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Dynamic Spectrum Access on OFDM Based Wireless Emergency Communications: Kolmogorov-Smirnov Test Based Sensing

S.Özbay[1], E.Erçelebi[2]

Lecturer, Department of Electrical and Electronics Engineering, University of Gaziantep, Gaziantep, Turkey [1]

Professor, Department of Electrical and Electronics Engineering, University of Gaziantep, Gaziantep, Turkey [2]

ABSTRACT: Current emergency communications services basically rely on public networks. However, these networks may fail in extreme situations, so emergency services become unreliable in emergency cases. The cognitive radio architecture can make the communication more efficient and reliable with dynamic network configuration. Spectrum sensing is considered as one of the most important and challenging issues for the establishment of dynamic spectrum access with Cognitive Radio (CR) architecture. This paper proposes a spectrum sensing algorithm based on Kolmogorov-Smirnov test on OFDM based wireless emergency networks. The paper also covers the implementation of the algorithm and performance analysis on real data.

KEYWORDS: Emergency communication, cognitive radio, dynamic spectrum access, spectrum sensing, Kolmogorov-Smirnov test, Orthogonal Frequency Division Multiplexing (OFDM).

I.INTRODUCTION

New demands on the wireless communication technology and the recent developments on the wireless medium need more spectral resources, while the radio spectrum is a finite natural source. On the other hand, usable frequency bands are nearly fully occupied by the licensed or authorized users. In fact, not all of these frequency bands are used efficiently. As a result of these facts, under-utilization of the current spectrum and the need to increase the spectrum efficiency are motivating researchers to exploit the wireless medium. In parallel with other wireless networks, existing emergency services traditionally have static band allocation architecture and each service has a uniquely assigned bandwidth. Static band allocation causes low efficient use on very valuable but finite spectral radio source. Meanwhile, the other fact on emergency services is that they are not reliable since the networks are overloaded in emergency cases.

The focus in new emergency communication systems are now to the two main issues: spectrum efficiency and mobility. First, OFDM is a good choice for emergency networks for high data rate information transmission to satisfy efficient spectrum use. Second, from this point of view, cognitive radio technology is considered as the solution for emergency case communications from the dynamic and opportunistic network perspective supplying efficient use of spectrum in a reliably manner. Spectrum sensing is one of the fundamental requirements of the CR architecture to achieve dynamic spectrum access and make spectrum sharing between the users. Therefore the growing interest in spectrum sensing research has spurred an increasing number of works recently. In this paper, we propose a new approach named as Kolmogorov-Smirnov Goodness of Fit (GoF) test to the spectrum sensing problem for OFDM-based wireless emergency communication.

This paper is organized as follows. Section II provides information about public safety networks used on emergency services with the next generation systems requirements. Cognitive radio and spectrum sensing basics are given in Section III and Section IV, respectively. The proposed algortihm formulation is introduced in Section V and performance analysis and results are discussed in Section VI. Finally, Section VII concludes the paper.

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II.EMERGENCY COMMUNICATION SYSTEMS

Current emergency communication systems mainly rely on public safety networks. As early as 1922, the primary problem of an unregulated radio broadcasting marketplace was interference [1]. The establishment made by the US Department of Commerce was the start date of public safety networks with the first frequency band allocation to solve the interference problem and each follow up allocation has been in a different frequency band of the spectrum [2]. In 1990s wireless communications technologies became dominant through today's communications systems including the public safety networks. The new technological advances enforced the transformation from analog communication to digital. Because of rapid increase on the users and needs of the other data format communications instead of only voice-based communication, emergency communication scheme required competent, flexible and reliable communications systems.

Nearly all of the existing public safety networks operate in the Land Mobile Radio (LMR) bands. As the illustration on Figure 1, the public safety agencies like Police Departments, Fire Departments, and Emergency Medical Services use LMR systems based on allocating fixed and finite amounts of resources to the user.

Fig. 1 Wireless emergency communication illustration

To meet the current needs and provide more efficient network, there have been remarkable efforts in recent years on emergency communications architecture. Federal Communications Commission (FCC) in US allocated nearly 10 MHz of spectrum in the D block of the 700 MHz band and 50 MHz spectrum block between 4940 and 4990 MHz to provide flexible, efficient and adaptive public safety networks. 24 MHz bandwidth allocation was also performed for public safety networks by changing NTSC analog television to ATSC digital TV. Beside these new assistances to the public safety networks, a communication program named SAFECOM, managed by the US Department of Homeland Security Office of Emergency Communications (OEC) and Office for Interoperability and Compatibility (OIC), allows researches on interoperability of communications related issues to emergency response agencies. Terrestrial Trunked Radio (TETRA), a digital trunked mobile radio Standard developed by the European Telecommunications Standards Institute (ETSI), has aimed to meet the needs of traditional Professional Mobile Radio (PMR) user organizations such as public safety, transportation, utilities, government, commercial, military, etc. The EUROPCOM project sponsored by several companies and research institutions has given the opportunity to investigate and demonstrate the use of ultra wide band (UWB) radio technology in emergency situations.

