Elliptic Radio Environments Cognitivity through Sequential Scanning Scheme

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***Abstract*— In this paper, a cognitive radio unit (CRU) model with a sequential scanning (S-scanning) scheme and cognitive perception ratio (CPR) metric under an elliptic radio environment for cognitive communications will be proposed. In this model, the real-time spectrum sensing characteristics are coordinated together with system parameters in temporal and frequency domains, e.g., scanning rate and framing processing time, for evaluating the performance of the CR communications under an elliptic operation scenario. High CPR value means high spectrum awareness, but low coexistence. Several intriguing numerical results are also illustrated to examine their interrelationships.**

Keywords*- *cognitive radio unit (CRU); cognitive perception ratio (CPR); sequential scanning

I. INTRODUCTION

For the past years, traditional spectrum management approaches have been challenged by their actually inefficient use or low utilization of spectrums even with multiple allocations over many of the frequency bands [1]. Thus, within the current regulatory frameworks of communication, spectrum is a scarce resource [2]. Cognitive radio is the latest emphasized technology that enables the spectrums to be used in a dynamic manner to relieve these problems. The term "cognitive radio (CR)" was first introduced in 1999 by Mitola and Maguire and is recognized as an enhancement of software defined radio (SDR), which could enhance the flexibility of personal wireless services through a new language called the *radio knowledge representation language* (RKRL), and the cognition cycle to parse these stimuli from outside world and to extract the available contextual cues necessary for the performance of its assigned tasks [3-4]. Haykin therefore defines the cognitive radio as an intelligent wireless communication system that is aware of its surrounding environment, and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming *RF stimuli* by making corresponding changes in certain operating parameters in real-time [5]. In addition, some engineering views and advances for helping the implementation of cognitive radio properties into practical communications are described [6-7]. With these groundbreaking investigations and developments, international standardization organizations and industry alliances have already established standards and protocols for cognitive radio as well [8-10].

Nowadays, the FHSS systems have been widely used in civil and military communications, but somewhat their benefits would be potentially neutralized by a follow-on jamming (FOJ) with wideband scanning and responsive jamming capabilities covering the hopping period. The FOJ concept is actually implicitly analogous to a CR communication with spectrum and location awareness, listen-then-act, and adaptation characteristics. The frequency hopping spread spectrum (FHSS) systems are widely used in civil and military communications, but somewhat the benefits of FHSS systems could be potentially neutralized by a follow-on jamming (FOJ) with an effective jamming ratio covering the hopping period [11-13]. In spite of the active jamming measures taken, FOJ is implicitly analogous to a cognitive radio communication with spectrum and location awareness, listen-then-act, and adaptation characteristics. For transmission security concerns, concurrent anti-jamming and low perception detection were investigated to have a secure communication [14]. Therefore, the cognitive process cannot be simply realized by monitoring the power or signal-to-noise ratio in some frequency bands of interest in a FH radio environment. A cognitive radio unit (CRU) model with a sequential scanning (S-scanning) technique and cognitive perception ratio (CPR) metric under an elliptic radio environment for cognitive communications will be proposed.

The remainder of this paper is organized as follows. In Section II, an operation scenario with an elliptic geometry will be addressed. In Section III, the architecture of a cognitive radio unit (CRU) for a FH communication system, latency breakdown for all possible response delays and effective dwell time in CRU, and a sequential scanning (S-scanning) scheme taken will be addressed, respectively. Moreover, a quantified metric of cognitive perception ratio (*CPR*) will be available for evaluations. In Section IV, several intriguing numerical results based on the proposed cognitive radio model will be illustrated. Conclusion is in final Section V.

II. ELLIPTIC RADIO ENVIROMENT

In this section, an operation scenario with an elliptic geometry for special domain analysis will be examined, which is dependent on their relative positions among CRU, FH transmitter, and FH receiver as shown in **Fig. 1** [11-12]. CRU is moveable.

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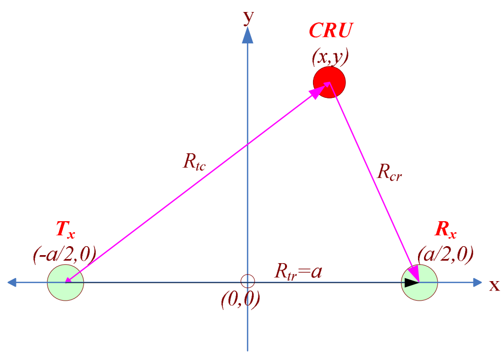

Fig. 1 Elliptic CRU operation scenario with movable CRU and fixed R_{tr} (=*a*)

