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Detecting White Spaces for Cognitive Radio

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Abstract---Radio Spectrum is a limited natural resource and hence must be utilized efficiently. Cognitive Radio (CR) specifications provide a way to improve spectral efficiency by allowing Secondary Users (SU) to utilize vacant frequency bands unoccupied by licensed Primary Users (PU). Continuous spectrum sensing is vital to implementation of any CR technique. There are various detection algorithms for spectrum sensing like energy detection, cyclostationary features detection and matched filter detection. In this paper a practical approach is presented to identify spectrum holes in GSM band (890 to 960 MHz) with the help of a general purpose Spectrum analyzer and a MS Windows application.

*Index terms— **Cognitive Radio, GSM, Spectrum Analyzer (SA), Spectrum sensing, white space.***

I. Introduction

In recent years, India has emerged as one of the most dynamic, promising and fastest growing telecom market in the world. It has second largest wireless network and third largest overall telecom networks in the world [1]. As per the Public Accounts Committee (PAC) draft report 2009-10 cellular Mobile service providers (CMSPs) in India use two types of technologies viz. Global Systems for Mobile Communication (GSM) and Code Division Multiple Access (CDMA). The allocation of spectrum to the CMSPs depends on the type of technology they use. Presently 50 MHz spectrum in 900 MHz band (890-915-Uplink and 935-960MHz- downlink) and 75 MHz in the 1800 MHz band (1710-1785MHz-uplink and 1805-1880MHz-downlink) are allocated for GSM services. The region of space-time-frequency unoccupied by PU is called a 'spectrum hole'. Spectral hole can be used by any SU without specific permission from the PU. For more spectral efficiency Orthogonal Frequency Division Multiplexing (OFDM) is widely used in many wireless communication systems. some of the issues are discussed in [10]-[13].

Software Defined Radio (SDR) can be dynamically configured to use available spectrum holes by combining the CR capabilities in SDR. SDRs implement of multi-mode and multi-standard radio communication. SDR is a technology to introduce cognitive capability in cognitive radios like dynamic spectrum management. In case of Spectrum requirement, a sensing device is needed that can be embedded in SDR (like antenna) or externally incorporated to SDR (like video camera). In other words, SDR can have structure like spectrum analyzer in order to provider spectrum information to cognitive engine. Either the existing receiver front end of SDR or a designated receiver parallel to the receiver side of SDR can be used to perform spectrum capturing. Captured spectrum is digitized by Analog-to-Digital Converter (ADC) and then the Digital samples are sent to digital signal processor for the post processing.[2]

There are various transmissions which happen within a specific frequency band. For example a cordless microphone transmits at 433 MHz, car keys transmit at 333MHz. So there are white spaces available in every frequency bands. Now the researchers are trying to build such a smart wireless communication system which can use these white spaces for other purposes like Wi-Fi, GSM etc. Wi-Fi is categorized in 802.11a, 802.11b, 802.11g, 802.11n and 802.11ac etc. After 802.11ac Wi-Fi has been divided into two directions, a) 60 GHz, low range, high speed applications or for in-house applications for higher throughput and b) lower frequency, higher range, lower data rate applications. Due to higher bandwidth, scientists/industry, R&D Engineers are trying to convert it into TV white spaces. Similarly they are trying for GSM and LTE band. That's why Cognitive radio is more preferred for higher spectral efficiency for various applications. Implementation of front end Cognitive Radio is a challenging work as channel, transmitter and receiver are dynamic in nature, the characteristics changes with respect to location, temperature and time.

II. Need of Software Defined Radio/ Cognitive Radio

The basic reason to go for software defined radio is to adapt the changes in RF environment and to have higher control on the operation using software. For that purpose the channel compression is necessary. For example, the 11MHz channel is compressed to 6MHz even though the data rate is much higher.

For instance, if the frequency of 500 MHz is taken, it is used for transmitting a local language channel in Maharashtra state. The similar 500 MHz channel can be used in Kolkata for transmission of their local channel. If the local language channel is vacated from analog channel and switched to higher frequency on Direct-To-Home (DTH) channel then the vacated band becomes available for other transmission purpose. If signal transmission takes place in 500 MHz band on DTH, then it can create interference in Kolkata based ground transmitting channel. Due to unoccupied frequencies, lots of frequency bands remain vacant. Therefore such vacant spaces (spectrum holes) become major hurdle in efficient spectral utilization. We need to have wide band transceiver, whose RF section can be prepared only once. That is the main reason;

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researchers are opting software defined radio. In order to reduce the complexity in designing the RF front end components and to reduce the time required for physical design, it is necessary to fix the radio. If SDR is designed in wide band then receiver can scan and find the vacant spaces. For example, 400 to 600 MHz band is vacant then every transmitter is allowed to transmit within this band provided, it should define whether it is primary or secondary. If authorized primary user wants to transmit then secondary user shall have to hop onto other frequency.

