

Google Scholar

47.

Ghasemi, A., & Sousa, E. S. (2005). Collaborative spectrum sensing for opportunistic access in fading environments. First IEEE international symposium on new frontiers in dynamic spectrum access networks 2005, DySPAN 2005 (pp. 1–6).

48.

Visotsky, E., Kuffner, S., & Peterson, R. (2005). On collaborative detection of TV transmissions in support of dynamic spectrum sharing. First IEEE international symposium on new frontiers in dynamic spectrum access networks, 2005, DySPAN 2005 (pp. 7–12).

49.

Peh, E. C. Y., et al. (2009). Optimization of cooperative sensing in cognitive radio networks: A sensing-throughput tradeoff view. IEEE Transactions on Vehicular Technology, 58(9), 5294–5299.

Article

Google Scholar

50.

Alvi, S. A., et al. (2015). A near-optimal LLR based cooperative spectrum sensing scheme for CRAHNs. IEEE Transactions on Wireless Communications, 14(7), 3877–3887.

Article

Google Scholar

51.

Han, W., et al. (2013). Efficient soft decision fusion rule in cooperative spectrum sensing. IEEE Transactions on Signal Processing, 61(8), 1931–1943.

MathSciNet

Article

Google Scholar

52.

Chaudhari, S., et al. (2012). Cooperative sensing with imperfect reporting channels: Hard decisions or soft decisions? IEEE Transactions on Signal Processing, 60(1), 18–28.

MathSciNet

Article

Google Scholar

53.

Huang, S., et al. (2012). Energy-efficient cooperative spectrum sensing with amplify-and-forward relaying. IEEE Communications Letters, 16(4), 450–453.

Article

Google Scholar

54.

Monemian, M., & Mahdavi, M. (2014). Analysis of a new energy-based sensor selection method for cooperative spectrum sensing in cognitive radio networks. IEEE Sensors Journal, 14(9), 3021–3032.

Article

Google Scholar

55.

Maleki, S., et al. (2015). To AND or To OR: On energy-efficient distributed spectrum sensing with combined censoring and sleeping. IEEE Transactions on Wireless Communications, 14(8), 4508–4521.

Article

Google Scholar

56.

Aziz, A., & Uppal, M. (2014). Energy-efficient cooperative spectrum sensing using rateless coded relaying. In 2014 IEEE on wireless communications and networking conference (WCNC) (pp. 827–832).

57.

Althunibat, S., Di Renzo, M., & Granelli, F. (2015). Towards energy-efficient cooperative spectrum sensing for cognitive radio networks: An overview. Telecommunication Systems, 59(1), 77–91.

Article

Google Scholar

58.

Wimalajeewa, T., & Varshney, P. K. (2014). OMP based joint sparsity pattern recovery under communication constraints. IEEE Transactions on Signal Processing, 62(19), 5059–5072.

MathSciNet

Article

Google Scholar

59.

Wei, D., Feng, C., & Guo, C. (2010). A sensing time saving cluster-based cooperative spectrum sensing scheme. In 2010 12th IEEE international conference on communication technology (ICCT) (pp. 1244–1247).

60.

Bresler, Y. (2008). Spectrum-blind sampling and compressive sensing for continuous-index signals. In Information theory and applications workshop, 2008 (pp. 547–554).

61.

Candès, E. J., Romberg, J., & Tao, T. (2006). Robust uncertainty principles: Exact signal reconstruction from highly incomplete frequency information. IEEE Transactions on Information Theory, 52(2), 489–509.

MathSciNet

Article

MATH

Google Scholar

62.

Hassanieh, H., et al. (2014). Ghz-wide sensing and decoding using the sparse Fourier transform. In 2014 proceedings IEEE INFOCOM (pp. 2256–2264).

63.

Feng, P., & Bresler, Y. (1996). Spectrum-blind minimum-rate sampling and reconstruction of multiband signals. In 1996 IEEE international conference on acoustics, speech, and signal processing, 1996, ICASSP-96 (Vol. 3, pp. 1688–1691).

64.

