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Radar spectrum opportunities for cognitive communications transmission

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***Abstract*—In relation to opportunistic access to radar spectrum, the impact of the radar on a communication system is investigated in this paper. This paper illustrates that by exploring the spatial and temporal opportunities in the radar spectrum and therefore improving the tolerance level to radar interference, a substantial increase on the throughput of a communication system is possible. Results are presented regarding the impact of swept radars on a WiMAX system. The results show the impact of SIR (Received WiMAX signal to received radar signal ratio), radar antenna radiation patterns and rotation period estimation on the feasibility of radar spectrum access.**

I. INTRODUCTION

In order to increase the spectrum utilization, 'Cognitive Radio' is presented in [1] and supported by new spectrum regulatory policy proposals [2]. They consider opportunistic access to spare spectrum by exploring unused portions of the spectrum, employing all the available degrees of freedom (specific time, location and frequency). The premise of employing cognitive radio is that unacceptable levels of interference to licensed users on the same channels will not be generated. Meanwhile, the quality of cognitive communication transmission should also be adequate under the existence of licensed systems, to ensure viable communications can exist.

The radar bands between 2.7GHz and 3.4GHz offer a great deal of potential due to its inefficient usage [3]. For cognitive systems, efficient spectrum usage is achievable by exploring the spatial and temporal separation opportunities in radar spectrum on the basis of non-interference into both the radar and cognitive system. It is therefore essential that a cognitive system can adequately detect the presence of a local radar system and therefore not cause interference. This paper investigates cases where cognitive systems can use these spatial and temporal opportunities in the radar spectrum without suffering unacceptable transmission degradation caused by the radar.

Previous work [4] has focused on the feasibility of coexistence between a radar and a communication system where the radar acts as the primary system. In particular both analytical and simulation methods were employed to determine the protection level of radar from the interference of the communication system. This is done in terms of minimum interference region calculations, with statistical path loss and correlated shadowing channels. Recent work also explores the sharing of radar spectrum in 5GHz bands using Dynamic Frequency Selection [5]. In this paper, we consider the performance of a WiMAX system in the presence of a S-band swept pulse radar. It is assumed that when radar activities are detected, WiMAX can still proceed with opportunistic transmission as long as it avoids interfering with the radar system. By exploring the spatial and temporal opportunities in the radar spectrum, the throughput of WiMAX system increases substantially which further proves the feasibility of radar spectrum sharing and therefore additional spectrum usage gain attained.

The rest of this paper is structured as follows. In Section II, the models of WiMAX packet transmission as well as the pulse radar system are presented. In Section III, the impact of radar pulse interference on WiMAX transmission is studied considering collisions on both the preamble and date symbols; transmission degradation by different pulse radar waveforms collision; and radar spectrum access opportunities by exploring the swept radar rotation rate and the antenna radiation patterns. Results can be further explored to design efficient sensing algorithms and access strategies in radar-WiMAX scenario. Finally, Section IV concludes the paper.

II. SIMULATION ARCHITECTURE

A . WiMAX system description

The key parameters of WiMAX transmission system assumed in this paper are given in [6]. It has been assumed that one WiMAX packet consists of 2 preambles in downlink and 1 preamble in uplink transmission for channel estimation and it is followed by 8 data symbols for data transmission. The sample rate is set as 5.76MHz, the WiMAX useful symbol duration T_b is 256 samples (44μs) and the Cyclic Prefix (CP) is 64 samples (11μs). Therefore, the OFDM symbol duration T_s is 320 samples (3200 samples for one WiMAX downlink packet of 10 OFDM symbols).

B. Radar system

The main parameters of the pulse radars considered in this paper, based on several types of commercial (aeronautical radio-navigation and meteorological) and military radars [7], are shown in Table I.

