Geo-location Spectrum Opportunities Database in Downlink Radar Bands for OFDM Based Cognitive Radios

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***Abstract*- In this paper a model to investigate the spectrum opportunities for cognitive radio networks in three radar frequency bands L, S and C at a specific location is introduced. We consider underlay unaware spectrum sharing model. The Secondary System we assume is an OFDM based system. The followed strategy is built upon defining a specific co or adjacent channel as a spectrum opportunity if -and only if- the interference generated by the secondary system occupying that channel into the radar system is less than the permissible interference defined by the value of Interference to Noise ratio (INR) and the radar receiver inherited noise level. The simulation results show that for the same transmission parameters C band offer more spectrum opportunities than S band which is itself offers more spectrum opportunities than L band.**

Keywords- Geo-location based spectrum sharing ; interference tolerance; downlink radar bands; INR; co and adjacent-channel interference

I. INTRODUCTION

COGNITIVE radio (CR) is a wireless communication paradigm where the spectrum is accessed dynamically by the wireless networks nodes according to its availability, a huge research has been done to find out the potential frequency bands which can adopt CR, mainly the underutilized bands have been looked for. One of the measurements campaigns reported in [1] showed that quite much radio spectrum which is statically assigned for some services is underutilized and part of this underutilized spectrum is the portion assigned for the radar systems. Being at different parts of the radio spectrum and having a wide dedicated bandwidth, radar bands would then be suitable bands for the co-existence of the Secondary Systems (SS) based on underlay unaware spectrum sharing where the SS is allowed to operate while a specific limit of injected interference to the Primary System (PS) is not exceeded. Spectrum sharing awareness reflects the situation of the PS regarding being aware of the SS coexistence or not and upon that spectrum sharing can be either aware or unaware and throughout the course of this paper unaware spectrum sharing will be considered.

Orthogonal Frequency Division Multiplexing (OFDM) is a spectrum efficient multiplexing scheme which makes it an attractive technology for most of today's and future's short range wireless networks. This high spectrum efficiency makes it worse than less efficient multiplexing schemes from the PS point of view when it comes to underlay spectrum sharing as the SS signal components is everywhere inside the band it occupies which drives it to be stronger source of interference to the PSs than the other traditional multiple access techniques.

The remaining part of this paper is structured as follows; Section II is a conceptual section on coexistence feasibility with the radar systems. Section III introduces mathematically the amount of the tolerable interference to the radar system injected by the SS works under underlay spectrum sharing basis. Simulation assumptions and simulation parameters are described in Section IV. In section V the simulation numerical results are presented. Finally, Section VI concludes the paper.

II. SPECTRUM SHARING FEASIBILITY OF RADAR BANDS

To claim a specific band of frequencies at a certain location as a feasible band to be utilized by CR devices then two aspects should be taken into account. At first, whether the characteristics of this band fit the SS requirements or not, secondly, what is the impact of coexisting of the SS on the PS performance. Below are some discussions concerning these two aspects for radars as PSs.

A. Prospective radar bands to adopt SSs co-existence

The most feasible radar bands for the SSs to utilize are: L band lies between 960-1400 MHz, S band lies between 2.7-3.4 GHz and C band lies between 5.255-5.850 GHz for the below listed reasons:

- In the spectrum assigned for the radar at lower bands such as VHF and UHF the offered bandwidth may not be wide enough to handle the SSs requirements which are expected to be short range high data rates systems.
- The higher bands beyond L, S and C bands are suitable for fixed point-to-point communication when directional antennas can be used while the SSs are most probably equipped with omni-directional antennas-due to the expected applications of cognitive radio networks- and L, S and C bands have suitable propagation behavior for this.
- The cost and power consumption of the radio technology increases with the increase of the operating frequency which makes it more costly for the SSs to operate in the higher radar bands beyond L, S and C bands.
- The technical characteristics and communication entities structure of the current existing unlicensed systems fit the operating frequencies of the old ISM bands around 900MHz, 2.4 GHz and 5 GHz which are closer to L, S and C radar bands frequencies and therefore less changes in these unlicensed systems which are likely to be the future CR SSs may be needed if those radar bands are considered instead of the others to deploy the secondary spectrum access.