Buljore, S, Harada, H., Filin, S., Houze, P., Tsagkaris, K., Holland, O., et al. (2009). Architecture and enablers for optimized radio resource usage in heterogeneous wireless access networks: The IEEE 1900.4 working group. IEEE communications magazine (pp. 122–129).

65.

Li, X. (20085). Traffic pattern prediction and performance investigation for cognitive radio systems. In Wireless communications and networking conference, 2008, WCNC 2008. IEEE (pp. 894–899).

66.

Tumuluru, V. K., Wang, P., & Niyato, D. (2010). A neural network based spectrum prediction scheme for cognitive radio. In 2010 IEEE international conference on communications (ICC) (pp. 1–5).

67.

El Gamal, H., Tadrous, J., & Eryilmaz, A. (2010). Proactive resource allocation: Turning predictable behavior into spectral gain. In 2010 48th annual Allerton conference on communication, control, and computing (Allerton) (pp. 427–434).

68.

Kotobi, K., et al. (2015). Data-throughput enhancement using data mining-informed cognitive radio. Electronics, 4(2), 221–238.

Article

Google Scholar

69.

Gorcin, A., et al. (2011). An autoregressive approach for spectrum occupancy modeling and prediction based on synchronous measurements. In 2011 IEEE 22nd international symposium on personal indoor and mobile radio communications (PIMRC) (pp. 705–709).

70.

Pourahmadi, M. (2001). Foundations of time series analysis and prediction theory (Vol. 379). Hoboken: Wiley.

Google Scholar

71.

Haykin, S. (2005). Cognitive radio: Brain-empowered wireless communications. IEEE Journal on Selected Areas in Communications, 23(2), 201–220.

Article

Google Scholar

72.

Yarkan, S., & Arslan, H. (2007). Binary time series approach to spectrum prediction for cognitive radio. In 2007 IEEE 66th vehicular technology conference, 2007, VTC-2007 fall (pp. 1563–1567).

73.

Wen, Z., et al. (2008). Autoregressive spectrum hole prediction model for cognitive radio systems. In IEEE international conference on communications workshops, 2008, ICC Workshops'08. 2008 (pp. 154–157).

74.

Kaneko, S., et al. (2008). Predicting radio resource availability in cognitive radio-an experimental examination. In 3rd international conference on cognitive radio oriented wireless networks and communications, 2008, CrownCom 2008 (pp. 1–6).

75.

López-Benítez, M. (2013). Can primary activity statistics in cognitive radio be estimated under imperfect spectrum sensing? In 2013 IEEE 24th international symposium on personal indoor and mobile radio communications (PIMRC) (pp. 750–755).

76.

Tandur, D., et al. (2012). Cognitive radio systems evaluation: Measurement, modeling, and emulation approach. IEEE Vehicular Technology Magazine, 7(2), 77–84.

Article

Google Scholar

77.

Wang, Z., & Salous, S. (2008). Time series arima model of spectrum occupancy for cognitive radio. In 2008 IET seminar on cognitive radio and software defined radios: Technologies and techniques (pp. 1–4).

78.

Tabassam, A. A., et al. (2011). Spectrum estimation and spectrum hole opportunities prediction for cognitive radios using higher-order statistics. In Wireless advanced (WiAd) (pp. 213–217).

79.

Koller, D., & Friedman, N. (2009). Probabilistic graphical models: Principles and techniques. Cambridge: MIT Press.

Google Scholar

80.

Park, C.-H., et al. (2007). HMM based channel status predictor for cognitive radio. In Microwave conference, 2007, APMC 2007. Asia-Pacific (pp. 1–4).

81.

Akbar, I. A., & Tranter, W. H. (2007). Dynamic spectrum allocation in cognitive radio using hidden Markov models: Poisson distributed case. In Proceedings SoutheastCon, 2007. IEEE (pp. 196–201).

82.

Chen, S., & Tong, L. (2011). Maximum throughput region of multiuser cognitive access of continuous time markovian channels. IEEE Journal on Selected Areas in Communications, 29(10), 1959–1969.

Article

Google Scholar

83.