TABLE I: SWEPT RADAR PARAMETERS

Parameters		Unit
Radar frequency	2.7	GHz
Pulse Repetition Time (PRT)	577*(100)*, 3331*(578)*, 5771*(1002)*, 3200*(555)*	Samples *(us)*
Pulsewidth	5*(1)*, 57*(10)*, 115*(20)*	Samples *(us)*
3dB main beamwidth	1.36 (Uniform aperture distribution) 1.84 (Cosine aperture distribution)	Degree

A one-dimensional radar aperture distribution is considered here, the antenna pattern is given by

$$E(\phi) = \int_{-\frac{a}{2}}^{\frac{a}{2}} A(z)\exp(j2\pi\frac{z}{\lambda}\sin\phi)dz \qquad (1)$$

Where a is the width of the aperture in z-dimension. λ is radar wavelength. ϕ is the radar swept rotation angle and $A(z)$ is the radar aperture distribution. Two aperture distributions are discussed as below,

Uniform aperture distribution $A(z) = 1$, the corresponding normalized field-intensity pattern is expressed by,

$$E(\phi) = \frac{\sin[\pi(\frac{a}{\lambda})\sin\phi]}{\pi(\frac{a}{\lambda})\sin\phi} \qquad (2)$$

where $E(0) = 1$.

The cosine aperture distribution is expressed by,

$$A(z) = \cos\frac{\pi z}{a}, \quad |z| < \frac{a}{2} \qquad (3)$$

and the corresponding field-intensity pattern is given by,

$$E(\phi) = \frac{\pi}{4}[\frac{\sin[\psi + \frac{\pi}{2}]}{\psi + \frac{\pi}{2}} + \frac{\sin[\psi - \frac{\pi}{2}]}{\psi - \frac{\pi}{2}}] \qquad (4)$$

Where $\psi = \pi(\frac{a}{\lambda})\sin\phi$.

Fig. 1 shows the radar power radiation distribution in terms of uniform aperture distribution and cosine aperture distribution respectively.

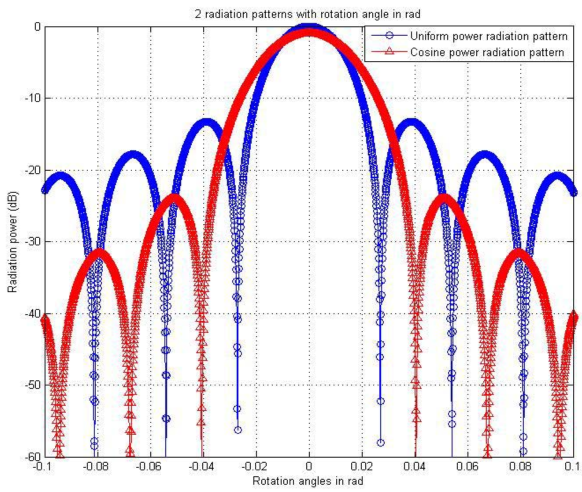
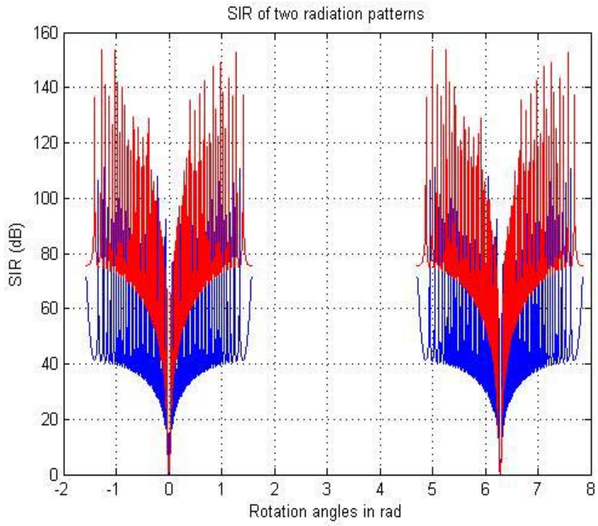
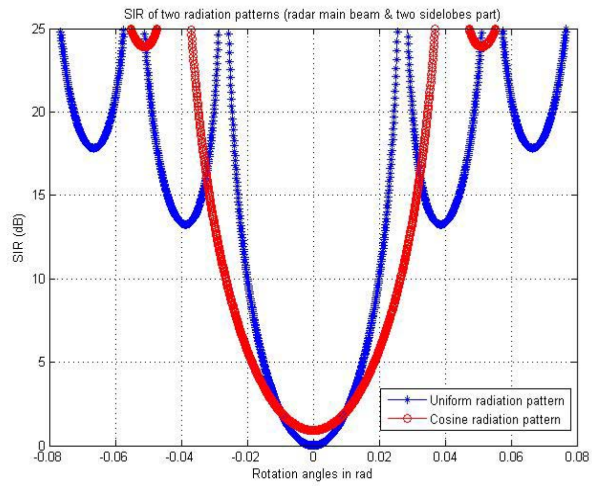