If the range between FH transmitter and FH receiver is fixed (i.e., $R_{tr}=a$) and CRU can roam around these two ellipse focuses, the following expression will be available by using the fact that the latency time (T_l) must be smaller than the hopping period (T_h) for effective hopping period coverage.

$$T_l = jT_z + \tau_r + \frac{(R_{tc} + R_{cr} - a)}{c} \leq T_h \text{,} \tag{1}$$

where τ_r can be assumed as zero for instant response, c is radio wave velocity, R_{tc} is the range between FH transmitter and CRU, and R_{cr} is the range between CRU and FH receiver. After a simple manipulation, an interesting ellipse equation will be available and given by

$$\frac{x^2}{(D+a)^2} + \frac{y^2}{D(D+2a)} \geq \frac{1}{4}, \tag{2}$$

where D is assumed to equal c (T_h − jT_z − τ_r) and is given by the following inequality

$$(R_{tc} + R_{cr} - a) \leq (T_h - jT_z - \tau_r) \cdot c = D \tag{3}$$

III. Sequential Scanning Scheme

The architecture of a cognitive radio unit (CRU) for a FH communication system, latency breakdown for all possible response delays and effective dwell time in CRU, and a sequential scanning (S-scanning) scheme taken will be addressed, respectively, in this section.

A. CRU architecture

In order to beware the frequency hopping features, the architecture of a cognitive radio unit (CRU) with the ability to sense the effective frequency hopping dwell time of a FHSS communication system is shown in **Fig. 2**. The total framing processing time needed to acquire the instant FH frequencies is jT_z and the total activation time needed to synthesize and amplify the intercepted signals of interest is τ_r. The jT_z is related to the FH emitter locations and incoming signal directions, which can be shortened by collaboration with other cognitive radio users. And τ_r is composed of the latency time of frequency synthesizer, power amplifier, filter banks, and etc. In addition, the propagation difference time ($\Delta\tau_d$) dependent on the relative positions among CRU, FH transmitter, and FH receiver should be included for effective cognitive capability analysis. Such spectrum sensing capability enables real-time measurement of spectrum information from radio environment.

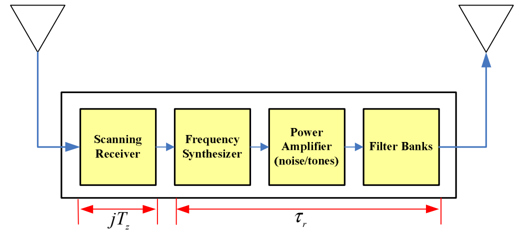

Fig. 2 Cognitive radio unit (CRU) architecture

B. Effective dwell time

In order to cover the hopping period of a FH communication system, the scanning rate of CRU should be fast enough to trace the hopping rate with more framing processing time (T_z) per scanning window. The CRU architecture, latency time breakdown, and window definitions in temporal and frequency domains will be addressed. **Fig. 3** shows the latency time breakdown for effective dwell time, where T_r represents the total response time and propagation delay (=τ_r+$\Delta\tau_d$), T_l the total latency time before effective dwell on FH hopping period (=jT_z+T_r), and T_J the effective dwell time (=T_h− T_l) within frequency hopping period T_h.

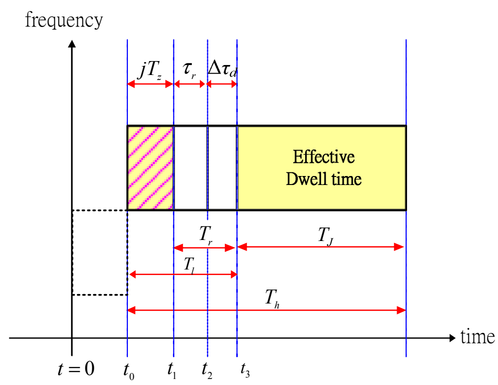

Fig. 3 Effective dwell time (T_J) and latency time breakdown for CRU operation

Suppose that a FH communication system operate in the bandwidth W only and CRU know the FH communication system parameters. Therefore, exactly at this moments (t=0), CRU will initiate scanning of the actual channel. FH terminal will start to transmit signal in a specific window at the moment t_0. Let t_1 be the moment when the actual FH transmit channel be found by the wideband scanning receiver of CRU ($t_1 = jT_z$). Let t_2 be the moment when CRU initiates transmission of the found channel if allowable. And let t_3 be the moment when the transmit signal of CRU reaches the receiver site of the found channel after passing through a propagation difference time $\Delta\tau_d$. Of course, under this circumstance, CRU will not interfere with the existing primary FH communication system. Their interrelationships are shown in (4) and (5), respectively.