Tang, W., et al. (2013). A fair scheduling scheme based on collision statistics for cognitive radio networks. Concurrency and Computation: Practice and Experience, 25(9), 1091–1100.

Article

Google Scholar

84.

Sung, K. W., Kim, S.-L., & Zander, J. (2010). Temporal spectrum sharing based on primary user activity prediction. IEEE Transactions on Wireless Communications, 9(12), 3848–3855.

Article

Google Scholar

85.

Wen, Z., et al. (2010). A learning spectrum hole prediction model for cognitive radio systems. In 2010 IEEE 10th international conference on computer and information technology (CIT) (pp. 2089–2093).

86.

Xing, X., et al. (2013). Channel quality prediction based on Bayesian inference in cognitive radio networks. In 2013 proceedings IEEE INFOCOM (pp. 1465–1473).

87.

An, C., et al. (2011). Spectrum sensing sequence prediction in cognitive radio networks. High Technology Letters, 17(4), 371–376.

Google Scholar

88.

Li, X., & Zekavat, S. A. (2009). Cognitive radio based spectrum sharing: Evaluating channel availability via traffic pattern prediction. Journal of Communications and Networks, 11(2), 104–114.

Article

Google Scholar

89.

Nguyen, T., Mark, B. L., & Ephraim, Y. (2013). Spectrum sensing using a hidden bivariate Markov model. IEEE Transactions on Wireless Communications, 12(9), 4582–4591.

Article

Google Scholar

90.

Shon, S. H., Jang, S. J., & Kim, J. M. (2010). HMM-based adaptive frequency-hopping cognitive radio system to reduce interference time and to improve throughput. TIIS, 4(4), 475–490.

Google Scholar

91.

Goldsmith, A. J., & Varaiya, P. P. (1996). Capacity, mutual information, and coding for finite-state Markov channels. IEEE Transactions on Information Theory, 42(3), 868–886.

Article

MATH

Google Scholar

92.

Mushkin, M., & Bar-David, I. (1989). Capacity and coding for the Gilbert–Elliott channels. IEEE Transactions on Information Theory, 35(6), 1277–1290.

Article

MATH

Google Scholar

93.

Haykin, S. (1994). Neural networks: A comprehensive foundation. Upper Saddle River: Prentice Hall.

Google Scholar

94.

Taj, M. I., & Akil, M. (2011). Cognitive radio spectrum evolution prediction using artificial neural networks based multivariate time series modelling. In 11th European wireless conference 2011-sustainable wireless technologies (European wireless). VDE (pp. 1–6).

95.

Pattanayak, S., Venkateswaran, P., & Nandi, R. (2013). Artificial intelligence based model for channel status prediction: A new spectrum sensing technique for cognitive radio. International Journal of Communications, Network & System Sciences, 6(3), 1–10.

Article

Google Scholar

96.

Huangyu, L. I., et al. (2014). Multilayer feedforward neural network based efficient spectrum occupancy prediction scheme for cognitive radio system. Journal of Computational Information Systems, 10(10), 4017–4028.

Google Scholar

97.

Bai, S., Zhou, X., & Xu, F. (2014). “Soft decision” spectrum prediction based on back-propagation neural networks. In 2014 international conference on computing, management and telecommunications (ComManTel) (pp. 128–133).

98.

Yin, S., et al. (2012). Mining spectrum usage data: A large-scale spectrum measurement study. IEEE Transactions on Mobile Computing, 11(6), 1033–1046.

Article

Google Scholar

99.

Huang, P., et al. (2014). Wireless spectrum occupancy prediction based on partial periodic pattern mining. IEEE Transactions on Parallel and Distributed Systems, 25(7), 1925–1934.

Article

Google Scholar

100.

Yin, S., et al. (2011). Prediction-based throughput optimization for dynamic spectrum access. IEEE Transactions on Vehicular Technology, 60(3), 1284–1289.

Article

Google Scholar

101.

Kone, V., et al. (2012). The effectiveness of opportunistic spectrum access: A measurement study. IEEE/ACM Transactions on Networking, 20(6), 2005–2016.