Fig. 1 Antenna power radiation patterns as a function of radar rotation angle



(a) SIR values in a single radar rotation period



(b) SIR ranging between 0dB and 25dB in terms of radar main beam and two sidelodes

Fig. 2 SIR values at WiMAX node as a function of radar swept rotation angle

As the power of uniform pattern is normalized to 0 dB, the relative gain of cosine pattern is 0.81. In addition, the cosine pattern has a wider main beam and lower sidelobes, in which the power of the first sidelobe below the maximum intensity of the main beam is -23dB, the counterpart in uniform pattern is -13.2dB.

It is assumed that the WiMAX nodes are static, and that the SIR value is set to be 0dB when being radiated by the radar main beam, where the impacts of the communication transmission at the same power level on the radar system have been discussed in [4]. Considering the WiMAX node, the received SIR values as a function of radar swept rotation rate can be seen in Fig. 2.

Fig. 2(a) presents the SIR ranges, seen at a WiMAX node according to different radar rotation angle steps. As can be seen, the SIR reaches the lowest value at 0dB when the WiMAX node is directly radiated by radar main beam. Fig.

2(b) shows detailed SIR values ranging from 0dB to 25dB (only main beam and two sidelobes are considered in this case).

III. PERFORMANCE RESULTS

The simulation scenario is described in Fig. 3. One or two preambles are used for channel estimation as indicated. Where necessary, to force collisions with specific parts of the OFDM symbol, the radar PRT is set as 3200 samples (555μs), the same as the WiMAX symbol duration T_s. In this example the pulsewidth is 57 samples (10μs). In the following sections, the discussions are provided on three different cases in terms of preamble-data symbol collision, impacts from different radar waveforms and access opportunities by exploring the radar swept rotation rate and radiation patterns.

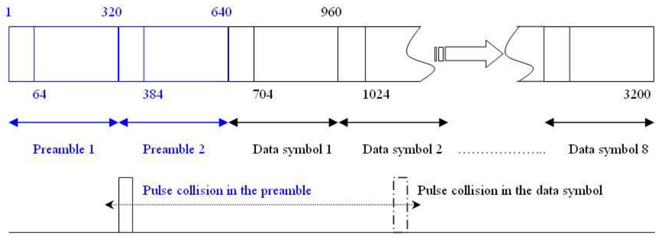


Fig. 3 WiMAX packet structure and radar pulse positioning

A. *Impact on WiMAX performance due to collisions in the preamble and data symbols by radar pulse*

In this part, the WiMAX performance is evaluated by considering collisions with the WiMAX preamble or the data symbol. We also investigate the performance in the case where the radar pulse collides at different positions within WiMAX data symbol (or preamble).

In Fig. 4, the radar PRT is set equal to the WiMAX packet duration, which ensures the radar pulse always collides with a specific part of the WiMAX packet.

