Journal of Engineering Science and Technology Review
Special Issue on Telecommunications, Informatics, Energy and Management 2019

Conference Article

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

Hybrid Fusion Algorithm to Improve the Accuracy of Spectrum Occupancy Evaluation and Management

MaheshNair[1,2] and Konstantinos N. Voudouris[1]

[1]*Department of Electrical and Electronics Engineering, University of West Attica, Athens, Greece*
[2]*Dept. of Electrical Engineering, Higher Colleges of Technology (HCT), Abu Dhabi, United Arab Emirates (UAE)*

Received 30 September 2019; Accepted 22 February 2020

Abstract

The areas of application of wireless communication are expanding rapidly which makes an increasing requirement for effective spectrum monitoring and management. It is very important to identify the primary, secondary and illegal users and accurate assessment of their usage of the spectrum. Accuracy in signal reception is a major concern in wireless communication especially in applications like Industrial, medical and military. This study proposes a method of hybrid fusion, hybrid between sensor level, information level and data level of same signals received using multiple receivers. Parameter extraction is done using a multi receiving digital communication system in a multi-path environment based on Bi-Linear Time-Frequency analysis. Classification accuracy of each receiver in the multi receiver system will be different as the propagation characteristics are different. Performance of classifiers is evaluated by comparing their performance at different SNRs. Different types and levels of information fusion are compared and the most suitable method for this application is selected.

Keywords: Multi-sensor data fusion; spectrum monitoring; hybrid fusion.

1. Introduction

The areas of application of wireless communication is expanding rapidly and this leads to a very high demand in the frequency spectrum allocation. Spectrum management efficiency and effectiveness will be improved when the radio frequency spectrum is characterized quickly and precisely. The spectrum monitoring process is mainly used to determine the occupancy of channels and spectral bands, and the characterization and localization of signals and their sources [1]. It is important to have a real-time analysis of the signals for effective spectrum surveillance.

The quality of reception in wireless communication is of utmost importance especially in medical, military and industrial applications. This study investigates how Multi Sensor Data / Information fusion of same signals from multiple receivers improves on the accuracy of reception when compared to reception by a single receiver. Data fusion techniques combine data from multiple sensors to achieve more specific inferences than could be achieved by using a single, independent sensor [1].

1.1 Advantages of Hybrid Fusion

Volume of data available for analysis is increasing rapidly with the development of new sensors and systems. This increases the importance to extract the most useful information from the data gathered in an effective manner. The fusion of information from sensors with different physical characteristics enhances the understanding of our surroundings and provides the basis for planning, decision-making, and control of autonomous and intelligent machines [1]. Multi sensor data fusion is a proven technique in wireless sensor network. The advantages of data fusion are many. A statistical advantage is gained by adding N observations [1] with identical sensors. The accuracy of the observation process can be improved by relative placement of multiple sensors.

The literature on data fusion in ocean surveillance, air to air and surface to air defense, battlefield intelligence, condition-based maintenance, robotics, medical diagnostics and environmental monitoring are substantial. Spectrum Monitoring and Management and Cognitive Radio Systems are the areas where Multi Sensor Data Fusion can play a pivotal role in improving the efficiency of the system. The focus of this paper is on improving the efficiency of spectrum monitoring and management using multi-sensor data fusion.

Precise target detection is achieved by fusion of multiple RADAR information and this makes multi-sensor data fusion an essential component for RADAR surveillance applications [2]. Air Traffic Controller systems is another area where information fusion is used to improve the accuracy of situation awareness and air and surface safety.Satellite systems and Air to Ground data links are emerging reliable technologies in Air Traffic Control apart from RADAR. If the information from these sensors are merged, it can improve the accuracy, speed and robustness of air traffic controller system in a much efficient way.

* E-mail address: kvoud@uniwa.gr
ISSN: 1791-2377 © 2020 School of Science, IHU.
All rights reserved.

The fusion can be performed at different levels like sensor level, feature level or at decision level depending upon the application. If all the data received is to measure the same phenomenon,then the raw sensor data can be directly combined at Sensor Level. Classic estimation methods such as Kalman filtering is commonly used for sensor level fusion. Fusion performed after extracting features from sensor data is called as feature level fusion. Multiple features extracted from different sensors are combined to form a feature vector (Example: measurement of air temperature, pressure and humidity to measure air refractive index) Pattern recognition techniques like neural network, clustering algorithms are used for fusion at feature level in general. If the fusion is performed when each sensor has made a preliminary estimation or decision, it is termed as decision level fusion. Weighted decision like voting techniques, Bayesian inference are the common methods used in this case.

