An energy-difference detection based spectrum sensing technique for improving the spectral efficiency of LDACS1 in aeronautical communications

Mathew, Libin K.; Vinod, A. P.

2016

Mathew, L. K., & Vinod, A. P. (2016). An energy-difference detection based spectrum sensing technique for improving the spectral efficiency of LDACS1 in aeronautical communications. Proceedings of the 2016 IEEE/AIAA 35th Digital Avionics Systems Conference (DASC), 1-5.
doi:10.1109/DASC.2016.7777944

<https://hdl.handle.net/10356/144686>

<https://doi.org/10.1109/DASC.2016.7777944>

© 2016 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works. The published version is available at:
<https://doi.org/10.1109/DASC.2016.7777944>

Downloaded on 26 Apr 2023 18:39:52 SGT

An Energy-difference Detection based Spectrum Sensing Technique for Improving the Spectral Efficiency of LDACS1 in Aeronautical Communications

Libin. K. Mathew and A. P. Vinod

School of Computer Science and Engineering, Nanyang Technological University,
Nanyang Avenue, Singapore 639798.

libin001@e.ntu.edu.sg , asvinod@ntu.edu.sg

Abstract—European Organization for the Safety of Air Navigation (EUROCONTROL) has proposed to use the part of L-band for future Air-to-Ground (A/G) communications. Two technology options are available for the proposed L-band digital aeronautical communication system (LDACS); LDACS1 and LDACS2. LDACS1 is considered as the most promising and matured candidate for future A/G communications. There is an agreement on European level to only consider LDACS1 further and LDACS1 is also referred to as LDACS. The efficiency of LDACS1 can be increased by the dynamic allocation of spectrum in an opportunistic fashion, which would require spectrum sensing to detect available frequency bands. In this paper, we propose an energy-difference detection based spectrum sensing scheme for cognitive radio enabled LDACS1 system. A mathematical formulation for the probability of detection, the probability of false alarm and the decision threshold in Additive White Gaussian Noise (AWGN) channel are derived for the proposed scheme. Simulation study shows that the proposed energy-difference detection based sensing scheme offers an improved detection performance than the conventional energy detection method at the low Signal-to-Noise Ratio (SNR) scenarios and identical performance at relatively high SNRs.

Keywords—LDACS1; cognitive radio; spectrum sensing; energy-difference detection.

I. INTRODUCTION

Air traffic is experiencing an enormous growth in the current decade and it is expected to double the current level by 2025 [1]. The traditional aeronautical communication systems use Very High Frequency (VHF) band (118-137 MHz), which is based on a static spectrum allocation. Studies show that the current communication systems are insufficient to support the air traffic demands in future [2]. In order to meet the future air traffic demands, European Organization for the Safety of Air Navigation (EUROCONTROL) and the Federal Aviation Administration (FAA) decided to develop the Future Communications Infrastructure (FCI) which comprises the current and future communication technologies. Future developments in the VHF band is not practical as the spectrum in this region is scarce and it is expected to become heavily saturated in the high density areas. Moreover, the future aeronautical communication systems are expected to support high data rates, which lead to high bandwidth requirements [2].

In order to modernize the Air Traffic Management (ATM) two projects have been initiated: 1: The Next Generation Air Transportation System (NextGen) [3] in United States, and 2: The Single European Sky ATM Research (SESAR) [4] in Europe. The International Civil Aviation Organization (ICAO) recommend that a part of L-band (960 MHz to 1164 MHz) can be used for Air-to-Ground (A/G) communications on a secondary basis. That is, the utilization of this L-band portion is allowed without any interference with legacy systems. Two candidate systems are being investigated concurrently, L-band digital aeronautical communication system type 1 and type 2, abbreviated as LDACS1 and LDACS2 respectively. LDACS1 is a Frequency Division Duplexing (FDD) based system with Orthogonal Frequency Division Multiplexing (OFDM) as modulation scheme and will operate in the frequency range 960-1164 MHz [5]. The LDACS2 is a Time Division Duplexing (TDD) based system and will operate in the frequency range 960-975 MHz [6].

