Spectrum Sharing in Radar and Wireless Communication Systems: A Review

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Abstract — **The idea of spectrum sharing between radar and wireless communication systems arise because of the need for extra bandwidth for wireless communication systems. Due to strong and ever growing economic, political, social, and technological driving factors, realization of this vision is inevitable in near future. Therefore, novel solutions for the efficient and fair sharing of the spectrum is needed. In this paper, we present a** 简洁的 **concise review of the state of the art on radar and communication system coexistence and bandwidth sharing.**

1 INTRODUCTION

Wireless communication technology has recently evolved dramatically with ever growing number of users and proliferation of applications, that it become a indispensable feature of human life [1]. With increasing number of mobile devices and demands on higher data transmission rates for advance wireless technology, more radio spectra are sought after by commercial service providers and federal agencies [2]. The demand on radio spectrum urges efficient use of spectrum and emerges a challenging problem on future spectrum planning.

In [1], it is clearly addressed that new Federal spectrum architecture should be based on sharing rather than clearing and reallocating the sought after spectrum. Thus, spectrum sharing technology has emerged as a developing research topic to both radar and communication communities. Hence, cooperation between these two established technology areas needs to be vitalized and extended. In this paper, we present a concise review of the state of the art on radar and communication system coexistence and bandwidth sharing.

2 SPECTRUM SHARING CONSIDERATIONS

Spectrum sharing, or shared spectrum access, involves a primary user, whom the bandwidth is licensed to, and a secondary user that utilizes the same spectrum band without endangering any mission of both sides [3]. Until recently, spectrum allocation (*i.e.*, a certain frequency band is assigned exclusively to a certain electromagnetic wave emitting technology like radar or wireless communications) was vital to prevent any interference among different systems. However, with the emergence of recent technologies in radio communication, spectrum sharing in time and space has a feasible future [4]. In particular cognitive radio is an emerging technology that can exploit unused/underutilized spectrum bands via opportunistic dynamic spectrum sharing [5].

Technical challenges of spectrum sharing involves both accurately sensing radio environment, and transmitting signals accordingly. Challenges of spectrum sharing in communication systems are widely investigated in numerous studies [6–10]. Although, the effects of RF interference in radar systems concerning spectrum sharing is investigated in the past (*e.g.*, [11]), more work needs to be done to understand drawbacks and fundamental limits of spectrum sharing in radar and communications systems coexistence.

3 SPECTRUM SHARING TECHNIQUES AND APPROACHES

Shared spectrum access for radar and communications is one of the important research and development areas which is identified by DARPA [12]. In fact, the solutions for spectrum sharing can be classified into three broad categories. 1 In the first category, radar system as taken as the primary user and the objective is the maximize the performance of the communication system utilizing radar spectrum as a secondary user (*i.e.*, radar performance should not be deteriorated by the communication system). In this category radar system is not affected by the shared use of the spectrum and the burden of ensuring this constraint is on the communication system, entirely. 2 In the second category, solutions are proposed to mitigate the interference caused by the communication system on the radar. 减轻，缓和 Although it is assumed the communication system is operating cognitively, the proposed solutions are developed by assuming the interference

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978-1-4673-5710-4/13/$31.00

mitigation responsibility is on radar itself without any level of explicit 明确的 cooperation among the radar and the communication system. ③ The third category is the most sophisticated category and it, potentially, brings the highest gains for both radar and communication systems operating in the same frequency band. In this category, both radar and 减轻，缓解 communication systems cooperatively alleviate the effects of interference to each other which necessitates joint design of both systems for interference mitigation.

3.1 Cognitive Communication in Presence of Radar

In [13], safe regions where radar and communication systems can coexist are investigated. The safe regions are defined as the operating conditions where the communication system causes acceptable level of interference to the radar. The level of interference created by the communication system to the radar is assessed and limited through cooperative spectrum sensing. In particular, the effects of number of sensing nodes utilized for channel sensing and the influence of channel correlation to each sensing node are explored. The main metric for the evaluation of interference caused by the communication is determined as the maximum interference-to-noise ratio threshold at the radar that defines the maximum allowable interference level relative to the noise floor (*i.e.*, detection performance of the primary radar system is not compromised).

Four operating regimes are considered according to the sensing and interference levels. ① The first regime is the non-interfering/detectable regime where the radar is detectable, yet, the communication system do not create any harmful interference. ② The second regime is the non-interfering/non-detectable regime where the radar is not detected and interference cannot occur. ③ The third regime is the interfering/detectable regime where the communication system can create harmful interference to the radar, however, will not create interference because the radar is detectable. ④ The fourth regime is the interfering/non-detectable regime which is the regime to avoided because the communication system can create harmful interference to the radar and it is not aware of this fact.

As the number of cooperating sensing terminals increase, the detection performance is shown to improve. Furthermore, the number of sensing terminals can be minimized if the selected terminals are sufficiently separated so the channel correlation is low. If the communication system comes to a halt 停止 when any radar signal presence is determined then the spectrum utilization is insufficient.