It has appeared many times from the unfortunate disasters and extreme situations that the most important task in emergency situations is to enable the information flow in a secure way. Information and communications needs for different emergency cases are highly diverse in nature, reflecting the multiple purposes for information and communication and the different activities and information and communications requirements that occur at different times and locations with respect to a disaster. Meanwhile, communications and information processing requirements in a disaster are very heterogeneous, varying according to context, use, time, latency, distance, and bandwidth [3]. Even if there are diverse natures of the needs and heterogeneous demands for different emergency cases, the emergency requirements can be grouped into the main common sets that contain the essentials in every case:

High capacity with flexible bandwidth

Emergency services often need high capacity and also high bandwidth in some emergency cases. As well as voice communication, still image or real time video must be sent and these data formats need more bandwidth than the voice-based communication. Building plan download for a rescue operation, real time video format for remote medical treatment are such scenarios with high capacity and flexible bandwidth channel requirements.

Multicast communication

While the point-to-point communication is still required, multicast should also be provided by the network. There may be some communication scenarios that cover many-to-one point communication giving information from the emergency personnel in emergency region to the commander.

Adaptivity

Emergency network must be able to support large number of case parameters without impacting the system performance. These parameters include number of nodes, traffic load and mobility issues. If an infrastructured based system parts are damaged, then the mobile solutions must substitute into the damaged network architecture.

Self-organization

To enable the emergency personnel more concentrated on the emergency case duties, the network should provide easy-and-fast use. As the communication system become more complicated to support more functions, not all users will have the capability to use complex equipment. The emergency services must provide complicated tasks with little effort.

Security

As the other communication schemes, security concern is always on the first places where the wireless network exists. It becomes more and more crucial when the wireless network is used in emergency case communication. Due to the broadcast nature of wireless signals, wireless network is vulnerable to attacks. The emergency services should overcome these attacks giving the system messages in a secure way. It may not have a chance to correct the mistake in an emergency case.

Power efficiency

Emergency service communication devices must be low-powered designed, thus extending the lifetime of whole network. Power saving must be the other important issue while designing the wireless emergency communication network.

III.COGNITIVE RADIO ON EMERGENCY NETWORK

Researchers agree that Cognitive radio (CR) is being considered as the candidate for the 5th Generation of wireless communications systems. Current public safety networks are not reliable since the networks are overloaded in emergency cases. They were also initially designed and assigned to support only voice communications although some other data type communications have been enabled in recent years with the technological improvements. In some situations, authorized emergency personnel may require real time video communication over the existing network but it may not be possible with the limited and fixed bandwidth. In existing public safety networks, another problem arises when an emergency situation occurs such as after an earthquake. Most of the public safety networks are infrastructured based so network equipments may be damaged in disaster regions.

The idea of applying Cognitive radio to the emergency network is first to alleviate this spectrum shortage problem by dynamically accessing free spectrum resources. Cognitive radio is able to work in different frequency bands and various wireless channels and supports multimedia services such as voice, data and video. One of the other major impacts of cognitive radio systems is seen on interoperability issues on public safety communications. In June 2004, National Public Safety Telecommunications Council (NPSTC), a federation of organizations whose mission is to improve public safety communications and interoperability, Software Defined Radio Working Group published the ”Cognitive and Software Radio: A Public Safety Regulatory Perspective” report [4] employing cognitive radio as solution address to solve the problems regarding to allocation of frequency bands, testing and security. FCC also addressed smart and cognitive radios as a first level commercial technology for the solution of interoperability issues of public safety communications systems that will operate in these new bands [5]. In 2008, the U.S. Department of Homeland Security (DHS) also released its first National Emergency Communications Plan (NECP) [6] and then National Broadband Plan [7] is released in 2010. Cognitive radio was identified as an emerging technology to increase efficiency and effectiveness of spectrum usage in those plans.