Fig. 1. Visualization of LDACS1 deployment as an inlay approach; LDACS1 channels placed in between two DME channels.

LDACS1 is the most promising and matured candidate for future A/G communication and it is proposed to be deployed as an inlay system between neighbouring Distance Measuring Equipment (DME) channels (that measures aircraft's distance from the ground station) which uses the frequency range 962-

1213 MHz. The LDACS1 channel of bandwidth 0.5MHz is placed at 0.5 MHz and 1 MHz from the adjacent DME and LDACS1 channels respectively [7]. The LDACS1 deployment as an inlay approach is shown Fig. 1.

The efficiency of LDACS1 can be increased by the dynamic allocation of spectrum in an opportunistic fashion. Cognitive radio (CR) is getting significant consideration as the enabling technology to accomplish Dynamic Spectrum Access (DSA) in licensed bands [8]. Spectrum sensing is required to find the spectrum holes so that the CR can use the vacant band for communication. The main spectrum sensing techniques include energy detection [9], matched filter detection [10], wavelet-based detection [11], and the cyclostationary feature detection [12]. Among all these spectrum sensing techniques, energy detection is widely used because of its reduced complexity and incoherent nature. The conventional energy detector measures the energy of the received signal over specified time duration and bandwidth. The measured energy is then compared with the decision threshold to determine the absence or the presence of the unknown signal [9].

In this paper, we propose a spectrum sensing technique for LDACS1 based on an energy difference algorithm, by exploiting the advantage of the spectral shape of OFDM after removing DME pulses from the neighborhood channels. The steps involved in the proposed technique are as follows: The wide band signal of interest is scanned and passed through a DME interference mitigation system to avoid false alarms which may arise due to the presence of DME pulses [13, 14]. The Fast Filter Bank (FFB) [15] is then used to simultaneously scan frequency bands corresponding to different LDACS1 and DME channels. Usage of FFB helps the simultaneous scanning of multiple sub-bands with a lower implementation complexity when compared with other similar filter banks or the per-channel approach. The absolute difference of the energies obtained from the LDACS1 channel and the nearby DME channels (after removing DME pulses) is compared with a predefined threshold. The LDACS1 signal is detected if the energy difference is above the predefined threshold. The performance of the proposed spectrum sensing scheme is evaluated and compared with the conventional energy detection scheme using Monte Carlo simulations.

The paper is organized as follows. In section II, the system model for the spectrum sensing is presented. In section III the proposed energy-difference detection based spectrum sensing scheme is described. The motivation for this work and the mathematical formulation for the decision threshold for the proposed method are also given in detail. Section IV presents the simulation results. Section V concludes the paper.

II. SYSTEM MODEL

A. Spectrum sensing as a binary hypothesis problem

With the presence of noise components, the Primary User (PU) signal detection can be viewed as a binary hypothesis problem with two hypothesis H_0 and H_1 which indicates the presence and absence of PU respectively [16]:

$$y(n) = \begin{cases} w(n) & H_0 \\ x(n) + w(n) & H_1 \end{cases} \quad (1)$$

where $x = hs$ and $n=1,2,\dots,N$. $w(n)$, $s(n)$, and $h(n)$ represents to noise samples (here the noise is assumed as Additive White Gaussian Noise (AWGN)), signal samples and the channel respectively. The hypothesis H_0 represents the absence of the PU signal and H_1 represents the presence of PU signal in the particular band.