In [14], the effects of spectrum sharing between a rotating radar and an OFDM (Orthogonal Frequency Division Multiplexing) based cellular system is investigated. The radar is considered as the primary user of the spectrum of interest and the communication system is the secondary user which utilizes the channel in an opportunistic fashion, therefore, the main constraint to be satisfied is that the secondary device is allowed to transmit when its resulting interference will not exceed the radar's tolerable level. The secondary system is not confined to the spectrum used by the radar system only but it also has its own dedicated spectrum (*i.e.*, the radar's spectrum is used cognitively to support the dedicated spectrum of the communication system). It is shown that the communication system can benefit substantially from the cognitive use of the radar's spectrum even when the communication system is located close to the radar. However, the interruptions and fluctuations are also present as the radar rotates. Applications such as non-interactive video on demand, peer-to-peer file sharing, file transfers, automatic meter reading, and web browsing can utilize the service provided the aforementioned spectrum sharing approach with satisfactory level of quality-of-service.

In [15], the design of a cognitive communication system operating at the same spectrum with a rotating radar is proposed. In fact, this work can be perceived as the integration of the ideas in references [13, 14]. The main motivation of [15] is that a satisfactory sensing capability within a secondary cognitive communication system is required to be able to share the radar spectrum efficiently. In a rotating radar setting, the use of weighted sensing algorithms in conjunction with node teaming algorithms are proposed for cooperative sensing. Mobile team spectrum sensing node selection and assignments of team nodes are investigated. The key factors in achieving high performance are identified as the selection of appropriate sensing nodes to join the sensing-active team in various sensing cycles and assignment of the sensing tasks at the most suitable frequency sub-channels. Furthermore, it is shown that characteristics of the radar signal and the computational capabilities of the sensing team nodes are vital inputs in the selection of teaming algorithms.

3.2 Cognitive Radar in Presence of Communication System

In [16], the feasibility of spectrum sharing between radar and communication systems is explored considering that the radar possesses a multiple-input multiple-output (MIMO) structure (i.e., MIMO radar transmit and receive coherent orthogonal phase-coded waveforms from each of the antenna elements) which is necessary for interference mitigation processing. To effectively minimize arbitrary interferences generated by wireless communication systems from any direction received through radar antenna main lobe and side lobes while achieving nearly ideal performances in target detection. A novel signal processing approach is developed for coherent MIMO radar. The proposed approach is investigated theoretically and validated through simulations.

In [17], an information theoretic waveform design algorithm for MIMO radar is proposed to reduce the interference to communication system, which can facilitate spectrum sharing with the radar, while minimizing the PAPR peak-to-average-power ratio and correlation levels of the radar in addition to clutter avoidance. More specifically, the power spectral density of the transmit waveform, which represents a water filling solution to maximize the radar's target detection capabilities, is designed through a convex optimization algorithm. Performance evaluations reveal a fundamental tradeoff between the power spectral density auto and cross-correlation, and the side lobe suppression.

3.3 Joint Cognition of Radar and Communication System

In [18], the concept of bandwidth sharing between multimodal radar and communication systems is introduced. A multimodal radar can change its bandwidth (*i.e.*, the lower the bandwidth is used the lower the resolution is) depending on the target scattering features. Thus, communication systems sharing the same spectrum with a multimodal radar can utilize the unused bandwidth for other applications. Radar's target scanning area is partitioned into sectors and prioritized through the use of a fuzzy logic based approach. A multi objective optimization framework is proposed to maximize the joint utility obtained by assigning the bandwidth to the radar and the communication system. Furthermore, novel scheduling algorithms are developed to increase the number of tasks scheduled for tracking and surveillance for specific target scenarios.

In [19], a proposal for integrating cognitive radio and cognitive radar paradigms for efficient spectrum sharing is made. In fact, the key design concept in this proposal is the exploitation of the location information provided by the cognitive radio in conjunction to spectrum sensing capability of the cognitive radar to minimize interference while achieving the optimal spectrum and power allocation. In fact, both cognitive systems (the radar and the communication system) require sharing of the perception of the radio environment and the radar scene. Entropy of the received signals are utilized to discover the unused frequency bands to achieve better spectrum utilization as opposed to the utilization of signal energy detection.

In [20], OFDM spectral sharing between the radar and the communication system is investigated. Performance metrics for the sharing efficiency are defined as the radar detection performance and communication channel capacity. OFDM waveforms are designed by optimal allocation of subcarriers to both radar and communication system to maximize performance metrics.

4 CONCLUSION

In its current state, spectrum sharing between radar and wireless communication systems is a vision and it is far from being a mature technology. However, due to the stringent demand on extra bandwidth for wireless communication systems can be eased by allowing the wireless communication systems to utilize the radar spectrum. Yet, radar is vital for many important missions and services necessary for military and civilian purposes. Hence, both radar and communication systems sharing the same spectrum should not be endangering the healthy operation of one another. To achieve this goal there has been several proposals in the literature which can be grouped into three broad categories (*i.e.* 1 cognitive communications, 2 cognitive radar, and 3 joint cognition of radar and communication systems). We present an overview of the literature on enabling radar and communication spectrum sharing.