A CR device can adaptively change its receiving and transmitting parameters to communicate using unoccupied frequency bands on a non-interfering basis with the primary users. Haykin [8] states that: Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming radio frequency (RF) stimuli by making corresponding changes in certain operation parameters (e.g., transmit-power, carrier frequency, and modulation strategy) in real-time, with two primary objectives in mind:

- highly reliable communications whenever and wherever needed
- efficient utilization of the radio spectrum.

IV.SPECTRUM SENSING

To be aware of the environment, CR scans the environment and finds the free spectrum holes in the available spectrum range by the use of spectrum sensing. CR then changes its parameters according to the channel condition. On the other hand, in the case of occupied channel condition, the CR should vacate the channel as soon as possible. In order to cope with interference issues between users, fast and accurate signal detection has become a fundamental task.

Spectrum sensing algorithms are hot topics and still have ongoing development. Valuable works exist on spectrum sensing area including energy detection, matched filter detection, cyclostationary feature detection, eigenvalue based detection and recently detection based on goodness of fit testing [9]- [17]. The matched filter based detection requires the prior information about the unknown signal to be sensed. Cyclostationary-based feature detection exploits the inherent cyclostationary properties on sensing; thus it also requires prior knowledge of the signal. The energy detection method does not require any prior information of the signal, but its performance highly depends on the noise parameters. It is also observed that its detection rate significantly falls down in a lower SNR values. Eigenvalue-based sensing algorithm needs a relatively large number of signal samples to achieve higher true detection rate, resulting an unpractical real time operations.

In an emergency case, it is natural to assume that several organizations may use the same spectrum, so it is very crucial not to interfere other users and also to try to share spectrum fairly with the other public safety agencies. There may be several types of signal formats during the emergency case communication, so blind signal detection techniques are required.

V. TWO-SAMPLE KOLMOGOROV-SMIRNOV BASED SPECTRUM SENSING

Goodness of fit (GoF) tests are some statistical methods used for describing how well they fit a set of observations or measurements. Based on the calculation of the difference between the empirical distribution of the measurements made locally at the sensing detector and the expected distribution, goodness of fit tests can be used as a spectrum sensing method in CR architecture. If there is no primary signal transmission, the measurements made locally at the sensing detector will be a sequence of samples drawn independently from the noise distribution. Otherwise, in the case of existence of signal transmission, measurements made will be different from the samples taken on the situation having only noise. Therefore, to determine the existence of primary signals on the channel, a GoF testing can be formulated to check whether the measurements are drawn independently from the noise distribution.

In all spectrum sensing algorithms, the presence of a signal is decided by taking some data (or samples) form the channel and then making a decision based on the algorithm analysis of the measured samples. The decisions are either the presence of the signal on the channel or no signal transmission. Let the received samples by the detector has the cumulative distribution function (CDF), $G(x)$. If there is no transmission on the channel, observed samples CDF approaches to the noise distribution. If there is a user, the presence of the signal, on the channel, $G(x)$ will now be different from the previous observations. Thus, a goodness of fit test for sensing detector is considered as making the decision between two hypotheses:

$$H_0: G(x) = F(x) \qquad (1)$$
$$H_1: G(x) \neq F(x) \qquad (2)$$

where H_0 is the case where the received signal was drawn from a noise distribution, H_1 is the case where the transmission occurs on the channel, and $F(x)$ is the noise CDF.

Let $r = [r_1, r_2, r_3, \ldots\ldots, r_N]$ be totally N received signal samples taken first and then transformed into the discrete samples on the detector of cognitive radio. Under H_0 hypothesis, no primary signal transmission on the channel case, $r = [r_1, r_2, r_3, \ldots\ldots, r_N]$ vector is the signal samples drawn from the random variables because of the specified noise distribution having $F(x)$ CDF. Otherwise, under H_1 case where the primary user signal transmission occurs, the vector $r = [r_1, r_2, r_3, \ldots\ldots, r_N]$ distribution follows a different CDF other than $F(x)$. Thus, the testing problem is a two-sample GoF test problem.

Kolmogorov-Smirnov (KS) statistic

The empirical cumulative distribution function $F_n(x)$ for a sequence of totally n independent and identically distributed (i.i.d.) samples r_i is defined as

$$F_n(x) = \frac{1}{n}\sum_{i=1}^{n} I(r_i \leq x) \qquad (3)$$

where $I(.)$ is the indicator function whose value is unity when the input $r_i \leq x$ is true and zero otherwise. The statistic (or distance) between two distributions $F_n(x)$ and a given $F(x)$ is defined by the relation:

$$D_n = \sup_x\{|F_n(x) - F(x)|: -\infty < x < \infty\} \qquad (4)$$

where sup is the supremum of the set of distances.