$$T_l = jT_z + (\tau_r + \Delta\tau_d) = jT_z + T_r \tag{4}$$

$$T_J = T_h - (jT_z + T_r) = T_t - jT_z \tag{5}$$

T_J should be smaller than T_h under any circumstance for effective coverage of the hopping period. The effective dwell ratio h is defined to be T_J over T_h. The framing window number available during each hopping period is defined to be m and represented as

$$m = \left\lfloor \frac{T_h - T_r}{T_z} \right\rfloor = \left\lfloor \frac{T_t}{T_z} \right\rfloor, \tag{6}$$

where T_z represents the framing processing time per scanning window W_s and the bracket symbol means the maximum integer equal to or smaller than the value inside is taken. It follows that CRU could analyze at most m windows during the dwell period, T_h. Furthermore, the scanning window number n available in the FH system bandwidth W is represented as

$$n = \left\lceil \frac{W}{W_s} \right\rceil, \tag{7}$$

where W represents the hopping bandwidth of a FH system, W_s represents the scanning window set by CRU, e.g., 1 or 5MHz, and the bracket symbol means the minimum integer equal to or larger than the value inside is taken. It follows that CRU could analyze at most n windows during the whole hopping bandwidth W. The wider the scanning window W_s is, the smaller the window number n will be. This means that a faster scanning but rougher scanning condition is set. Let k be the window number of framing and scanning during each hopping period, it is evident that $k=\min\{m,n\}$, which means the smaller one of m or n is selected as the window number.

C. Sequential scanning scheme

A sequential scanning scheme will be taken as the scanning measure to scan the incoming frequency hopping signals fast enough to implant CRU transmit signal if it is allowable. Based on the basic definitions as aforementioned, if CRU analyzes all scanning windows randomly with sequential perception $p(T_J)=1/(n+1-j)$, then $p(T_J)=(n-k)/(n+1-j)$ will be the perception not analyzed in the scanning window. Therefore, the perception distribution of the effective dwell time can be given by

$$p(T_J) = \begin{cases} \dfrac{n-k}{n+1-j}, & j > k\,(T_J = 0) \\[2ex] \dfrac{1}{n+1-j}, & j = 1,2,\ldots,k \end{cases} \tag{8}$$

It is assumed that T_r is assumed not zero and $T_r=\tau_r+\Delta\tau_d=l\times T_h$, where l is the propagation time ratio between T_r and T_h. The average effective dwell time can therefore be derived and given by

$$\overline{T}_J = \sum_{j=1}^{k} T_J \cdot p(T_j) = \sum_{j=1}^{k} \left(\frac{(1-l)\cdot T_h - jT_z}{n+1-j} \right) \tag{9}$$

From (9), the criterion of hopping rate ($r_h=1/T_h$) and framing processing time product (T_z) for effective dwell time can be available and given by

$$r_h \cdot T_z \le \frac{\displaystyle\sum_{j=1}^{k} \left(\frac{1-l}{n+1-j} \right)}{\displaystyle\sum_{j=1}^{k} \left(\frac{j}{n+1-j} \right)}, \tag{10}$$

which is the basic criterion whenever $T_r \neq 0$ for effective coverage of the hopping period.

D. Cognitive perception ratio (CPR)

In order to explore and "probe" the spectrum awareness further with geometry-dependent situation as described in **Fig. 1** for cognitive communications, an effective dwell time ratio by sequential scanning scheme under an elliptical operation scenario can be defined as cognitive perception ratio (CPR) and given by

$$CPR = \frac{\overline{T}_J}{T_h} = \sum_{j=1}^{k} \left(\frac{1-l}{n+1-j} \right) - T_z \cdot r_h \cdot \sum_{j=1}^{k} \left(\frac{j}{n+1-j} \right), \tag{11}$$

where

$$l = r_h \cdot (a + R_{cr} - R_{tr}) \cdot c^{-1} \tag{12}$$

CPR is the quantified metric for cognitive communication in a FHSS system. If *CPR* value is high when in comparison with specific *CPR* level set by incorporating many system parameters (e.g., $>$ 0.8), CRU will beware much more the existence of the FH communication and should rescan and shift to other frequency bands of interest for specific communication purpose in an opportunistic manner without affecting any existing FH communication system. Nevertheless, on the contrary, if *CPR* value is low (e.g., $<$ 0.2), CRU will coexist well with the FH communication system and should prepare to acquire and utilize this spectrum resource for specific cognitive communication purpose. Furthermore, the ellipse area encompassed with a specific hopping rate is defined to be the constrained area A_{se} and given by

$$A_{se} = \frac{\pi}{4}(D+a)\sqrt{D\cdot(D+2a)}, \tag{13}$$

where D is defined the same as aforementioned.