Multi-sensor data fusion is widely used in defense in the areas like ocean surveillance, air to air and surface to air defense battlefield intelligence and strategic warning etc. Condition based maintenance, robotics, medical diagnostics and environmental monitoring are some of the areas where multi-sensor data fusion combines information from different types of sensors for effective decision making.

1.2 Parameter extraction using Time Frequency Distribution

Wigner Ville Distribution (WVD) is a popular method to perform time frequency analysis of non-stationary time varying signal and it uses an auto correlation function for calculating the power spectrum. The signal is compared to itself for any relative lags or shifts as shown in the equation below which makes it an ideal technique for signals in a multi-path fading environment.

$$\gamma_{ss}(\tau) = \int s(t)s(t+\tau)dt \tag{1}$$

[Where τ - Shift of the signal with respect to itself]

WVD has a Time and Frequency shift invariance. Regardless of location in the time frequency plane, the components of two signals – the time shifted versions of each other – look the same. This makes WVD better than similar techniques like STFT. But when we have several frequency components similar to applications like spectrum monitoring, WVD will have issues like cross terms. The cross terms is the cross-over effect between the different signal components of the multicomponent signal.

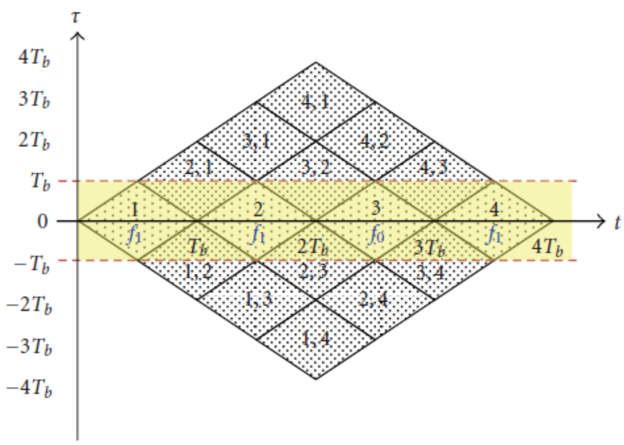

Fig 1. Bilinear product of FSK signal with lag-window. The bilinear products beyond the shaded area are removed [4].

Tan J.L et. al [3] proposes a method adaptive Smooth-Windowed Wigner Ville bi-spectrum (SWWVB) for accurate estimation of modulation parameters of digital communication signals in a multipath fading environment. Fading makes instantaneous variation in the SNR but the proposed method, adaptive Smooth-Windowed Wigner Ville bi-spectrum (SWWVB) combines the advantage of time-frequency analysis and higher order statistics (HOS).
The adaptive smooth windowed Wigner Ville distribution can be expressed as [4]:

$$W_z(t,f) = \int_t G(1,t) * Kz\,(1,t)e^{j2\pi f t}dt \tag{2}$$

Bilinear product:

$$K_z(1,t) = z\left(1+\frac{t}{2}\right)z^*(1,-t/2) \tag{3}$$

Kernel function is given by:

$$G(1,t)=H(t)w(t) \tag{4}$$

where *H(t)* is the Time smooth function and *w(τ)* the lag window function. So the Smooth Window Wigner Ville function is given as

$$\rho_{z,swwvd}(t,f) = \int_{-\infty}^{+\infty} H(t,\tau)\frac{*}{(t)}K_z(t,\tau)w(\tau)\,\mathrm{e}^{-j2\pi f t}\,\mathrm{dt} \tag{5}$$

With this technique the cross terms are supressed and signal parameters are extracted very accurately. These parameters can be given to a classifier to identify the modulation type of the digitally modulated signal.

1.3 Spectrum monitoring concerns in today's wireless system:

Effective monitoring and management of the frequency spectrum has become a growing concern as new applications, technologies and standards are being developed and deployed in the wireless spectrum. Studies are being carried out globally to make an effective use of the available spectrum as an intelligent spectrum management mechanism is required to manage systems with complex digitally modulated waveforms with wide bandwidths and having low power. Technologies like dynamic spectrum allocation, aggregation of non-contagious spectrum allocations, cognitive radios and packet-based burst data transmission are some of the new methods to utilize the spectrum more effectively.