One-sample KS test

The Kolmogorov-Smirnov (KS) test is a nonparametric GoF testing method for the approval of the null hypothesis that two data samples are drawn from the same distribution with a certain critical value. On the test, however, rejecting the null hypothesis determines that the samples are drawn from different distributions. On the one-sample KS test, the null hypothesis H_0 is rejected if and only if the distance D_n is greater than a predefined threshold value.

Two-sample KS test

In the case of two-sample Kolmogorov-Smirnov testing, the statistic of two CDFs, denoted by $G_1(x)$ and $G_2(x)$, respectively, is defined as:

$$D_n(G_1, G_2) = \sup_x\{|G_1(x) - G_1(x)|: -\infty < x < \infty\} \qquad (5)$$

where $G_1(x)$ and $G_2(x)$ are the CDFs of the first and second n-valued i.i.d. samples vectors. Thus, the statistic is determined by the largest absolute difference between two CDFs. The statistic is evaluated practically by the calculation of the maximum vertical distance between $G_1(x)$ and $G_2(x)$ shown as the relation:

$$D^* = \max_i |G_1(x_i) - G_2(x_i)| \qquad (6)$$

for a set of uniformly spaced sample points.

The significance level α^* of the measured value D^* is formulated using the relation:

$$\alpha^* = P(D > D^*) = \varphi[(\sqrt{\tilde{N}} + 0.12 + \frac{0.11}{\sqrt{\tilde{N}}} D^*] \qquad (7)$$

where

$$\varphi[x] = 2\sum_{m=1}^{\infty}(-1)^{m-1}e^{-2m^2x^2} \tag{8}$$

and

$$\widetilde{N} = \frac{N_1N_2}{N_1+N_2} \tag{9}$$

The null hypothesis H_0 is accepted at a significance level α if $\alpha^* = P(D > D^*) \geq \alpha$ and rejected if α^* is less than α. Here the significance value α is an input of the test which is used to determine the probability of false alarm under the null hypothesis and formulated as:

$$\alpha = P(D > \delta|H_0) \tag{10}$$

where δ is a certain threshold value.

As a summary, the null hypothesis H_0 is accepted if the two-sample KS statistic is less than a predefined threshold, otherwise the hypothesis H_0 is accepted.

VI. PERFORMANCE ANALYSIS

Experimental setup

For the performance evaluation of the proposed method, we have used an experimental setup for implementing the sensing algorithm. The setup includes mainly Universal Software Radio Peripheral 2 (USRP2) board attached with computer with GNU Radio software. The setup is also equipped with sub components such as antenna and RF frontend (called also as daughterboard) with support of different frequency bands. USRP2 is a flexible low-cost cognitive radio platform developed by Ettus Research [18]. It provides radio front-end functionalities with an FPGA. The USRP2 allows making signal processing operations on a computer and general purpose tasks including decimation, interpolation, digital up-down conversions in it. The WBX daughterboard whose frequency range is 50 MHz to 2.2 GHz covering public safety networks is used as a RF frontend. The selected antenna is for wideband receive covering 250-290MHz frequency band. GNU Radio is a free and open source toolkit providing a library of signal processing blocks for implementing the cognitive radio applications [19].

We used OFDM-based real primary signals for the performance analysis. It is known that OFDM is a method of encoding digital information. The idea behind the OFDM is to transmit data by dividing it into several parallel bit streams modulated by orthogonal frequencies. The major advantage of OFDM is that the high data rate information is transformed into relatively low data rate streams on each subcarrier which is more robust to inter symbol interference (ISI) caused by multipath delay spread. Thus, it is suitable to be implemented in emergency wireless communication networks. We chose the channel in the frequency range between 400-500 MHz. The selection in this range is basically because of the suitable propagation conditions, power requirements and antenna dimensions for emergency relief networking. Real signal samples are produced by a transmitter design which is a combination of GNU Radio and USRP2. The transmitter produced an OFDM signal with 60 sub carriers with BPSK modulation at a centre frequency of 435 MHz. For spectrum sensing implementation, sensing detector is also formed using GNU Radio and USRP2. The detector is responsible for collecting data on the channel.