Moreover, in [2] the authors conclude that based on secondary device transmission power and radiation considerations L and S radar bands would offer significant opportunities compared to C and X bands which they are themselves relatively congested.

B. SSs co-existence impact on radar performance

The purpose of this paper is to inspect the effects of the existing of a SS on the radar system in contrast with what has been done in [3] where the impact of the radar system on the SS is studied and in [4] where the degradation of Radio Local Area Networks (RLANs) is investigated.

In the context of the coexistence between radars and SSs there are two fundamental criteria to claim a specific location as a feasible place for coexistence or not and therefore to determine the minimum required separation distance between the radar and the coexisting SS, these fundamental criteria are:

- Detect-ability of the radar signal existence by the SS, the SS can use one of the detection algorithms reported in [5] which are the foreseen proposed detection methods so far according to the best of our knowledge.
- Interfere-ability which is the interference injected by the SS to the radar signal, the SS is assumed to be a 'harmful' interferer if it generates an interference more than the defined maximum permissible interference by the value of the maximum interference-to-noise ratio (INR) at the radar system which defines the maximum tolerable interference relative to the noise floor for the radar as introduced in [6]. Consequently the range at which the SS will cause a harmful interference to the radar can be calculated depending on the channel behavior or the applied path loss model.

SS interferes with both transmitted radar pulses and scattered back signals from the target as in Figure 1 which illustrates the overall system when a SS coexists with a radar system

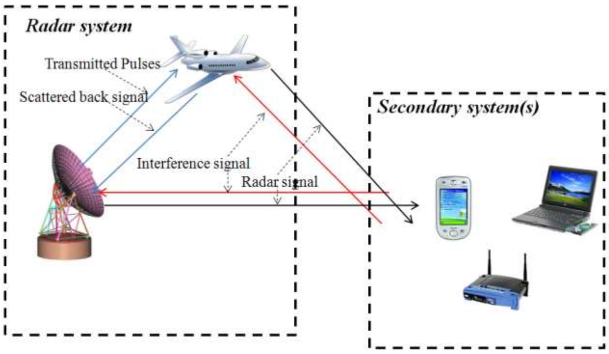


Figure 1. Radar-SSs band sharing mutual impacts.

In [7] and [8] Dynamic Frequency Selection (DFS) is proposed where the secondary system should change the channel it occupies when the radar system wants to use it to mitigate the interference caused by the SS and to distribute the SS load among the available channels.

The authors of [9] defined four spatial regions regarding the ability of operation of the SS in a certain channel in a specific radar band as follows:

- *Region1- Non-interfering/detectable region*: Where the radar system signal is detected but the SS will not cause a harmful interference to the radar, accordingly blocking SS transmission is safe if other opportunities are found, but if not, then the SS can utilize radar frequencies in this region.
- *Region2- Non-interfering/non-detectable region*: Here the radar signal cannot be detected and no interference is to be generated to the radar signals; therefore, this is a safe region for SS to operate in.
- *Region3- Interfering/detectable region:* Radar system signal is detected and if the SS operates it would interfere the radar; hence, SS operation is forbidden in this region.
- *Region4- Interfering/non-detectable region:* Interference to the radar would occur if the SS operates but it cannot detect the radar signal appearance and this is unsafe region and it should be avoided to fall in in system design and this is one of the research challenges in CR arena.

The above mentioned regions are Equivalent Isotropic Radiated Power (EIRP) dependant as the transmission power of both radar system and SS will determine the boundaries for these regions, if a constant EIRP for both systems is to be applied then the radar EIRP determines the detect-ability of the radar signal and the SS EIRP determines the interference that radar system would suffer from. Furthermore, it is also doable to consider a specific separation distance and then determine the regions boundaries referring to the EIRP of the SS. Figure 2 demonstrates the regions boundaries for an arbitrary radar receiver SNR and INR.