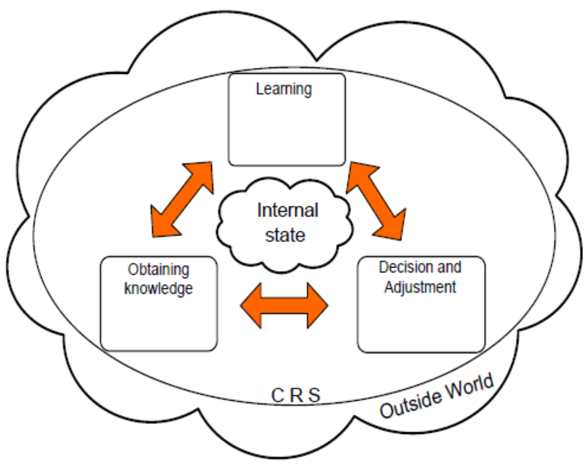

Fig 2. Cognitive Radio System model

Spectrum sensing is an important part of Cognitive Radio System (CRS) as it is important to decide the presence of primary signal from the observed signal. Objective of the spectrum sensing is to provide more spectrum access opportunities to Cognitive Radio users without interference to the primary users [5]. Cooperative spectrum sensing using multiple receivers used as an effective method to improve detection performance by exploiting spatial diversity [6].

The key users of the spectrum are broadly classified as commercial and public safety spectrum users, spectrum regulators and security and defense agencies. The growth of wireless technology and its application areas and the increased mobility offered by hand-held computing devices makes the physical layer congested and that encourages more people to use the spectrum illegally.

Identification of an unknown transmitting station can be facilitated if the location of the transmitter can be determined by triangulation using Direction-Finding (DF) equipment. This is widely used in spectrum monitoring. Multi-channel system for Direction Finding requires less time to obtain a result than a one channel DF [7].

There are many challenges in spectrum management like: weak signal masked by the stronger ones, higher noise levels, short duration events produced by spread spectrum and frequency-hopping etc. The illegal users of the spectrum and overlapping spectrum boundaries between countries are considered to be concerns which require serious attention. The hybrid fusion technique proposed here is an effective solution to all the above difficulties of spectrum monitoring.

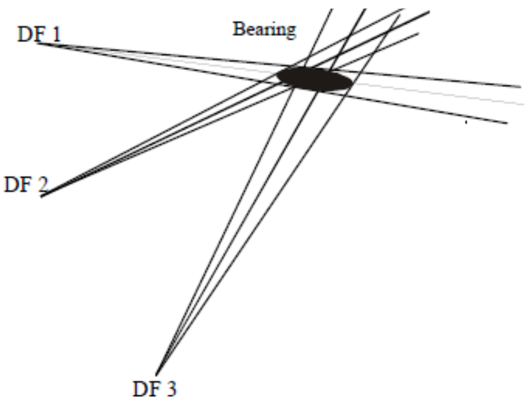

Fig 3. Direction Finding using triangulation method [8]

Table 1. Equipment used for spectrum management

Equipment used for spectrum management	Application / Types
Antennas	Monitoring Measurement
Receivers	Analog Digital
Direction Finding	Antenna DF equipment Receivers
Additional Equipment	Frequency measuring RF field strength Spectrum and BW Modulation Recording RF identification
Automation Monitoring	Computers Modem Client service architecture

2. Material and method

Efficient spectrum monitoring and management is essential because of the following reasons:

1. Resolution of electromagnetic spectrum interference so that stations may coexist compatibly.
2. Ensuring quality reception of radio and television channels.
3. Monitoring channel occupancy and band congestion, verification of license compliance, detection of illegal transmitters and verification of frequency records.

Multipath fading, shadowing and receiver uncertainty issues affect the quality of signal reception by a single receiver. Spectrum Monitoring demands highly accurate signal reception to detect any interference or dynamic access to the spectrum. Transmitter identification is the biggest challenge in spectrum management. It is difficult to determine transmission source, more specifically, if the transmitter is a primary user (PU) or secondary user (SU) or an illegal user. There is always a competition for white spaces between the PU and the SUs in the medium. Andre et.al suggests [9] the use of a Hidden Markov model to distinguish signals from licensed devices in scenarios where their SNR values are comparable to the ones from cognitive devices. PUs normally exhibit a statistically well-defined access pattern when compared to SUs. SUs are allowed to use the white spaces and the silent periods of the PU transmission is used for SU transmission. Using HMM, these patterns along with their signatures are studied and then classified to identify the type of user.

Inter-signal interference and Doppler shift deteriorate the quality of reception and the performance of spectrum monitoring facility. Hybrid fusion helps to eliminate these problems to a greater extend. Increased computational complexity and data link bandwidth are the concerns of hybrid fusion and this could affect the performance of the spectrum monitoring process.

2.1 Types of fusion

When there are multiple receivers to receive the same signal, there will be concerns like alignment of received signals from multiple receivers, correlation and association of data corresponding to each receiver etc. This raises the question where to fuse – raw data level, feature level, information level or at multiple levels?

