Interference based Detection Spectrum Sensing in Cognitive Radio - A Survey

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Abstract –Since spectrum is a scarce resource in wireless communication, it should be utilized efficiently. The better utilization of spectrum can be achieved by Cognitive Radio (CR) technology. Spectrum sensing is believed to be most of the crucial task to establish CR networks. There are three spectrum sensing techniques. This paper surveys interference based detection techniques for CR out of the three techniques. In today's radio frequency environment, interference generally limits the useable range of communication signal. Hence, understanding of the interference based detection techniques is main attraction towards efficient utilization of spectrum in context of Cognitive Radio.

Keywords – Cognitive radio, spectrum sensing, interference based detection, interference temperature model.

I. INTRODUCTION

The available electromagnetic radio spectrum is a limited natural resource and getting crowded day by day due to increase in wireless devices and applications. It has been also found that the allocated spectrum is underutilized because of the static allocation of the spectrum. With most of the useful radio spectrum already allocated, it is difficult to find vacant bands to either deploy new services or to enhance existing ones. In order to overcome this situation, Cognitive radio (CR) technology is emerged for improved utilization of the spectrum creating opportunities for dynamic spectrum access. A CR is a radio that can change its transmitter parameters based on interaction with the environment in which it operates. Spectrum sensing function enables the CR to adapt to its environment by detecting spectrum holes i.e. unused spectrum. There are three spectrum sensing techniques to detect spectrum holes, as shown in Fig.1.

This paper focuses on interference based detection technique for spectrum sensing. Interference is typically regulated in a transmitter-centric way, which means interference can be controlled at the transmitter through the radiated power, the out of band emission and location of individual transmitter [1]. However, interference actually takes place at the receivers, as shown in Fig. 2(a) and 2(b).

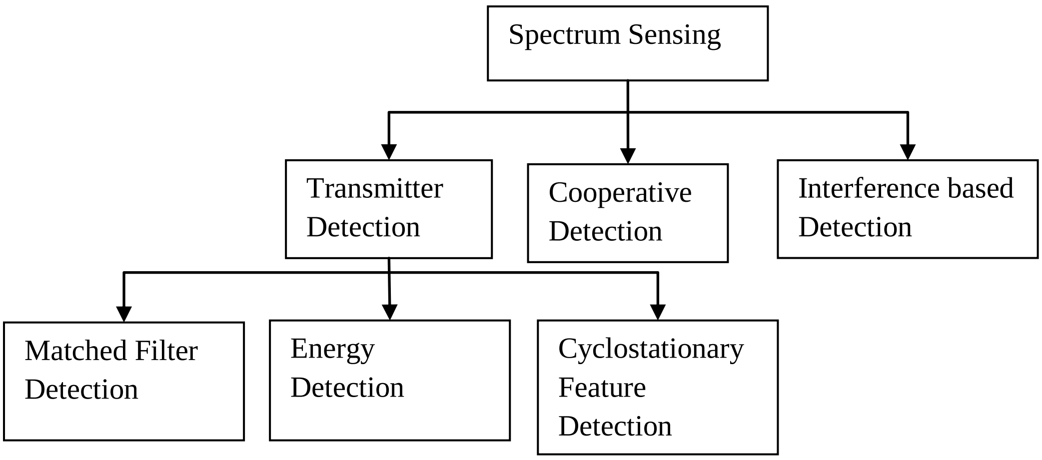

Fig.1. Classification of Spectrum Sensing Techniques.