Assuming an operating region with the Bit Error Rate (BER) $<10^{-5}$, a preamble-collision is preferred for lower radar power levels. In addition, as shown by the triangle curves in Fig. 4, if the preamble is extended to doubled length (downlink transmission case), BER is improved since more uncorrupted samples exist for channel estimation. Therefore, preamble-collision is more acceptable than colliding with data symbols when sufficient preamble symbols are available. Consequently, downlink transmission is more robust in the presence of radar.

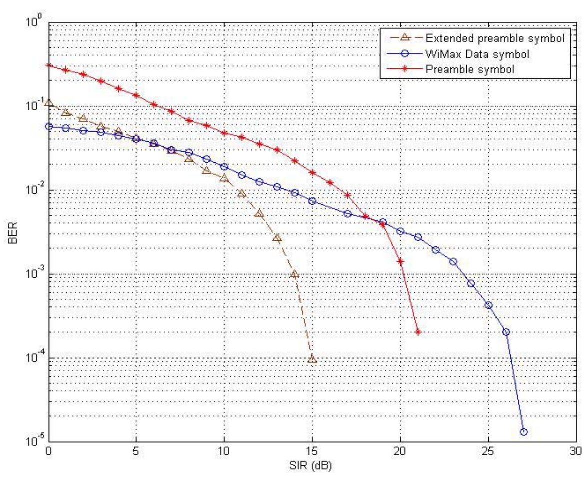
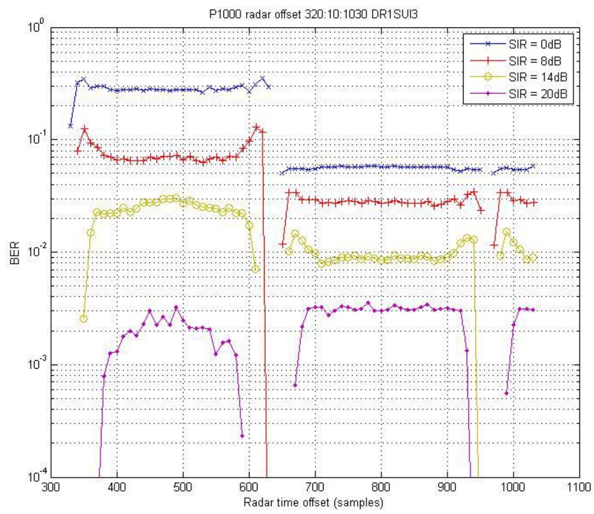


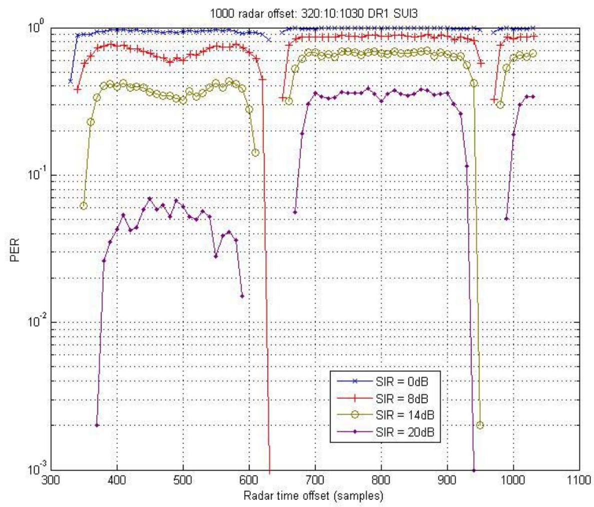
Fig. 4 QPSK ½ rate, SUI3 Channel

Fig. 5(a) shows the BER performance when the radar pulse is moved from the WiMAX preamble to the data symbol in the SUI3 channel [8].