2.2 Hybrid Fusion algorithm

Observational data may be combined at different levels such as raw data level, feature level or at the decision level depending upon the application. This study proposes a fusion method which is hybrid between sensor level, feature level and information level.

Initially for the study we use three receivers with identical parameters. These receivers are kept at different directions and locations for statistical advantage. The fig 5 shows Time Frequency Distribution of FSK signals received through three different sensors having different channel gains.

Fusion is initially performed at all levels and later a hybrid fusion engine combines the decisions to reach a conclusion in real time. It is essential to eliminate correlation of input signals as it could lead to imperfections in fusion algorithm. It is achieved by explicit removal method [10].

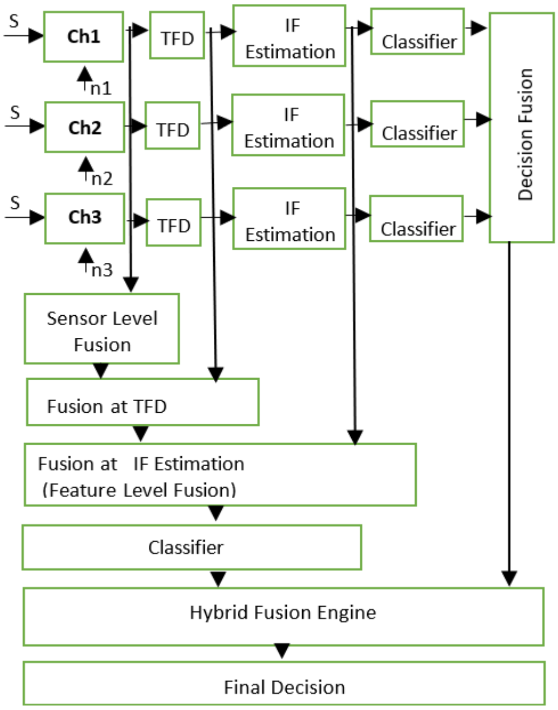

Fig 4. Hybrid fusion architecture

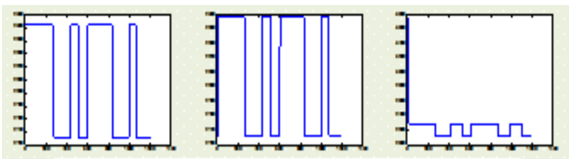

Fig 5. Time Frequency Distribution of BFSK signal at different channel gains of 1, 0.5 and 0.25 respectively

Once the effects of correlation and other data imperfections are minimized, the methodology for fusion after the IF stage is developed based on Fuzzy Dempster-Shaffer evidence theory FDSET algorithm. The Dempster-Shafer theory allows us to integrate heterogeneous information from multiple sources to obtain collaborative inferences for a given problem. This method assigns beliefs and plausibilities to possible hypotheses of each decision maker and uses a combination rule to fuse information from various sources. This method can be employed at the information fusion level as the experimental results show that the WFDSF is superior to several existing methods [11]. Popular methods for probabilistic data fusion are Kalman filter for its ease of use and for its flexibility. They are capable of treating data uncertainty but incapable of addressing other imperfections as they are very sensitive to outliers. Whereas fuzzy Dempster-Shaffer evidence theory (FDSET) provides more comprehensive treatment of imperfect data. Hybrid fusion system will have to face several data related challenges as it is dealing with real time data. Input data to the system may be imperfect, inconsistent and correlated.

Decision of the classifiers are fused using a weighted average optimal diversity scheme or optimal partial decision scheme or a soft fusion scheme [12]. Determining spectrum monitoring efficiency is a complex task as this study focuses on HF, VHF and UHF bands of the spectrum. Receivers with very high sensitivity would be less linear [7] but hybrid fusion extracts the best of receivers of different characteristics.

The performance of a monitoring station is directly related to the quality of the station equipment [6, 7]. So the efficiency of the detection will be improved by accurate detection by hybrid fusion of multi receivers as data fusion is a proven method from sensor networks.

Monte Carlo simulation is performed to evaluate the performance of the hybrid fusion system and the spectrum monitoring facility. The simulation is performed in the presence of additive white Gaussian noise and multipath fading to emulate practical application environment.

3. Results and discussion

A comparative study has been carried out with 100 iterations to verify the performance of classifiers and it has been observed that KNN classifier gives better results when compared to a rule based classifier and SVM classifier. It was observed that performance of both the classifier methods are good when the signal strength is 8dB and above. But the performance of KNN classifier is much better compared to that of rule based classifier at lower SNRs.