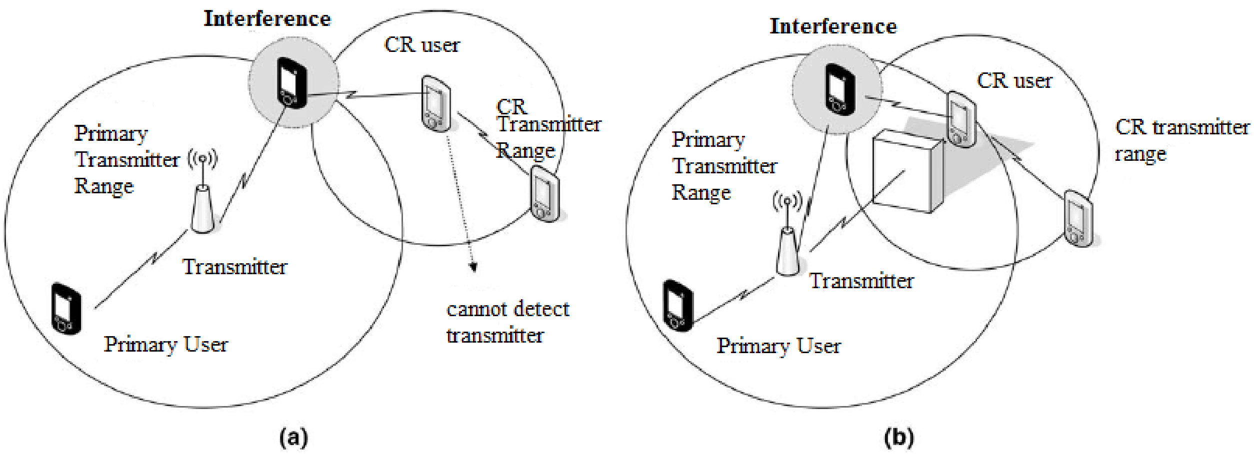

Fig.2. Transmitter detection problem (a) Receiver uncertainty (b) Shadowing uncertainty [1]

There are two approaches for interference based detection technique to sense unoccupied spectrum in CR: 1) Primary Receiver Detection and 2) Interference Temperature Model. This paper seeks to explain these two interference based detection techniques. Section II overviews primary receiver detection technique, section III investigates interference temperature model and section IV concludes the paper.

II. PRIMARY RECEIVER DETECTION

In this, the possibility of detecting the primary receivers by exploiting the local oscillator (LO) leakage power emitted by RF front end of primary receivers was proposed [2].

a. Superheterodyne Receiver Architecture –

This architecture allows the RF signal to be converted down to a fixed lower intermediate frequency (IF), replacing a low Q tunable RF filter with a low-cost high-Q IF filter. In order to down-convert an RF band to IF, a local oscillator (LO) is used. This local oscillator is tuned to a frequency such that when mixed with the incoming RF signal, the desired RF band is down-converted to the fixed IF band.

b. Direct Conversion Architecture –

In a direct conversion architecture, where the RF is converted directly down to baseband, the LO frequency will fall within the band of interest. The LO leakage radiation will then mix back into the receiver and cause a DC offset to be added to the signal of interest. This problem is called “self mixing” and is also solved by using an IF.

Detecting this leakage power directly with a CR would be impractical for two reasons. Firstly, it would be difficult for the receive circuitry of the CR to detect the LO leakage over larger distances. The second reason that it would be impractical to detect the LO leakage directly is that the LO leakage power is very variable, depending on the receiver model and year. If the CR used this variable power level to estimate proximity to the primary receiver, there would be too much error introduced by this variability. Hence, building tiny, low cost sensor nodes that would be mounted close to the primary receivers is proposed

c. Sensor Node Architecture –

It would consist of an RF amplifier, filter, and a bank of local oscillators each tuned such that the desired incoming LO leakage signal will fall into a fixed IF band. After the IF filter, the signal would be sent to the detection circuitry. One detector would be implemented for each channel that the node is supervising [3]. This architecture is shown in Fig. 3. The input into the detector is the desired down-converted LO leakage signal in addition to additive Gaussian noise. The noise power will be directly proportional to the IF filter bandwidth. The availability of primary user is determined by the formula:

$$P(A_{N,j}) = (1 - \tfrac{1}{M})^N \qquad (1)$$

where $A_{N,j}$ denote the event that channel i is free when there are N primary users within the interference radius R and M is the number of channels.