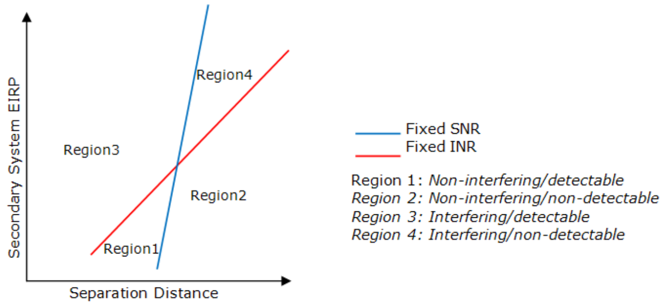


Figure 2. Regions of detect-ability and interfere-ability as functions of SS EIRP and separation distance

With severe requirements when INR is too low and SNR is too high then the safe region (region 2) starts at a higher separation distance and then the coexistence between radar and SSs is more restricted. However, with lenient requirements of INR and SNR the safe region starts at lower distances and then the SSs can enjoy a higher ability of operation but with a higher degradation in the radar performance.

III. Radar Interference Tolerance and Required Separation in Space and Frequency Domain for SS Operation

A link budget formula is needed in order to estimate the minimum required separation spatial distance between the radar system and the coexisting SS for a specific carrier separation between the two systems where the radar performance will not be degraded according to the maximum permissible interference determined by INR requirments as

$$I_{max} = INR + N\ [dBm], \qquad (1)$$

where

I_{max} is the maximum permissible interfering signal level

N is the receiver inherited noise level calculated over its bandwidth.

In order to find the interference that SS will generate and therefore to determine whether the SS can operate on the frequency band occupied by the radar located at a specific distance from the radar, a link budget formula is introduced in [6] as

$$I(d, RF) = P_T + G_T + G_R + L_T + L_R + L_P(d) - FFDR(RF)[dBm], \quad (2)$$

where

I is the peak power of the SS signal at the radar receiver input (dBm)

RF is the band width of the SS falls inside the radar band (MHz).

d is the separation distance between the SS and the radar receiver (km).

P_T is the transmitted power of the SS (dBm)

G_T is the antenna gain of the SS in the direction of the radar (dBi)

G_R is the antenna gain of the radar in the direction of the SS (dBi).

L_T is the SS insertion loss (dB).

L_R is the radar insertion loss (dB).

L_P is the propagation loss between the radar and the SS antennas which is separation distance dependant (dB).

FDR is the frequency dependant rejection produced by the receiver RF selectivity curve on SS signal spectra. FDR is described in [10] and it accounts for the energy coupling loss of the interferer signal in a victim receiver and it is composed of two components Off-Frequency Rejection (OFR) and On-Tune Rejection (OTR) as

$$FDR = OFR - OTR \text{ [dB]}, \quad (3)$$

OFR accounts for the lost signal energy due to filtering operation at the receiver and can be obtained by

$$OFR = 10log_{10} \int 10^{[\mathbb{P}(f) - \mathbb{G}(f+\Delta f)]/10}\, df - 10log_{10} \int 10^{[\mathbb{P}(f) - \mathbb{G}(f)]/10}\, df \text{ [dB]}, \quad (4)$$

where:

$\mathbb{P}(f)$ is the transmitted signal power spectrum density in dB

$\mathbb{G}(f)$ is the receiver selectivity curve in dB.

On-Tune Rejection (OTR) which accounts for the mismatch between the transmitted signal and the receiver bandwidth and can be calculated using (5),

$$OTR = \begin{cases} 20log_{10}\left({B_R}/{B_T}\right), & B_T > B_R \\ 0 & , B_T < B_R \end{cases} \text{ [dB]}, \quad (5)$$

where

B_R is the receiver 3 dB bandwidth (radar receiver)

B_T is the transmitted signal 3 dB bandwidth (SS signal).

Equation (2) does not consider some existing types of losses such as polarization loss and buildings penetration loss and to overcome that a distant dependent propagation loss model can be assumed with a correction factor for multipath and other losses described in [6] and given by

$$CF(d, \alpha) = 2.6(1 - exp(-d/10)) \log_e\left({\alpha}/{50}\right) \text{ [dB]}, \quad (6)$$

where

CF is a multipath, polarization and buildings penetration losses correction factor at distance d.