B. Test statistics of conventional energy detector

Let $y_i(n)$ be the received signal samples on the i^{th} sensing interval from a frequency band of interest. The test statistic of the conventional energy detector is defined as,

$$T_i(y_i) = \sum_{n=1}^N |y_i(n)|^2 \underset{H_0}{\overset{H_1}{\gtrless}} \lambda \quad (2)$$

$T(y)$ is the test statistic and λ is the decision threshold for the hypothesis H_0 or H_1 [16]. Conventional energy detection fails to offer good performance in low Signal-to-Noise Ratio (SNR) scenarios. This is because the detector does not have a prior knowledge about the noise variance in practical scenarios (the noise variance needs to be estimated). This leads to a performance degradation if the SNR falls below an SNR wall [17]. In LDACS1 spectrum sensing using energy detector, the interference from DME pulses may cause false alarms. Some parts of LDACS1 signals also get removed by the interference mitigation systems used for DME removal which results in a reduction of SNR. This reduction in SNR affects the detection performance. The proposed energy-difference algorithm reduces the effect of noise (reduces SNR degradation) as it takes the difference in energies of LDACS1 and DME channels.

III. ENERGY-DIFFERENCE-DETECTION BASED SPECTRUM SENSING

A. Motivation for proposing energy-difference algorithm

LDACS1 is proposed to deploy as an inlay system in the spectral gaps between two adjacent channels used by the DME channels. The power of DME pulses would be considerably high at LDACS1 receiver, and it significantly affects the LDACS1 performance. The performance of the conventional energy detection also gets affected by the DME interference. The out-of-band radiation of DME pulses may lead to false alarm (the detector may chose the hypothesis H_1 even if the LDACS1 signal is absent). In order to reduce the false alarm rate we need to pass the wideband signal through a DME interference mitigation system. Several pulsed interference mitigation techniques are available in the literature [13, 14]. In order to reduce the overhead in spectrum sensing we need to use the simple interference mitigation systems such as pulse blanking or clipping techniques. In pulse blanking, the signal component is compared with a predefined threshold and if the amplitude of the pulse is above the threshold that component is blanked. It is observed that along with DME signals, some parts of LDACS1 signals are also removed by the DME interference mitigation system which results a reduction in SNR. If the conventional energy detection is used, this

reduction in SNR will degrade the detection performance. The unique spectral shape of OFDM after removing DME pulses from the neighborhood channels can be exploited for a better detection performance. The spectral scenario in L-band is shown in Fig. 2 for different scenarios such as;

- a) LDACS1+DME with mutual interference.
- b) LDACS1 channels after removing DME Pulses.

Fig. 2 (a). LDACS1 and DME together: the spectral scenario with mutual interference.

Fig. 2 (b). LDACS1 spectral view after DME removal.

From Fig. 2 (a), it is clear that the energy due to DME pulses is very high compared to the LDACS1 signals and it offers considerable interference towards LDACS1 channels. This interference raises false alarms in the conventional energy detection. It is observed in Fig. 2(b), there is a reduction in power levels of LDACS1 channels after DME removal. This reduction results SNR degradation. As shown in Fig. 2 (b), if an OFDM signal is present in the LDACS1 channel, there should be a considerable difference in power levels of LDACS1 channel and DME channel (after removing DME pulses). This unique characteristics motivates us to propose an energy-difference detection algorithm for spectrum sensing. Moreover, the energy difference algorithm avoids the problem of SNR degradation by considering the difference in energy values of neighbouring channels (LDACS1 channel and DME channel) which reduces the effect of noise.

B. Energy-difference detection based spectrum sensing

The steps involved in the proposed technique is shown in Fig. 3 are as follows: The wide band signal of interest is scanned and passed through a DME interference mitigation system to avoid false alarms which may arise due to the presence of DME pulses [13,14]. A low-complexity FFB [15] is then used to simultaneously scan the frequency bands corresponding to different LDACS1 and DME channels. FFB gives sharp frequency response at relatively low complexity [15]. FFB uses interpolation and masking techniques in several stages to extract the desired sub-band and it can be realized as bank of filters arranged in a parallel tree structure. For a k -stage FFB, the prototype filter is interpolated by a factor of 2^{k-1} in the i^{th} stage. A k -stage FFB gives $N = 2^k$ sub-bands of equal bandwidths. Energy values are computed for the filtered outputs of each of the frequency bands obtained using the FFB. In the final decision making stage, the absolute difference of the energies obtained from the LDACS1 channel and the nearby DME channels (after removing DME pulses) is compared with a predefined threshold. The LDACS1 signal is detected if the energy difference is above the predefined

Fig. 3. Wide band spectrum sensing using energy-difference detection.

threshold. The schematic diagram of the energy-difference detection based spectrum sensing scheme is shown in Fig. 3.