II. Spectrum Sensing

The static allocation of spectrum is a conventional approach which leads to underutilized frequency bands. Also, once the frequency bands are allocated, it becomes difficult to know the vacant bands to deploy new services within that band. To overcome this issue, it is necessary to have such solution that can dynamically access the vacant bands i.e. dynamic spectrum access [3] –[5].

II.1 Principle of Spectrum Sensing

In a primary user network, when primary transmitter transmits the signals to P.U., secondary transmitter makes sure that there is no harmful interference to the primary user communication with primary transmitter. S.U. transmitter needs to perform spectrum sensing to detect whether there is a P.U. receiver in the coverage of S.U. transmitter. A cognitive radio spectrum sensing algorithms development is necessary to be aware of and sensitively adapt the changes in it's surroundings, which makes spectrum sensing an important requirement for the realization of CR networks. Spectrum sensing enables CR users to adapt to the radio environment by determining currently unused spectrum portions, without causing interference to the primary network. CR user must have the ability to determine presence of a signal from the primary transmitter.

As the primary users are having higher priority to access the bands, the unlicensed users have to continuously monitor the licensed user's activities to avoid the interference and collision.[8]. A basic hypothesis model for transmitter detection can be defined as follows:

$$X(t) = \begin{cases} n(t) & \text{..... } H0 \\ h\,(s(t)) + n(t) & \text{..... } H1 \end{cases} \qquad (1)$$

Where X(t) is the signal received by CR user, s(t) is the transmitted signal of the primary user, n(t) is a zero-mean Additive White Gaussian noise (AWGN) and h is the amplitude gain of the channel. H0 is a null hypothesis, which states that there is no licensed user signal in a certain spectrum band. H1 is a hypothesis, which indicates that there exists some primary user signal. Generally spectrum sensing techniques can be classified into four groups: 1) Primary transmitter detection, 2) Cooperative detection, 3) Primary receiver detection and 4) Interference temperature management. In this paper, the focus is on primary transmitter detection, which is commonly used to detect the primary user. There are again three techniques used for detection of primary transmitter signals. Those are: energy detection, matched filter detection and feature detection [6].

III. Experimental setup

In India, GSM cellular operators currently have 50 MHz spectrum (890-902.5 paired with 935-947.5 MHz & 902.5-915 MHZ paired with 947.5-960 MHz). During traffic peaks, the need of additional spectrum in a smaller lot is always arises to meet the traffic demand, but there is no such provision for a service provider to acquire a smaller amount of spectrum in small spatial and a temporal dimension. As the popularity of bursty data traffic increases compared to voice traffic, the spatial-temporal dimension of traffic in a network varies suddenly. To cope up with the variation of traffic, it is necessary to acquire spectrum on small spatial-temporal granularity. GSM band allotted to cellular operators is 890MHz to 960 MHz (uplink from 890 MHZ to 915 MHz and downlink from 935 MHz to 960 MHz). Total 124 carrier frequencies are allotted for both uplink and downlink for 2G (900MHz) services. Out of which 31 carrier frequencies are allotted to Bharat Sanchar Nigam Limited (BSNL). BSNL is one of the most preferred cellular network in India. Every sector will be provided with an Absolute Radio Frequency Channel Number (ARFCN) with which we can identify the Base Transceiver Station (BTS) located nearby in our vicinity. Every BTS has unique ARFCN, uplink and downlink frequency.

Among the different types of spectrum sensing methods, we have focused on primary transmitter detection method in this paper. Figure 2 shows the scenario of communication between two Primary users via nearby BTS. In primary network, licensed user would be connected with another licensed user via BTS and Mobile switching center (MSC). In order to find the white spaces in both uplink and downlink, it is necessary to provide span of 70 MHz in SA.