α is an accuracy margin factor for which the calculated transmission loss is not exceeded. The value of α determines the probability that the radar system is safe having no harmful interference and it is subjected to the severity of preventing the harmful SS interference.

The coexistence of the SS with the radar is claimed to be possible if and only if I is smaller than I_{max}.

IV. Simulations

To carry out the simulation of the interference injected by the SS to the radar system the following assumptions have been taken into account

- The SS nodes are equipped with RF front-ends which enable them to operate in the whole band under investigation.
- The channel is modeled as a flat fading channel with a multi path effect described by (6).

A single interferer is omnipresent at a time, never the less, if multiple interferers are to operate then they should all together keep the limit of the permissible interference and accordingly the spectrum opportunities are determined by the maximum permissible interference together with the existing interferers injected interference to the radar system if no priorities are to be considered among the SSs.

The following radar specifications in terms of radar type and operating frequency are applied in the simulation

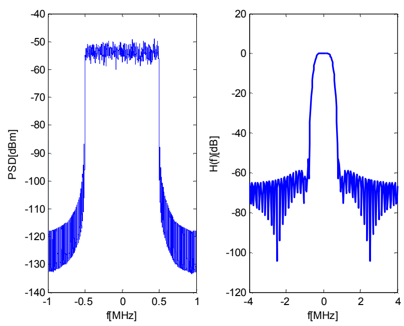
- Aeronautical radio navigation radar operates at 1250 MHz.
- Terminal traffic control radar operates at 2725 MHz.
- Airborn weather radar operates at 5500 MHz.

At the radar receiver the maximum permissible INR is taken to be -6 dB as recommended in [11] and [12]. Below Table 1 contains the applied parameters to carry out the simulation. Besides, Figure 3 illustrates the normalized SS power spectral density and the radar filter baseband magnitude response.

TABLE 1. SIMULATION PARAMETAERS

Parameter	**Value**
Radar pulse width	1 μsec*
SS OFDM Signal 3dB bandwidth	1 MHz
SS OFDM Signal modulation scheme	QPSK
SS OFDM Signal code rate	1/2
Number of carriers in OFDM signal	64
FFT size	128
SS transmission power	23 dBm
Radar antenna gain	30 dBi
SS antenna gain	0 dBi
Path loss model	Hata model
Radar receiver inherent noise power spectral density	-204 dBW/Hz
α	0.99

* Pulse width of 1 μsec would result in signal bandwidth of 1 MHz; hence the Radar filter cut-off frequency is chosen to be 1 MHz



(a) (b)

Figure 3. (a) Normalized SS OFDM baseband spectra and (b) The radar magnitude filter response.

From the values of the parameters given in Table 1 and the value of the permissible INR, the maximum permissible interference is obtained to be -116 dB.

V. Results

Below Figures 4-6 show the simulation results for L, S and C bands in terms of the interference caused by the secondary

OFDM signals located at different distances from the radar receiver and transmitted at different RF separations from the radar central operating frequency.

Figure 4a shows the interference injected by the secondary OFDM based system into the L band radar receiver and Figure 4b determines the spectrum opportunities for the SS by illustrating where the received SS interference crosses the permissible interference level and it found to be at 93 km for the co-channel, 38 km for the 1st adjacent channel, 3.2 km for the 2nd adjacent channel and down to 1.5 km for the 7th adjacent channel.

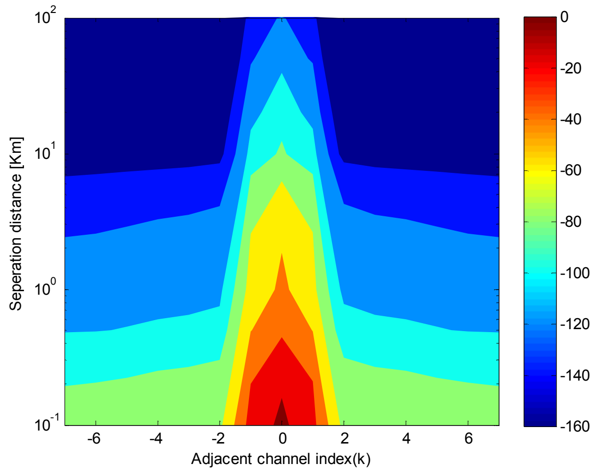


Figure 4a: Interference at the victim L band radar receiver as a function of spatial and frequency separation of k channels from the radar system.