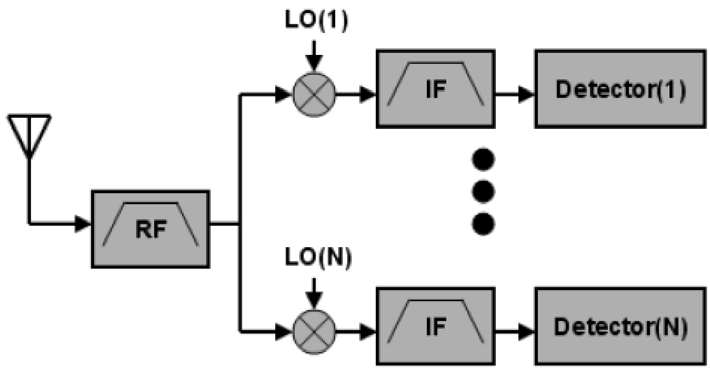

Fig.3. Sensor node receiver architecture [3]

III. INTERFERENCE TEMPERATURE MODEL (ITM) –

The interference temperature model is an entirely new concept for dynamic spectrum access. Radio nodes treat licensed users, other unlicensed radio networks, other unlicensed nodes within the same network, interference, and noise all as interference affecting its signal-to-interference ratio (SIR). Higher interference yields lower SIR, which means lower capacity is achievable for a particular signal bandwidth. Radio nodes search for gaps in frequency and time where the measured interference is low enough to achieve communication at a target capacity, subject to overall interference constraints defined by the interference temperature model as shown in Fig.4. Unlike the primary receiver detection, the basic idea behind the interference temperature management is to set up an upper interference limit for given frequency band in specific geographic location such that the CR users are not allowed to cause harmful interference while using the specific band in specific area. Typically, CR user transmitters control their interference by regulating their transmission power (their out of band emissions) based on their locations with respect to primary users. This method basically concentrates on measuring interference at the receiver.

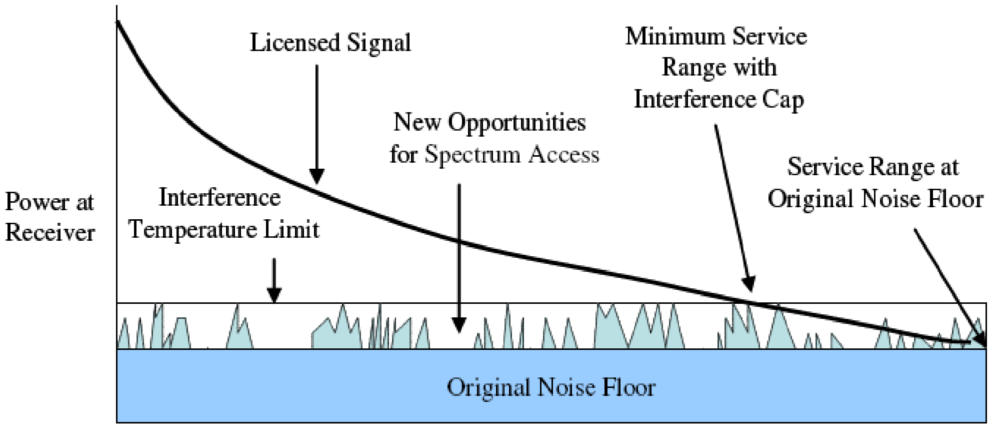

Fig.4. Interference Temperature Model [1]

a. ITM Concept –

The concept of interference temperature is identical to that of noise temperature [4]. It is a measure of the power and bandwidth occupied by interference. Interference temperature T_I is specified in Kelvin and is defined as

$$T_I(f_c, B) = \frac{P_I(f_c, B)}{kB} \qquad (2)$$

Where $P_I(f_c, B)$ is the average interference power in Watts centered at f_c, covering bandwidth B measured in Hertz, Boltzmann's constant k is 1.38×10^{-23} Joules per Kelvin degree. The idea is that by taking a single measurement, a cognitive radio can completely characterize both interference and noise with a single number. However, interference is typically more deterministic and independent of bandwidth over noise. For a given geographic area, an interference temperature limit, T_L would be established. This value would be a maximum amount of tolerable interference for a given frequency band in a particular location. Any unlicensed transmitter utilizing this band must guarantee that their transmissions added to the existing interference must not exceed the interference temperature limit at a licensed receiver.