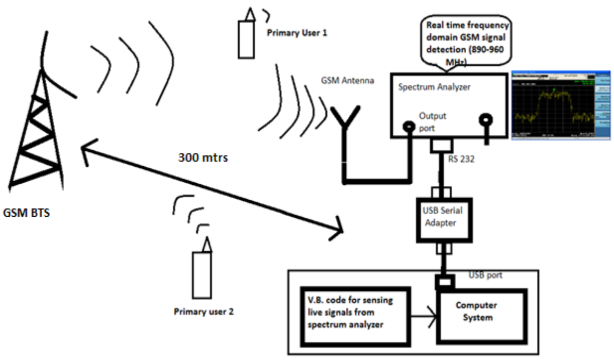

Figure 2. Scenario of communication between two primary users.

The location of experimental setup is 300mtr away from GSM BTS. Observations show that downlink

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940 to 960 MHz band of frequency spectrum is heavily occupied by the licensed user. Rest of the band i.e. uplink ranging from 890 to 915 MHz is partially occupied or not at all occupied, when it has been observed continuously over the period of time. Base Station Controller (BSC) is capable of handling allocation of radio channels, frequency administration, power and signal measurements from the Mobile station (MS). It also handovers the control to one BTS from another (if both BTS's are controlled by same BSC).

When we observe the GSM signal on spectrum analyzer, we can easily differentiate between various channels. Each channel in the band is having bandwidth of 200 KHz as every operator uses different ARFCNs. Frequency reuse pattern is used for efficient use of the resources as frequencies allotted to each operator is limited and it has to be reused by BTS without collision between them. The power level defined for BTS located at experiment site is 43dBm. BSNL is also having 1800 MHz band along with 900 MHz band but it is used depending on the need of coverage area.

Generally, GSM band width =25 MHz

Uplink :-890 to 915 MHz and Downlink :- 935 to 960 MHz

Channel bandwidth : 200 KHz

$$\text{No. of channels} = \frac{25 \times 10^6}{200 \times 10^3} = 125 \qquad (2)$$

Out of 125 channels, one channel is reserved for Guard band i.e. 100KHz at the start and 100KHz at the end of the band and remaining 124 channels are spread at 200KHz intervals. First carrier is not used due to interference to other systems.

Bifurcation of ARFCN is given as:

Up Link Frequency = 890 + 0.2 x N (N-channel number 1-62)

Down Link Frequency = 935 + 0.2 x N (N-channel number 63 -124)

Figure 3 shows frequency vs amplitude plot along with settings. Spectral density of downlink is always greater than uplink. This means that traffic is more from BTS to Mobiles users and not from mobile users to BTS.

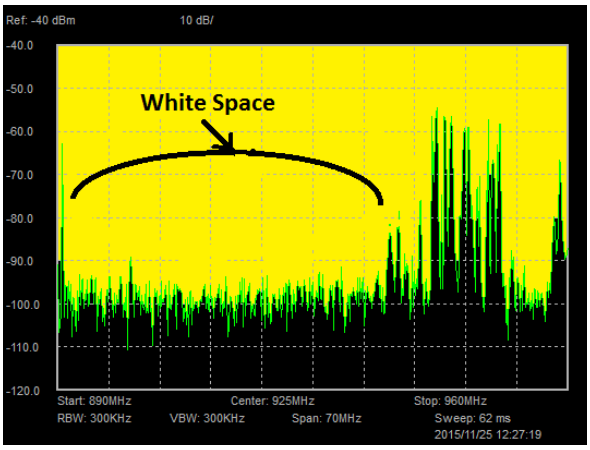

Figure3. Spectrum of GSM Signals (890 MHz to 960 MHz) shows spectrum holes.

This observation is carried out for many hours to capture real time samples. A Software named as EagleShot provided by Good Will Instruments Co. Ltd., is capable of recording only five peak signals at a time. Using this software the limit lines can be uploaded from the GSP-830 or edited directly from PC.

Since the recording of five peak signals is not sufficient for spectral analysis of a particular frequency band, it is necessary to have total trace data within span. Further we can go for spectral estimation and forecasting based on this real time data.

We have overcome this problem of limited trace data by writing/modifying the windows application. We have successfully detected and captured five hundred samples with their power level. In this way we are not missing a single frequency signal reception within band.

There are various commands used for capturing different basic RF components from GSP-830. [9] When we receive ADC data from spectrum analyzer, it is necessary to convert it into real time dBm value. The application is modified in such a way that we can get trace of frequency and it's respective power in dBm along with the date and time. The thread delay is maintained as 1 second.

The figure5 shows the process flow in windows application, in which output is in text file in term of frequencies and dBm. This is one of the ways to sense the GSM spectrum.