As can be seen in Fig. 5, there are regions of zero BER, which occur when the radar pulse is positioned at the WiMAX guard band (CP) duration which will be removed at the receiver. Similar performance is obtained in non-fading channels. As shown in Fig. 5, the zero BER regions are wider



(a) SIR = 0, 8, 14, 20dB, SUI3 Channel



(b) SIR = 0, 8, 14, 20dB, SUI3 Channel

Fig. 5 Transmission performance according to different radar pulse time offsets with a higher SIR. Therefore, where possible, WiMAX transmission scheduling is recommended to make radar pulses collide with the WiMAX guard band, or downlink preambles, in order to significantly reduce the WiMAX transmission degradation.

Fig. 5 indicates, initially when SIR increases, BER drops faster by colliding with the middle of the useful symbol than colliding with the edge of the useful symbol (e.g. half CP, half useful symbol). However, with further increase in SIR (means radar power further decreased), the BER drop is more obvious/sensitive at the edge of the useful symbol than that colliding with the useful symbol entirely. The relative performance of preamble collisions and data symbol collisions in Fig. 5 can be seen to be consistent with Fig. 4.

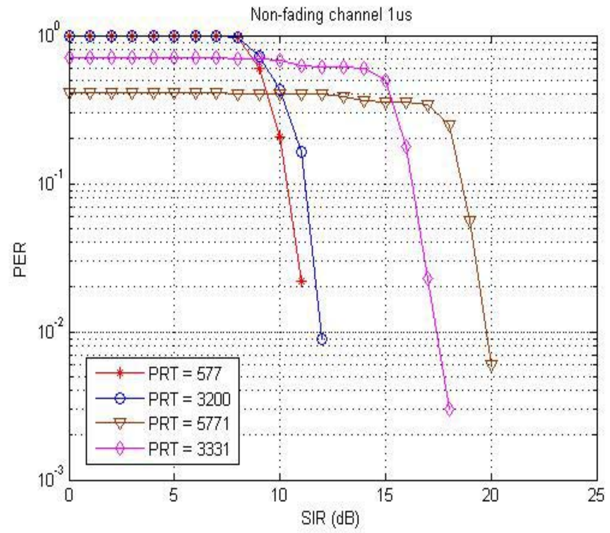
This result can be explained with the periodicity of the FFT interval, if there is no integer number of cycles for each subcarrier within the FFT interval, then the problem of intercarrier interference (ICI) would arise, which means subcarriers are no longer orthogonal, leading to BER degradation. To eliminate ICI, the OFDM symbol is cyclically extended in the guard band (CP) by replicas of last 64 samples of useful symbol. Therefore, as long as the length of the CP is longer than the multipath delay, the delayed replicas of OFDM symbol always have an integer number of cycles within the FFT interval. As a result, no ICI occurrs, and subcarriers are still orthogonal. In this case, corrupting the middle of the useful symbol does not affect the periodicity of the FFT interval (still has integer number of cycles), and only partially colliding the beginning part or end part of the useful symbol can result in periodicity-corruption, which further degrades the BER performance. Therefore it provides good reference to decide which part of WiMAX symbol is more resilient to radar pulse collision according to different SIR values. In relatively low SIR, the BER degradation is less with middle-collision than with periodicity-lost by edge-collision. Further increase in SIR, edge-collision brings less BER degradation than that by middle-collision.