b. Ideal ITM model –

In the ideal interference temperature model an attempt to limit interference specifically to licensed signals is proposed. Assume the unlicensed transmitter is operating with average power P, at center frequency f_c, with bandwidth B. Assume also that this band $[f_c - B/2, f_c + B/2]$ overlaps n licensed signals, with respective frequencies and bandwidths of f_i and B_i. The goal is to then guarantee that

$$T_I(f_i, B_i) + \frac{M_i P}{kB_i} \le T_I(f_i) \qquad \forall\ 1 \le i \le n \qquad (3)$$

where M_i will be defined shortly [4].

In other words, the constraint guarantees that the transmission does not violate the interference temperature limit at licensed receivers, as shown in Fig.5. Each signal overlapped by the unlicensed transmission adds a new power constraint, over which the minimum is taken. If the unlicensed signal does not overlap a licensed one, then the transmit power is unconstrained, though a regulatory maximum would likely be set. In Fig.5, the dashed lines represent the interference power limit computed using the interference temperature and the bandwidth of the licensed signals. Notice that each licensed signal places a different constraint on the total allowable interference, and an unlicensed transmitter must guarantee that none of the individual interference constraints are violated. Note that the constant M_i is a fractional value between 0 and 1, representing a multiplicative attenuation due to fading and path loss between the unlicensed transmitter and the licensed receiver. The idea is that the interference temperature model restricts interference at the licensed receiver, not the unlicensed transmitter. Since typically it's impossible to know the distance to all licensed receivers, assume that this value is fixed by a regulatory body to a single constant M.

c. Generalized ITM Model –

The generalized interference temperature model has a different interpretation to signals and bandwidths [4]. The fundamental premise of the generalized model is that no apriori knowledge of the RF environment, and no way of distinguishing licensed signals from interference and noise is known, as shown in Fig.5. Again, the dashed line in Fig.5 represents the interference power constraint. However, in this model it is computed using the interference temperature and the bandwidth of the transmitter, resulting in a single constraint. Under these assumptions, the interference temperature model must be applied to the entire frequency range, and not just where licensed signals are detected. This translates into the following constraint:

$$T_I(f_c, B) + \frac{MP}{kB} \le T_I(f_c) \qquad (4)$$

Notice that the constraint is in terms of the unlicensed transmitter's parameters, since the parameters of the licensed receivers are unknown. One question that immediately comes to mind: under what conditions does the generalized model limit interference as well as the ideal model? If both constraint equations (ideal ITM and generalized ITM) are solved for P, the following results:

$$P^{id} = B_i\left(T_I(f_c) - T_I^{id}(f_i, B_i)\right)$$
$$P^{gen} = B(T_I(f_c) - T_I^{gen}(f_c, B))$$

To cause less interference in the generalized model, $P^{id} \ge P^{gen}$ case is considered.