Results

We have used OFDM-based signals as a primary user transmission and we assumed that the transmitted signal is noise-free. To simulate a noisy channel, we have also produced and transmitted noisy signal samples based on additive white Gaussian channel (AWGN). AWGN is a channel model in which the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density and a Gaussian distribution of amplitude. AWGN is a good model to simulate background noise of the channel under study, in addition to multipath, terrain blocking, interference, ground clutter and self interference that modern radio systems encounter in terrestrial operation. In an AWGN channel, the noise is represented by N_i, where i is some discrete time event index and N_i are independently and identically distributed on normal distribution with mean zero and standard deviation σ ($N(0,\sigma)$). Thus, when there is no primary signal transmission, the only signal on the channel is noise; and when the primary signal transmission exists on the channel, the sensed samples are the addition of primary signal and noise. Totally 9600 data samples are collected for sensing algorithm.

The Receiver Operating Characteristic (ROC) curves of the proposed two-sample KS method (TSKS) and one-sample KS method (KS), and Energy Detection (ED) method are depicted in Figure 2. The measurements on the sensing detector are done in approximately -6dB signal-to-noise (SNR) values and sampling number is taken 32.

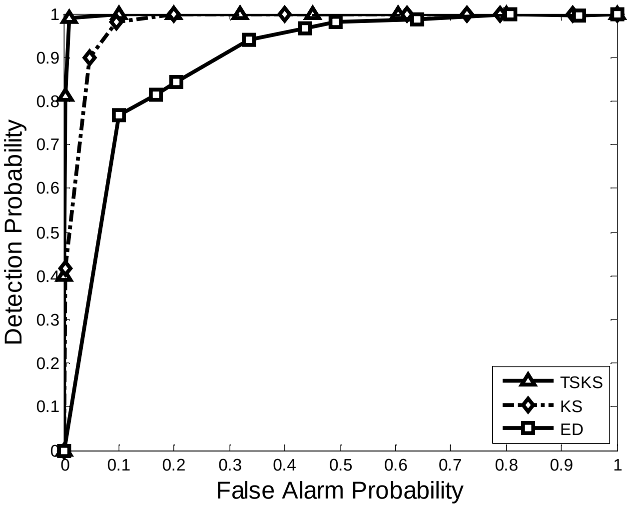

Fig. 2 ROC curves at SNR=-6dB with n=32

To see the performance of the proposed two-sample KS test method under lower SNR values, the probability of detection P_d values versus different SNR values are shown in Figure 3. The target probability of false alarm P_f value is set to 0.1 and sampling number is taken 32.

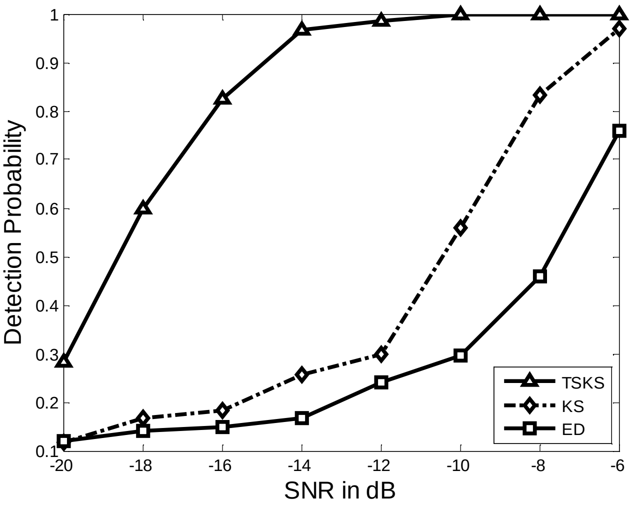

Fig. 3 The graph of P_d versus different SNR values for $P_f = 0.1$

VII.CONCLUSION

This article basically provides two-sample KS test based spectrum sensing algorithm based on cognitive radio architecture for dynamic spectrum access in wireless emergency networks. Existing public safety networks and their characteristics are reviewed by considering drawbacks during emergency situation. Wireless communications requirements are discussed according to the aspects of emergency communications. The concept of cognitive radio is introduced to address the emergency case issue and sensing algorithm based on two-sample KS test has been proposed for OFDM based emergency communication systems. The proposed spectrum sensing algorithm performance analysis has been conducted using real data and the experimental observations have been obtained. It was shown that the proposed algorithm outperforms the existing methods and robust on the AWGN channel model. The method is also found that it is effective under low SNR values. 90% detection performance is achieved on the orders of nearly -15 dB lower SNR values. Cooperative sensing approach and the analysis of the proposed algorithm under fading channels that may be encountered in emergency case situations will be the subject of our future research.

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