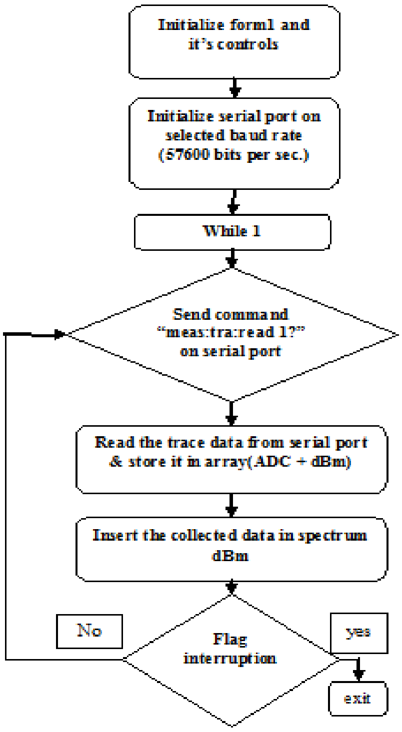

Figure 5. Control flow chart of windows application

IV. ANALYSIS

The figure 6 shows the GSM bands (uplink) along with guard band that is being continuously

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monitored for the analysis of trace data. Trace data has been received in the format as mentioned below. *Frequency-dBm-ADCvalue-(Decimal Equivalent) hex digits. i.e.*
892.400:-95.37dBm-ADC=(315)-00.2e.01.0d

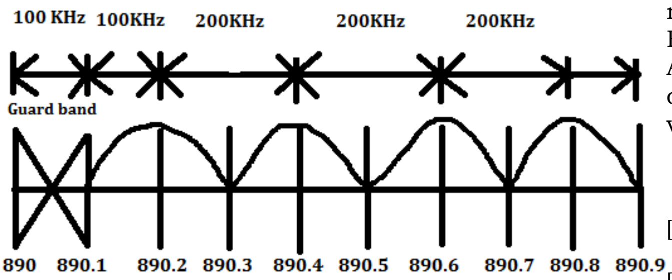

Figure 6 GSM uplink 1MHz frequency band with guard band

The data from ADC to serial port have been received and converted from hex to decimal format in order to get the real time trace from SA for respective frequency. Figure 6 shows the span of 1MHz with guard band interval between 890 to 890.1 MHz. As the band width of channel is 200 KHz, at the beginning of GSM band i.e. 890 and at the end of band i.e. 960, there will be 100 KHz reserved as guard band in order to avoid the interference with other services. The range observed is 890.1 to 959.8 MHz. In this total band 916 to 934 MHz is not at all used. The Average received signal power variation above the threshold with respect to the frequency span of the measurement study is depicted into the plot shown in Figure 7. It shows the variation of Average power with reference to frequency range i.e. [(890 to 902.5MHz),(935 to 947.5),(902.5 to 915) & (947.5 to 960)]

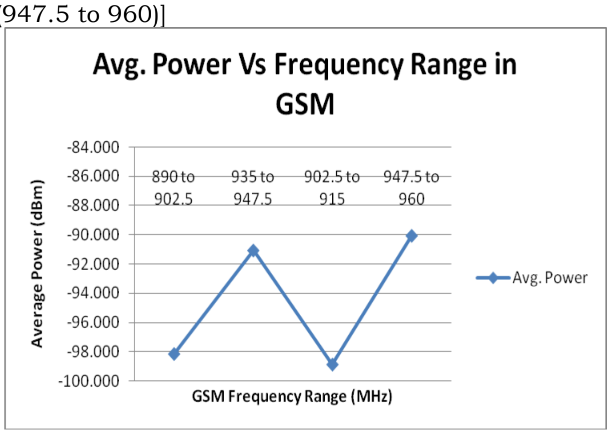

Figure 7 Average power Vs Frequency Range

We have received trace data of 2 months for analysis. The data of hourly occupancy rate of frequencies get stored in text file over the measurement period. The location at which measurements are taken is 16^0 56' 443" North and 74^0 36' 913" East.(reading taken by device named as GARMIN, etrex-10 module)

V. CONCLUSION

In this paper, a practical approach for spectrum sensing using spectrum analyzer & windows application is presented. By this method, it is possible to get real time trace data samples along with their respective power to find the spectrum holes in GSM bands. This data can be provided to signal processing block or can be used for further spectral analysis. This approach leads to opportunistic access to white spaces for Cognitive radio applications.

Recording of the real time signals in Microsoft Access is possible for further analysis. With the help of Microsoft Access database, we can get the power values to find various spectral parameters.

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