IV. Numerical Analysis

In this section, several intriguing numerical results based on derivations from previous sections will be illustrated and addressed. **Fig. 4** shows the *CPR* vs. R_h curves for different framing processing time (T_z) with the assumption of W_s=1MHz and T_r =0.1T_h. Basically, *CPR* changes inversely with hopping rate with other parameters fixed, i.e., the higher R_h is, the smaller *CPR* will be. Moreover, for fixed R_h, the shorter T_z is, the higher *CPR* will be, i.e., CRU will beware more the existence of a primary FH communication system and should avoid interference to it.

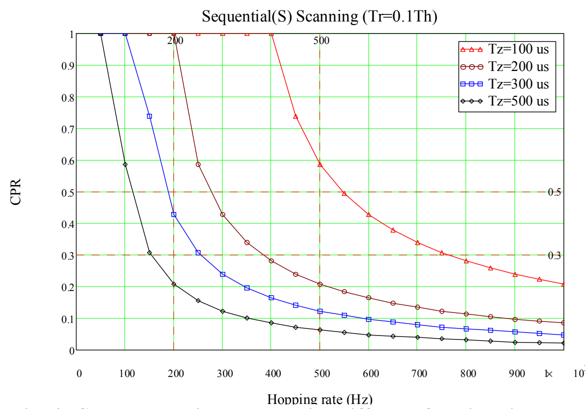

Fig. 4. *CPR* vs. hopping rate r_h with different framing times T_z

In order to examine the location awareness, the elliptic *CPR* contours are shown in **Fig. 5** with S-scanning, T_z=100*us* and R_h=400Hz (*y*-axis vs. *x*-axis: ±250km×±250km) The red dashed lines show the constant tilted angles formed by the varying CRU and the other two fixed FH transmitter and receiver; blue solid lines show the elliptic *CPR* trajectories and values. It is observed that when CRU changes its trajectory in an elliptic manner and approaches to FH transmitter and receiver located on the positions of (*x*, *y*)=(±50km, 0), the *CPR* values are varied from about 0.1 to 0.9. If location awareness through *CPR* is established, the cognitive perception can therefore be sensed and analyzed from where it is located. For example, when CRU is located on (*x*, *y*)=(100km, 100km), its analyzed *CPR* value is around 0.52. **Fig. 6** also shows the elliptic constrained area vs. hopping rate results.

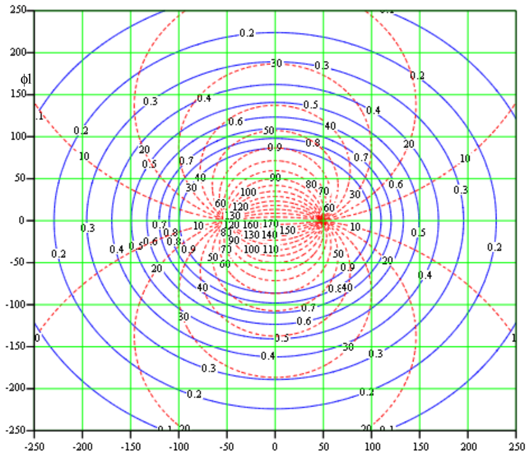

Fig. 5 Elliptic *CPR* contours with sequential scanning scheme

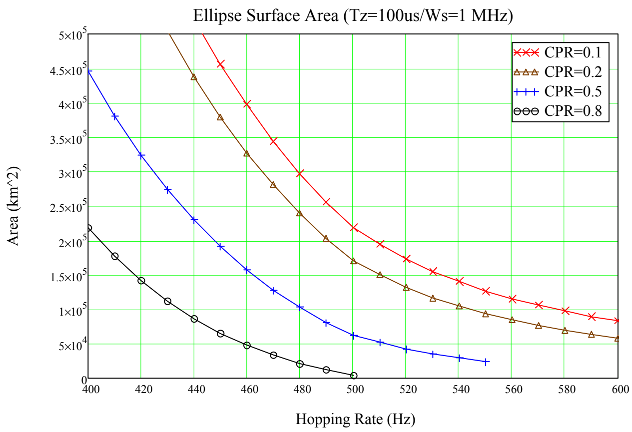

Fig. 6 Elliptic constrained area vs. hopping rate r_h

V. Conclusion

In this paper, a sequential scanning scheme for CRU architecture under an elliptic operation scenario has been proposed, which can be applied for radio spectrum and location awareness in cognitive radio communications. Moreover, a quantified CPR metric is available for evaluations of the coexistence of radio resources. The proposed scheme and metric can pave one practical way for the system evaluations of cognitive radio communications.

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