Since radar and communication system spectrum sharing is a research area which is currently in its infancy phase, an explosive growth of this research area should be expected within the coming decade until it is matured enough for large scale field deployments. It is also worth mentioning that experimental studies and field trials are lacking in the literature on spectrum sharing between radar and communication systems. It is of utmost importance to demonstrate the feasibility of spectrum sharing through direct experimentation, which should be one of the important research directions in spectrum sharing.

References

[1] "Report to the president: Realizing the full potential of government-held spectrum to spur economic growth," Executive Office of the President of the USA Presidents Council of

Advisors on Science and Technology, Tech. Rep., 2012.

[2] (2014) TIA white paper: Spectrum sharing research and development. [Online]. Available: http://www.tiaonline.org/policy/spectrum-sharing-research-development-white-paper

[3] C. Jackson, J. Holloway, R. Pollard, R. Larson, C. Sarno, C. Baker, K. Woodbridge, R. Ormondroyd, M. Lewis, and A. Stove, "Spectrally efficient radar systems in the L and S bands," in *Radar Systems, 2007 IET International Conference on*, Oct 2007, pp. 1–6.

[4] A. Ghasemi and E. Sousa, "Fundamental limits of spectrum-sharing in fading environments," *Wireless Communications, IEEE Transactions on*, vol. 6, no. 2, pp. 649–658, Feb 2007.

[5] E. Axell, G. Leus, E. Larsson, and H. Poor, "Spectrum sensing for cognitive radio : State-of-the-art and recent advances," *Signal Processing Magazine, IEEE*, vol. 29, no. 3, pp. 101–116, May 2012.

[6] D. Porcino and W. Hirt, "Ultra-wideband radio technology: potential and challenges ahead," *Communications Magazine, IEEE*, vol. 41, no. 7, pp. 66–74, July 2003.

[7] D. Cabric, I. O'Donnell, M.-W. Chen, and R. Brodersen, "Spectrum sharing radios," *Circuits and Systems Magazine, IEEE*, vol. 6, no. 2, pp. 30–45, 2006.

[8] A. Ghasemi and E. Sousa, "Spectrum sensing in cognitive radio networks: requirements, challenges and design trade-offs," *Communications Magazine, IEEE*, vol. 46, no. 4, pp. 32–39, April 2008.

[9] H. Mahmoud, T. Yucek, and H. Arslan, "OFDM for cognitive radio: merits and challenges," *Wireless Communications, IEEE*, vol. 16, no. 2, pp. 6–15, April 2009.

[10] F. Khozeimeh and S. Haykin, "Dynamic spectrum management for cognitive radio: an overview," *Wireless Communications and Mobile Computing*, vol. 9, no. 11, pp. 1447–1459, 2009.

[11] F. H. Sanders, R. L. Sole, B. L. Bedford, D. Franc, and T. Pawlowitz, "Effects of RF interference on radar receivers," U.S. Dept. of Commerce, National Telecommunications and Information Administration, Tech. Rep. TR-06-444, 2006.

[12] J. M. Chapin, "Shared spectrum access for radar and communications (SSPARC)," Defense Advanced Research Projects Agency, Tech. Rep. DARPA BAA-13-24, 2013.

[13] L. Wang, J. McGeehan, C. Williams, and A. Doufexi, "Application of cooperative sensing in radar-communications coexistence," *Communications, IET*, vol. 2, no. 6, pp. 856–868, July 2008.

[14] R. Saruthirathanaworakun, J. Peha, and L. Correia, "Opportunistic sharing between rotating radar and cellular," *Selected Areas in Communications, IEEE Journal on*, vol. 30, no. 10, pp. 1900–1910, November 2012.

[15] L. Wang, A. Doufexi, C. Williams, and J. McGeehan, "Cognitive node selection and assignment algorithms for weighted cooperative sensing in radar systems," in *Wireless Communications and Networking Conference, 2009. WCNC 2009. IEEE*, April 2009, pp. 1–6.

[16] H. Deng and B. Himed, "Interference mitigation processing for spectrum-sharing between radar and wireless communications systems," *Aerospace and Electronic Systems, IEEE Transactions on*, vol. 49, no. 3, pp. 1911–1919, July 2013.

[17] S. Amuru, R. Buehrer, R. Tandon, and S. Sodagari, "MIMO radar waveform design to support spectrum sharing," in *Military Communications Conference, MILCOM 2013 - 2013 IEEE*, Nov 2013, pp. 1535–1540.

[18] S. Bhat, R. Narayanan, and M. Rangaswamy, "Bandwidth sharing and scheduling for multimodal radar with communications and tracking," in *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2012 IEEE 7th*, June 2012, pp. 233–236.

[19] Y. Nijsure, Y. Chen, C. Yuen, and Y. H. Chew, "Location-aware spectrum and power allocation in joint cognitive communication-radar networks," in *Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM), 2011 Sixth International ICST Conference on*, June 2011, pp. 171–175.

[20] S. Gogineni, M. Rangaswamy, and A. Nehorai, "Multi-modal OFDM waveform design," in *Radar Conference (RADAR), 2013 IEEE*, April 2013, pp. 1–5.