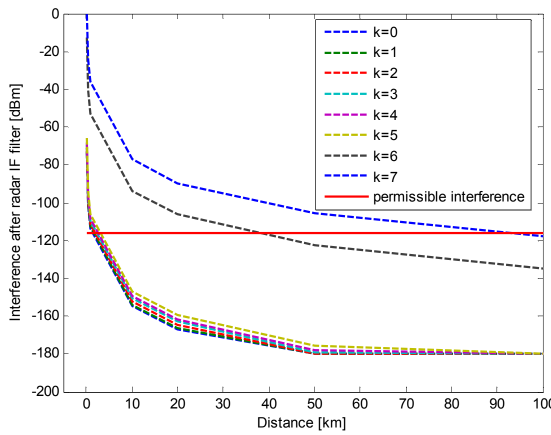


Figure 4b: Interference at the victim L band radar receiver injected by an adjacent channel apart by ±k channels from the radar operating channel.

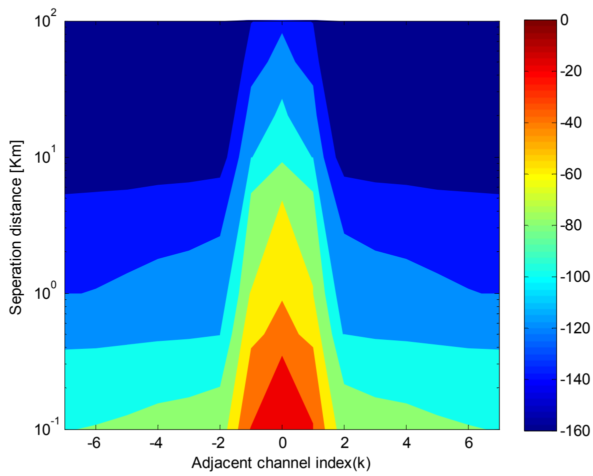


Figure 5a. Interference at the victim S band radar receiver as a function of spatial and frequency separation of k channels from the radar system.

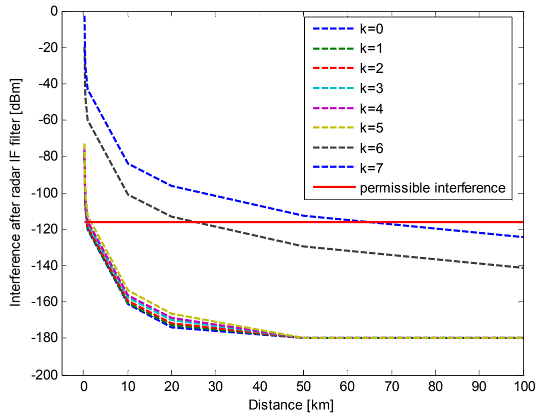


Figure 5b. Interference at the victim S band radar receiver injected by an adjacent channel apart by ±k channels from the radar operating channel.

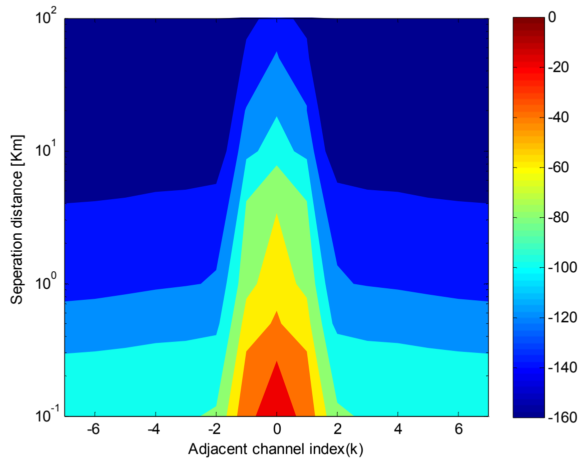


Figure 6a. Interference at the victim C band radar receiver as a function of spatial and frequency separation of k channels from the radar system.