B. *WiMAX Packet Error Rate (PER) for different radar waveforms in terms of pulsewidth and PRT*

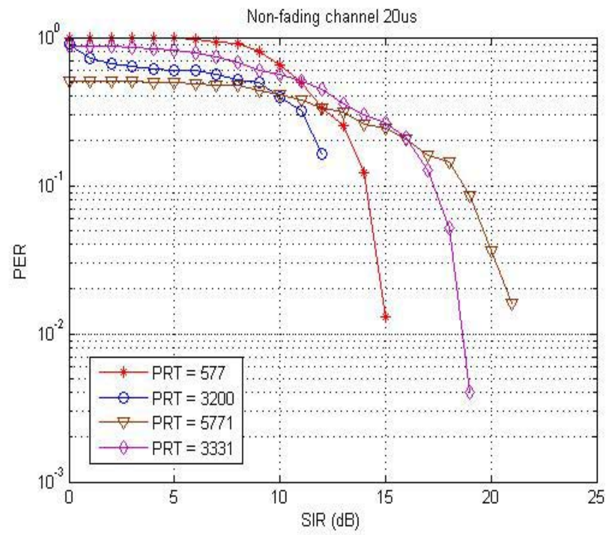
As illustrated in Fig. 6(a), for a short-pulsewidth radar condition (pulsewidth = 1μs), assuming PER< 10^{-1} is acceptable, the performance of low-PRT radar is better than that of high-PRT radar due to power normalization, by which the power level of low-PRT radar is lower than the power of high-PRT radar, although more pulses occur in low-PRT than that in high-PRT radar.

Fig. 6(b) shows that in high-pulsewidth radar conditions (pulsewidth = 20μs), there is no obvious PER performance difference between the low-PRT radar and the high-PRT one, especially when the SIR value is low. In addition, in contrast to the low-pulsewidth case, where PER drops sharply when SIR approaches a certain threshold-like value, the PER performance in the high-pulsewidth case is improved gradually as SIR increases.

Therefore, considering a fixed pulsewidth and power level, the radar with the highest PRT has the worst impact on a WiMAX system in terms of practical PER requirements.



(a) Pulsewidth = 1μs



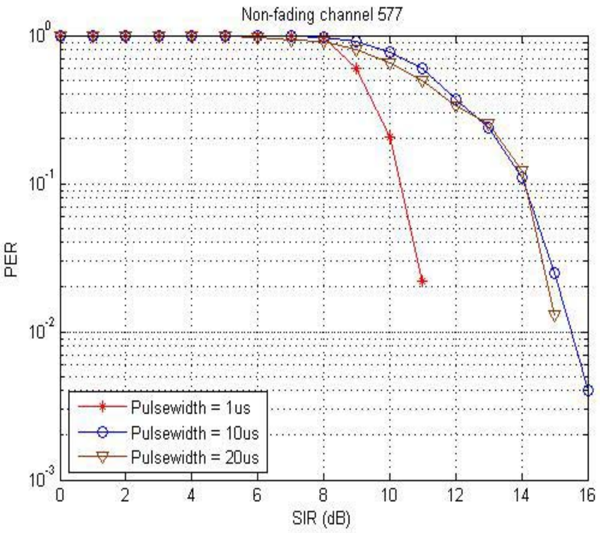
(b) Pulsewidth = 20μs

Fig. 6 PER performance at fixed radar pulsewidth in a Non-fading channel for different PRT values

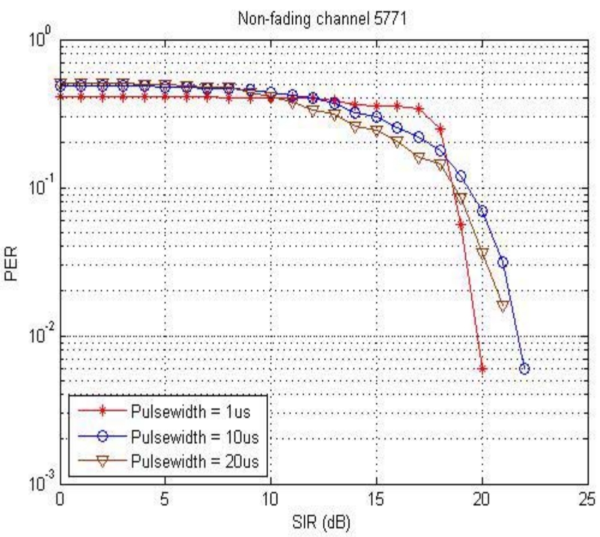
There is an exception when radar pulses keep colliding with a WiMAX specific packet portion, e.g. guard band or preamble as shown in the circle curve (PRT = 3200 samples) in Fig. 6, where PER can be improved substantially. It can be seen that short-pulsewidth radar performs better when SIR increases.