C. Test statistic of energy-difference detection algorithm

The closed form expressions for the probability of false alarm (P_{fa}) and probability of detection (P_d) can be obtained from the test statistic $T_i(y_i)$. Note that $T_i(y_i)$ follows the central (under H_0) and non-central (under H_1) chi-square distribution with $2N$ degrees of freedom. For low SNR regimes, to get an acceptable performance we need to use a large number of signal samples ($N \gg 1$). If the signal sample is large the test statistic can be assumed to be Gaussian.

The test statistic of the energy in the LDACS1 channel follows the distribution as below.

$$T1_i(y_i) \sim \begin{cases} \mathcal{N}(N\sigma_{w1}^2, 2N\sigma_{w1}^4), & H_0 \\ \mathcal{N}(N(\sigma_x^2 + \sigma_{w1}^2), 2N(\sigma_x^2 + \sigma_{w1}^2)^2), & H_1 \end{cases} \quad (3)$$

For DME channels after removing DME pulses is given as,

$$T2_i(y_i) = \mathcal{N}(N\sigma_{w2}^2, 2N\sigma_{w2}^4), \quad H_0 \& H_1 \quad (4)$$

where, σ_{w2}^2 and σ_x^2 are the noise variance of LDACS1 channel, noise variance of DME channel and the signal variance in the LDACS1 channel respectively.

For the proposed scheme, the test statistic $T_i(y_i)$ follows $T_i(y_i) \sim T1_i(y_i) - T2_i(y_i)$. If the random variables $X_1, X_2, \dots, X_k$ are independent, if X_i has a Gaussian distributions with mean μ_i and variance σ_i^2 ($i = 0, 1, \dots, k$), and if $a_1, a_2, \dots, a_k$ and b are constants with at least one $a_i \neq 0$. Then the new random variable $a_1X_1 + a_2X_2 + \dots + a_kX_k + b$ follows the Gaussian distribution with mean, $\mu = a_1\mu_1 + a_2\mu_2 + \dots + a_k\mu_k + b$ and with variance $\sigma^2 = a_1^2\sigma_1^2 + a_2^2\sigma_2^2 + \dots + a_k^2\sigma_k^2$ [18]. Then the test statistic for the proposed method follows normal distribution as shown in (5).

$$T_i(y_i) \sim \begin{cases} \mathcal{N}(N(\sigma_{w1}^2 - \sigma_{w2}^2), 2N(\sigma_{w1}^4 + \sigma_{w2}^4)), & H_0 \\ \mathcal{N}(N(\sigma_x^2 + \sigma_{w1}^2 - \sigma_{w2}^2), 2N((\sigma_x^2 + \sigma_{w1}^2)^2 + \sigma_{w2}^4)), & H_1 \end{cases} \quad (5)$$

From (5) the probability of false alarm can be derived as,

$$P_{fa} = P(T_i(y_i) > \lambda/H_0) = Q\left(\frac{\lambda - N(\sigma_{w1}^2 - \sigma_{w2}^2)}{\sqrt{2N(\sigma_{w1}^4 + \sigma_{w2}^4)}}\right) \quad (6)$$

The probability of detection can be derived as,

$$P_d = P(T_i(y_i) > \lambda/H_1) = Q\left(\frac{\lambda - N(\sigma_x^2 + \sigma_{w1}^2 - \sigma_{w2}^2)}{\sqrt{2N((\sigma_x^2 + \sigma_{w1}^2)^2 + \sigma_{w2}^4)}}\right) \quad (7)$$

where λ is the decision threshold.