Article

Google Scholar

102.

Park, H. K. (2012). Channel allocation using spectrum hole prediction in CR networks. In 2011 9th international conference on ICT and knowledge engineering (ICT & knowledge engineering) (pp. 1465–1473).

103.

Research, Microsoft, “Finding more space in spectrum”. Jan. 2014.

104.

Ofcom, Digital dividend: Cognitive access statement on license exempting cognitive devices using interleaved spectrum. July 2009.

105.

El-Refaey, M., Magdi, N., & Abd El-Megeed, H. (2014). Cloud-assisted spectrum management system with trading engine. In 2014 international wireless communications and mobile computing conference (IWCMC) (pp. 953–958).

106.

http://spectrumbridge.com/ProductsServices/WhiteSpacesSolutions.

107.

FCC. (2010). Second report and order and memorandum opinion and order in the matter of unlicensed operation in the TV broadcast bands, additional spectrum for unlicensed devices below 900 MHz and in the 3 GHz band, docket 08-260.

108.

Ofcom, Implementing geolocation, summary of consultation responses and next steps. Sept. 2011.

109.

Caufield, J. (2011). Protocol to query a white space database.

110.

Joslyn, D., Malyar, J., & Das, S. (2012). Device to database protocol for white space.

111.

FCC. Code of federal regulations title 47, Part 73.699.

112.

Srikanteswara, S., et al. (2015). Cloud-based spectrum management services. US Patent, 2015. US 8,958,813 B2.

113.

Srikanteswara, S., et al. (2015). Cloud-based spectrum management services. Google patents.

114.

Bhattacharjee, S., & Marinescu, D. C. (2014). A cloud service for trust management in cognitive radio networks. International Journal of Cloud Computing, 3(4), 326–353.

Article

Google Scholar

115.

Dionisio, R., et al. (2012). Cross-platform demonstrator combining spectrum sensing and a geo-location database. In Future network & mobile summit (FutureNetw), 2012. IEEE.

116.

De Domenico, A., Strinati, E. C., & Di Benedetto, M.-G. (2012). A survey on MAC strategies for cognitive radio networks. IEEE Communications Surveys & Tutorials, 14(1), 21–44.

Article

Google Scholar

117.

Cordeiro, C., Challapali, K., & Ghosh, M. (2006). Cognitive PHY and MAC layers for dynamic spectrum access and sharing of TV bands. In Proceedings of the ACM TAPAS.

118.

Roos, T., Myllymaki, P., & Tirri, H. (2002). A statistical modeling approach to location estimation. IEEE Transactions on Mobile Computing, 1(1), 59–69.

Article

Google Scholar

119.

Beluri, M., et al. (2012). Mechanisms for LTE coexistence in TV white space. In 2012 IEEE international symposium on dynamic spectrum access networks (DYSPAN) (pp. 317–326).

The authors would like to thank Malaysia's Ministry of Higher Education for their financial support under Grant Ref. No. ERGS/1/2013/ICT03/UKM/02/1.

Author information

Affiliations

Department of Electrical, Electronic and System Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600, Bangi, Selangor, Malaysia

Hilary K. Anabi, Rosdiadee Nordin & Nor Fadzillah Abdullah

Department of Electrical and Electronics Engineering, Faculty of Engineering, Al-Madinah International University, Shah Alam, Malaysia

Omar B. Abdulghafoor

Department of Computer and Communication Systems, Faculty of Engineering, University Putra Malaysia, Serdang, Malaysia

Aduwati Sali, Ahmed Mohamedou & Abdulmajid Almqdshi

Correspondence to Hilary K. Anabi.

About this article

Verify currency and authenticity via CrossMark

Cite this article

Anabi, H.K., Nordin, R., Abdulghafoor, O.B. et al. From Sensing to Predictions and Database Technique: A Review of TV White Space Information Acquisition in Cognitive Radio Networks. Wireless Pers Commun 96, 6473–6502 (2017). https://doi.org/10.1007/s11277-017-4487-6

Issue DateOctober 2017

DOIhttps://doi.org/10.1007/s11277-017-4487-6