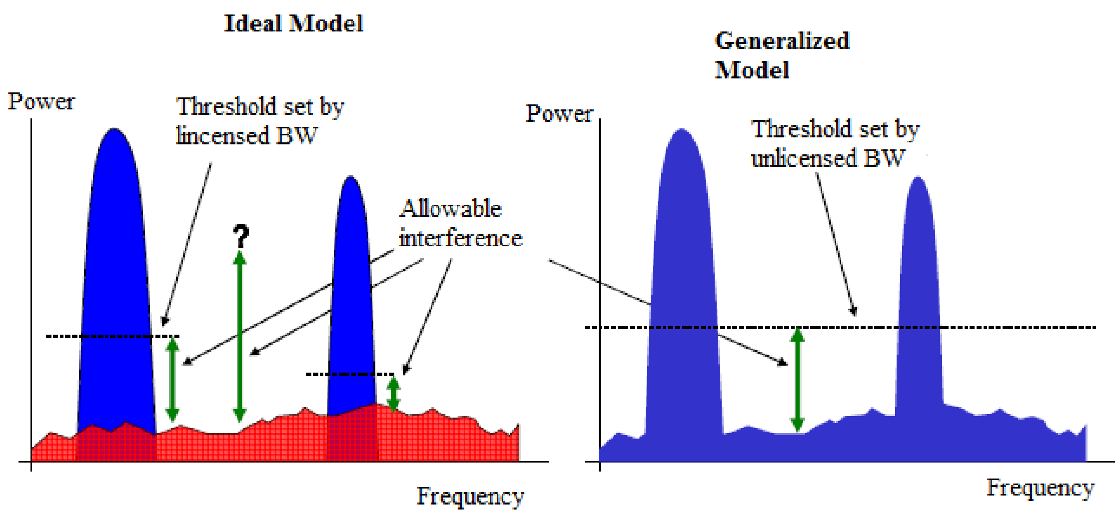

Fig.5. Ideal and Generalized interpretations of ITM [4]

d. Cooperative approach to ITM –

In this, algorithms for selecting the most appropriate channel for transmission by a multi interface node in a cognitive mesh network were described. It is considered that the ITM in which a channel is assumed to be available for transmission by a mesh node if the node's transmission does not increase the interference temperature within its interference range beyond a predefined threshold [5]. Two cases were considered: one, in which each mesh node transmits with a fixed power, and second, in which each mesh node employs an adaptive transmission power control. Each mesh node computes a set of channels available for transmission (without increasing the interference temperature beyond the threshold in its interference range). It then uses a per-hop link cost metric and end-to-end routing metric to select channels from the available channels set for each hop on the end-to-end path.

e. Modified Underlay approach to ITM –

In the overlay approach, cognitive radios referred to as secondary users (SUs) are able to opportunistically use spectrum whenever licensed users referred to as primary users (PUs) are absent. In the case when a PU signal reappears, cognitive radios must vacate the spectrum to avoid causing interference. The disadvantage of this approach is that it does not allow SUs to coexist with the PUs. In the underlay approach used by interference temperature model, an upper interference limit is set up for a given frequency band in a specific geographic location such that the cognitive radio users are not allowed to transmit above the set limit in order not to cause any harmful interference to the PU while using the specific band in the specific area. The disadvantage of this approach is that even when licensed users are absent, CR users cannot transmit above the set interference limit even though doing otherwise would not cause any harmful interference.

In modified approach [6], sensing capabilities were incorporated in the ITMA (Interference Temperature Multiple Access) protocol to detect the absence of primary users and thereby utilizing the spectrum maximally by transmitting above the temperature limit as shown in Fig.6. This will be done by designing an algorithm that will be implemented in the ITMA. From the figure T_I is the interference limit, B is the bandwidth required for the data to be sent, C is the capacity in bits per second, and L is the range of transmission. If the bandwidth is below a maximum value B_{max}, the data will be sent; otherwise there should be a back-off and wait for a lower T_I. If it is necessary for the data to be sent, then it will be necessary to either reduce the capacity or the range of transmission is increased. At some point, if some time out period has expired while the value of C is smaller than C_{min} and the value L is higher than L_{max}, the system should change the centre frequency.