D. Threshold setting

In energy detection based spectrum sensing techniques the threshold is set either for a fixed P_{fa} or for a target P_d . Threshold based on P_d requires the knowledge of noise and signal powers. The noise power can be estimated, whereas the signal power estimation is a difficult task because it depends on varying factors such as propagation and transmission characteristics. Conventionally the threshold is chosen to limit the P_{fa} to an acceptable value, as it requires only the knowledge of noise power. In (8) the decision threshold λ is chosen for a fixed probability of false alarm.

$$\lambda = Q^{-1}(P_{fa})\sqrt{2N(\sigma_{w1}^4 + \sigma_{w2}^4)} + N(\sigma_{w1}^2 - \sigma_{w2}^2) \quad (8)$$

If the energy difference is greater than the decision threshold (8), the proposed algorithm choses the hypothesis H_1 . Otherwise the algorithm choses the hypothesis H_0 .

The conventional energy detection compares the energy value of the LDACS1 channel with the predefined threshold. The test statistic of conventional energy follows $T1_i(y_i)$. P_{fa} for the conventional energy detection scheme is given from (3) as [16],

$$P_{fa} = P(T1_i(y_i) > \lambda/H_0) = Q\left(\frac{\lambda - N\sigma_{w1}^2}{\sqrt{2N\sigma_{w1}^4}}\right) \quad (9)$$

From (9) decision threshold for conventional energy detection is,

$$\lambda = Q^{-1}(P_{fa})\sqrt{2N\sigma_{w1}^4} + N\sigma_{w1}^2 \quad (10)$$

IV. SIMULATIONS AND RESULTS

A. Simulation setup

The performance of the proposed scheme is analyzed using MATLAB simulations. LDACS1 signal generated according to the LDACS1 prototype specifications [5] and the DME pulses are generated using the mathematical model of DME. The DME signals can be modeled as a pair of Gaussian pulses and is given as [13].

$$P(t) = e^{-\frac{\alpha}{2}t^2} + e^{-\frac{\alpha}{2}(t-\Delta t)^2} \quad (11)$$

The parameters α and Δt defines the width of the pulse and spacing between the pulses. The value of $\alpha = 4.5 \cdot 10^{11} \cdot 1/s^2$ gives a pulse width of $3.5 \mu s$ at 50% of the maximum amplitude.

A signal of 8 MHz bandwidth (satisfying interleaved LDACS1 and DME channels of 0.5 MHz) is considered for simulations. A 4-stage FFB is used for the simultaneous extraction of 16 channels, each having 0.5 MHz bandwidth and

the energy corresponding to the each channel is calculated. The performance of the proposed scheme in AWGN channel is analyzed by using 10000 Monte Carlo simulations.

B. Results and discussions

The performance of the proposed scheme and the conventional energy detection is compared by plotting the Receiver Operating Characteristic (ROC) curves (P_d against P_{fa}). The detection performance for different SNRs in the range -26 dB to -6 dB for two false alarm rates ($P_{fa} = 0.1$ and 0.01) is also evaluated and compared with the conventional energy detection (absolute energy obtained from the LDACS1 channel is compared with the decision threshold). It can be seen that from Fig. 4 the proposed energy difference algorithm-based scheme offers a better detection performance than the conventional energy detection method at the low SNR scenarios and identical performance at relatively high SNRs. In Fig. 5 the detection performance of the proposed and conventional schemes are analyzed using ROC curves. The ROC curves are plotted for SNR=-24 dB. From the ROC curves it is clear that the proposed scheme offers better performance than the conventional scheme. For example, when $P_{fa}=0.1$, the proposed scheme gives about 35% improvement in probability of detection when compared to the conventional scheme.