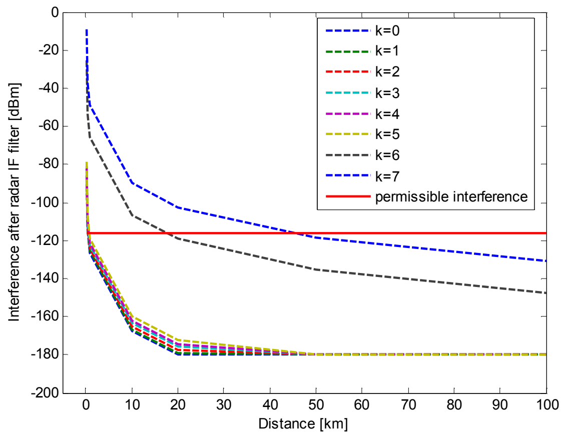


Figure 6b. Interference at the victim C band radar receiver injected by an adjacent channel apart by ±k channels from the radar operating channel.

As same as what Figures 4a and 4b demonstrates, Figure 5a and 5b depict the spectrum opportunities in the S radar band to be at 65 km for the co-channel, 25 km for the 1st adjacent channel and between 1.7 km and 0.8 km for the remaining adjacent channels.

From Figures 6a and 6b the spectrum opportunities at C band radar receiver can be extracted basically by the crossing points between the permissible interference and co-channel or each adjacent channel, therefore, the spectrum opportunities are at 45 km for the co-channel, 17 km for the 1st adjacent channel and between 0.9 km and 0.6 km for the channels between the 3rd and the 7th adjacent channels.

Figure 7 summarizes Figures 4, 5 and 6 and demonstrates the minimum distance for coexistence of SSs with the L, S and C radar band system for different adjacent channels.

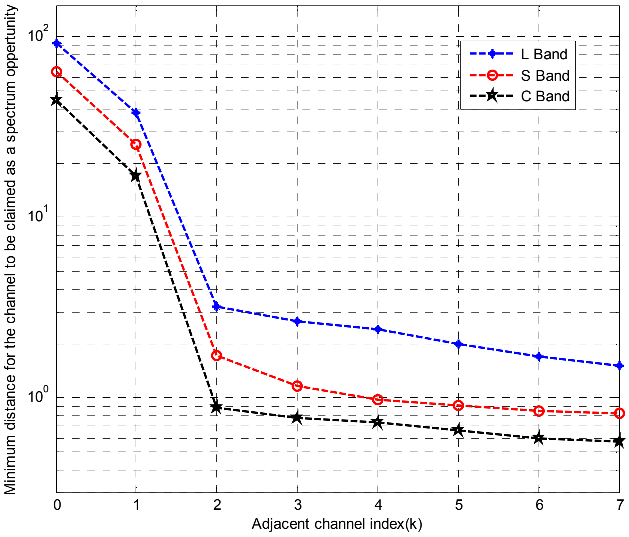


Figure7. Minimum distances from the radar receiver to the SS to occupy a channel apart by ±k from the radar channel

VI. CONCLUSIONS

The coexistence of secondary systems with radar systems in downlink L, S and C bands is feasible whenever the degradation caused by the secondary systems to the radar system is kept under a specific limit; this degradation is basically seen due to interference injected by the coexisting secondary systems.

The interference limit at the radar receiver is determined by the pre-specified INR value, hence the possibility of spectrum sharing with the radar by the secondary systems is subjected to this INR value and consequently to the spatial separation, transmit power of the secondary system and the RF separation. The obtained results show that investigated radar bands can be put in a descending order as C, S and L in the term of the offered spectrum opportunities when same transmission parameters are used.

Following the same methodology for spectrum opportunities determination described in this paper, a geo-location database containing the spectrum opportunities in downlink radar bands can be built as a function of the location and available channels at that location to assist the secondary systems finding free spectrum.

The work carried out in this paper considered co-channel and adjacent channel interference generated by a single interferer and no cumulative effects are considered for multiple interferers, however, if INR is taken as the regulator of secondary system coexistence then each interferer can determine its own allowed interference taking into account the interference caused by the other interferers where the overall allowed permissible interference defined by the value of INR should not be exceeded.

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