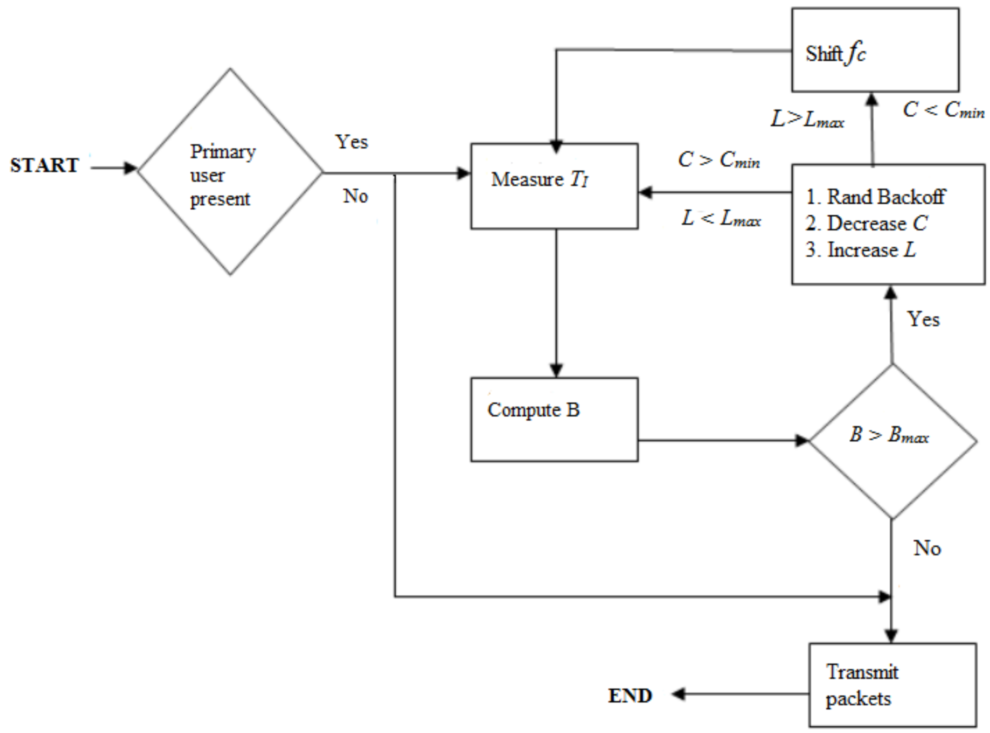

Fig.6. modified underlay approach to ITM [6]

f. Future Scope –

The implementation of ITM in CR has two primary challenges: (1) the determination of the “background” interference environment as a function of spatial location and frequency and (2) the measurement of interference temperature to determine optimal radio transmission parameters [7]. To get over these challenges could be the area of research. Also, compressive sensing (CS) theory has gaining much attention these days. Incorporating CS with ITM for spectrum sensing will enhance sensing capability for sure.

IV. CONCLUSION

With the advent of cognitive radio technology, new paradigms for spectrum access can achieve near-optimal spectrum utilization by letting each user sense and utilize available spectrum opportunistically while regulating the interference it imposes on other users through interference constraints. The ability to quantify the RF environment has benefits for insuring the interference rights of spectrum users, to the capacity to efficiently adapt to the environment dynamics and the potential to provide new opportunities to use the spectrum more intensively. The implications of the implementation of the based detection techniques transcend technology arena. Overall, the interference based detection techniques offer an exciting new paradigm for dynamic spectrum access through CR.

REFERENCES

[1] I. Akyildiz, Won-Yeol Lee, Mehmet C.Vuran * and S. Mohanty, "NeXt generation / dynamic spectrum access cognitive radio wireless networks: A survey", computer networks journal (ELSEVIER Journal), vol 50, p.p. 2127-2159, 2006.

[2] M.Subhedar and G.Birajdar, "Spectrum Sensing Techniques in Cognitive Radio Networks: A Survey", International Journal of Next-Generation Networks (IJNGN) Vol.3, No.2, June 2011

[3] B.Wild and K.Ramchandran, "Detecting Primary Receivers for Cognitive Radio Applications", 1st IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, p.p. 124-130, Nov 2005

[4] T. Charles Clancy, "Formalizing the Interference Temperature Model", wiley journal on wireless communications and mobile computing, vol. 7, p.p. 1077-1086, Nov 2007

[5] M. Sharma, A. Sahoo and K. D. Nayak, "Channel Selection under Interference Temperature Model in Multihop Cognitive Mesh Networks", 2nd IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, p.p. 133-136, Apr 2007

[6] B. S. Olanrewaju and O. Osunade, "Proposed Interference Temperature Model for Improved Spectrum efficiency in Cognitive Radios", EIECON Dspace Covenant University, 2012

[7] Paul J. Kolodzy, "Interference Temperature: A metric for Dynamic Spectrum Utilization", International Journal of Network Management, vol. 16, p.p.103-113, Mar 2006.

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