For a fixed radar PRT, in low PRT conditions as illustrated in Fig. 7(a), a short pulsewidth results in lower PER than a long pulsewidth radar when SIR increases. However, in high PRT conditions, using a short pulsewidth has limited transmission improvement, compared to using a long-pulsewidth one.

Fig. 8 considers the performance at the SUI3 channel and demonstrates similar performance trends for the different radar waveforms. However, exploring a short pulse with high PRT can lead to better PER performance in a SUI3 channel.



(a) PRT = 577 samples



(b) PRT = 5771 samples

Fig. 7 PER performance at fixed PRT in Non-fading Channel for different pulsewidth values

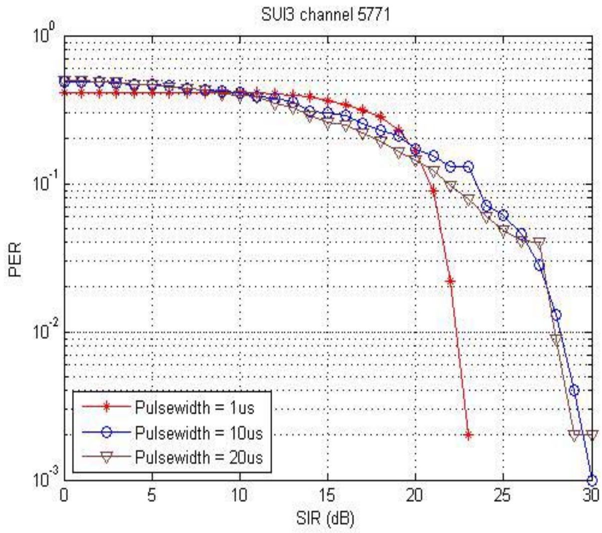


Fig. 8 PRT = 5771 samples, SUI3 Channel

C. Opportunities from radar swept rotation rate & antenna radiation patterns

In the case of swept radar, opportunistic access to radar spectrum can be further explored considering the swept rotation rate and antenna radiation patterns. The term Access Denial Rate (ADR) is introduced and defined as the ratio of the radar spectrum access-enable time duration to entire radar rotation period under a certain PER threshold. In this paper, the acceptable WiMAX PER threshold is set to be 10^{-1}, over which the WiMAX node will not be able to access the radar band due to unacceptable packet retransmission cost. The radar swept rotation period is chosen as 4.8 second, which is the typical value in Air Traffic Control radar [9].

PER vs. SIR performance shown earlier in this paper is used to determine whether service is viable or would be denied for antenna orientations over a whole sweep. This assumes the received radar power is constant over a packet.

Fig. 9 demonstrates the ADR performance with a peak SIR of 0dB (radar main beam points directly at the receiver) and where two side lobes are considered in a non-fading channel. At low PRT, a uniform pattern provides a lower Access Denial Ratio than a cosine pattern. When the PRT increases, the uniform pattern results in higher ADR. Overall, the ADR is increased with increasing PRT. In addition, a specific PRT (e.g. PRT = 3200 samples, which keeps colliding with the WiMAX preamble symbol only) has a lower ADR. Similar performance can be observed for a SUI3 channel, but leads to higher ADR. Furthermore, the impact of different pulsewidths on ADR is not obvious, especially in the high PRT case. Fig. 10 shows the radar spectrum Access Denial Rate in one radar rotation period as a function of peak SIR values. Lower SIR occurs when the WiMAX node is approaching the radar. As illustrated in Fig. 10, the ADR increases as a WiMAX node is approaching the radar. For the same radar radiation pattern, a SUI3 channel results to a greater ADR than that occurred in non-fading channel.