Fig. 4. Detection performance comparison of proposed energy difference algorithm and conventional energy detection technique (SNR Vs probability of detection).

V. CONCLUSIONS AND FUTURE WORK

An energy-difference detection based spectrum sensing scheme for LDACS1 is proposed to increase the spectral utilization efficiency of the future aeronautical communication systems. The decision threshold for the proposed scheme is derived by taking considerations of difference of two random variables. Simulation study shows that the proposed scheme performance is better than the conventional energy detection scheme, especially at low SNR scenarios. In future, the performance evaluation and mathematical formulation for the proposed scheme under multipath fading and shadowing will be conducted.

Fig. 5. Detection performance comparison of proposed energy difference algorithm and conventional energy detection technique using ROC curves (Probability of false alarm Vs Probability of detection).

REFERENCES

- [1] <https://www.eurocontrol.int/dossiers/single-european-sky>
- [2] EUROCONTROL, "Medium-term forecast: IFR flight movements 2011--2017," Brussels, Belgium, Oct. 2011.
- [3] <https://www.faa.gov/nextgen/>
- [4] http://ec.europa.eu/transport/modes/air/sesar/index_en.htm
- [5] EUROCONTROL, "L-DACS1 System Definition Proposal: Deliverable D2," Dec. 2008.
- [6] EUROCONTROL, "L-DACS2 System Definition Proposal: Deliverable D2," May 2009.
- [7] Schnell, M., Eppe, U., Shutin, D. and Schneckenburger, N, "LDACS: future aeronautical communications for air-traffic management," *IEEE Commun. Mag.*, 52(5), pp.104-110, 2014.
- [8] J. Mitola and G. Q. Maguire, "Cognitive radio: Making software radios more personal," *IEEE Trans. Pers. Commun.*, vol. 6, no. 4, pp. 13-18, Aug. 1999.
- [9] H. Arslan and T. Yucek, "Spectrum sensing for cognitive radio applications," in *Cognitive Radio, Software Defined Radio, and adaptive Wireless Systems*, H. Arslan, Ed. New York: Springer-Verlag, 2007.
- [10] J. Proakis, *Digital Communications*, 3rd ed. New York: McGraw-Hill, 1995.
- [11] Z. Tian and G. B. Giannakis, "A wavelet approach to wideband spectrum sensing for cognitive radios," in *Proc. 1st Int. Conf. CROWNCOM*, Jun. 2006, pp. 1-5.
- [12] N. S. Shankar, C. Cordeiro, and K. Challapali, "Spectrum agile radios: Utilization and sensing architectures," in *Proc. of 1st IEEE Int. Symp. on New Frontiers Dyn. Spectr. Access Netw. (DySPAN)*, Baltimore, MD, Nov. 2005, pp. 160-169.
- [13] Eppe U and Schnell M, "Overview of interference situation and mitigation techniques for LDACS1," in *Proc. Digital Avionics Systems Conference (DASC)*, pp. 4C5-1-4C5-12; 2011.
- [14] Brandes S, Schnell M, "Mitigation of pulsed interference in OFDM based systems," in *Proc. 13th Int. OFDM-Workshop (InOWo)*, 2008.
- [15] Y. C. Lim and B. Farhang-Boroujeny, "Fast filter bank (FFB)," *IEEE Trans. Circuits and Systems II (TCAS II)*, vol. 39, no. 5, pp. 316-318, May 1992.
- [16] López-Benítez, M. and Casadevall, F, "Improved energy detection spectrum sensing for cognitive radio," *IET Trans. on Commun.*, 6(8), pp.785-796, 2012.
- [17] A. Mariani, A. Giorgetti and M. Chiani, "SNR Wall for Energy Detection with Noise Power Estimation," in *Proc. of IEEE Int. Conf. on Communications (ICC)*, Kyoto, 2011, pp. 1-6.

Morris, H.D. and Mark, S.J., 1975. Probability and statistics.