Fig 6 shows the results from a multi-receiver system with three receivers with a Majority Combiner used for fusion. The receivers were simulated with channel gain of 1, 0.5 and 0.25 and the figure shows the probability of classification versus noise.

Fig 7 shows the results of a Weighted Majority Combiner used for decision level fusion where more weight age is given to the channel with maximum gain when the majority rule is implemented at the decision level for fusion. If the decision is fused using a majority rule, the fused output may not be better than the output of the receiver with maximum gain.

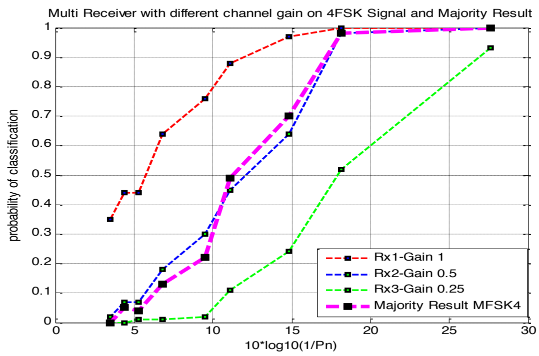

Fig 6. Majority combiner results for a multi-receiving system for 4 MFSK signals

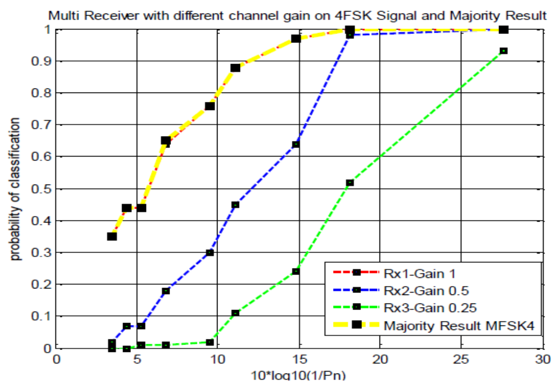

Fig 7. Weighted Majority combiner results for a multi-receiving system for 4 MFSK signals

4. Conclusions

The proposed approach can be applied to wireless digital communication systems such as amplitude shift keying, frequency shift keying, phase shift keying, multi-carrier code division multiple access, and multiple inputs multiple outputs sensor networks. The technique of multiple receivers and data fusion will improve the quality of reception which is important for spectrum monitoring and management as we have an opportunity of extracting parameters through multiple channels and then classifying them for a better reception.

The proposed method of hybrid fusion in a multi-receiver system exhibits better results at even lower SNRs in comparison to a single receiver system in a multipath fading environment.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License

References

1. David L Hall, James Llinas, Introduction to Multi-sensor data fusion CRC press LLC @2001
2. A.A. Bardwaj, Anandraj A., Kapil K, Multi sensor Data Fusion Methods using Sensor Data Compression and Estimated Weights, IEEE international conference on Signal Processing 2008
3. Tan, J.L. Sha'ameri A.Z.B., "Signal analysis and classification of digital communication signal using Time Frequency Analysis Techniques in the Multipath Fading Environment, ISSPA 2010.
4. Tan, J.L and Sha'ameri, AZ., "Adaptive Optimal Kernel Smooth-Windowed Wigner-Ville Distribution for Digital Communication Signals" EURASIP Journal on Advances in Signal Processing, Hindawi Publications Corp, Nov 2008.
5. Tripathi P.S.M, Chandra A., Radio Spectrum Monitoring for Cognitive Radio, IEEE international conference on Wireless Communication, 2011
6. F.A Ian, Lo B.F, R. Balakrishnan, Cooperative spectrum sensing in cognitive radio networks: A survey, Physical communication journal, ELSEVIER
7. Radio Communication Bureau, International Telecommunication Union, Handbook Spectrum Monitoring, 2011
8. ITU-R, SM.2156-0, 09/2009 The role of spectrum monitoring in support of inspections
9. Andr´e, L. S. Ferreira J., A Strategy to Improve Sensing Accuracy of Energy Detection for Distributed Spectrum Management Systems, IEEE transactions, 2011
10. S.P. McLaughlin, R. J. Evans, V. Krishnamurthy, Data incest removal in a survivable estimation fusion architecture, in: Proc. of the International Conference on Information Fusion, 2003, pp. 229–236.
11. Liu Y.T, Pal N.R and Marathe A.R., Weighted Fuzzy Dempster–Shafer Framework for Multimodal Information Integration, IEEE Transactions on Fuzzy system, Feb 2018.
12. Ashraf M. A, A.M. ElBakly, G.A, Hamid, A New Soft Fusion Approach for Multiple- Receiver Wire-less Communication System, Volume 33, ETRI Journal, June 2011.