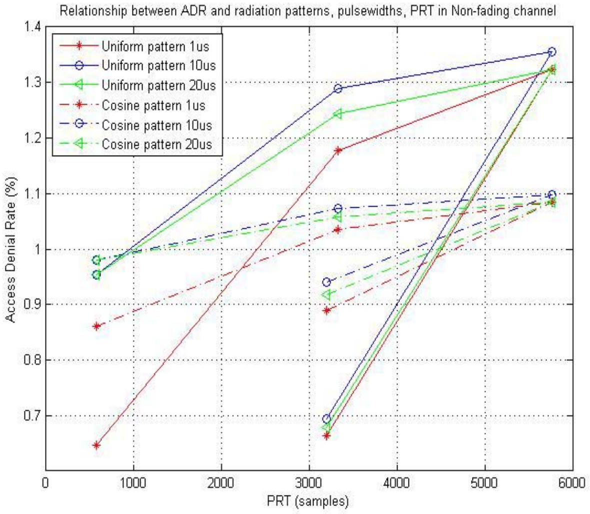


Fig. 9 Radar spectrum Access Denial Rate for different radiation patterns in Non-fading channel

It can be seen that the radar with a Cosine radiation pattern is preferred as a consequence of the much lower power level of the first several sidelobes than that in a uniform pattern, even though the cosine pattern has wider main beam width.

From a detection algorithm design perspective, a wider main beam width provides more pulses for non-coherent integration detection, which can increase detection probability. In addition, cumulative detection is also promising for cooperative detection algorithms which further increase the detection probability under certain false alarm constraints. The analysis of the opportunistic access on radar detection shows some delay-sensitive communication services, e.g. voice call, are not suitable for radar-spectrum access. Delay-insensitive services, such as web browsing and content downloading, are promising application for radar-spectrum access.

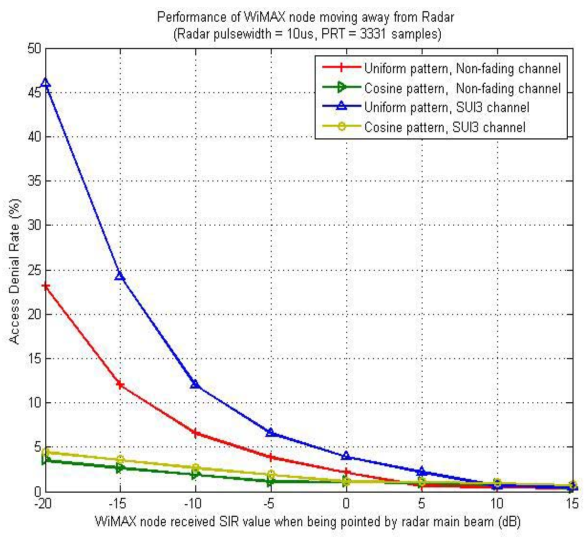


Fig. 10 ADR performance related to peak SIR

IV. CONCLUSIONS

In this paper, the impact of swept radar on a WiMAX system has been studied. Results indicate communication preamble-collision is preferred under low radar transmitter power than colliding with the data symbol. Performance degradation is further relaxed when an extended preamble is available. It was shown that short pulse and lower PRT radar is preferred for better communication transmission performance and that a Cosine radar antenna radiation pattern leads to better radar spectrum-access opportunities than a Uniform radar radiation pattern under the same radar swept rotation period. Radar swept rotation estimation is important to the feasibility of radar spectrum access, which determines the best access timeslots for WiMAX nodes to achieve low Packet Error Rates. In local spectrum sensing, nodes do not know whether the power sensed is from the radar's main beam or the sidelobes, hence the radar spectrum can not be accessed efficiently. When cooperative sensing is introduced, assuming nodes' relative positions are known, then radar rotation rate and power radiation distribution (e.g. main-side lobe ratio, whether nodes are pointed by main beam or sidelobes) are available. It has been shown that efficient and reliable radar spectrum access by secondary communication systems (e.g. WiMAX) is achievable. Future work will consider novel cooperative sensing algorithms in a mobile scenario.

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