FOPEN Capabilities of Commensal Radars

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Abstract— ***Use of passive or parasitic radars has been an active area of research in recent years. Such radars mostly depend on communication emitters of opportunity. One recent development in the field of communication engineering is the newly adopted standards for whitespace communication which frees the usage of analog TV bands. These bands because of their low-frequency nature, are suitable for foliage penetration (FOPEN). This paper investigates the use of whitespace communication for commensal use as a FOPEN radar system. It proposes the architecture of such an integrated communication radar (COMMRAD) system and concludes that such an FOPEN system is possible using the whitespace bands.***

Keywords: FOPEN, passive Radar.

I. Introduction

Research in the field of passive radar has been active for the past decade. Passive radars have also been termed as parasitic and symbiotic radars. However, the term *commensal* is the most accurate term. Because these radars depend on emitters of opportunity and do not affect the transmitters either in beneficial (in which case they can have been termed as symbiotic) or detrimental (in which case they could have been termed parasitic) way. Lastly they definitely need emitters, and hence are not passive. Hence, in this paper we will call these systems as commensal radars [1]–[3]. Recently there have been papers in the open literature on commensal Radar using FM signal, digital TV signal and even satellite signal [4]–[6]. The current paper describes a novel system based on the concept of extending the commensal principle to the whole system, such that the Radar can become an integrated commensal function of the communication system. The choice of Whitespace spectrum has got many advantages. First of all this will give access to a wide bandwidth, which in turn means better resolution for the coexisting Radar system. Secondly, the standardization process for Whitespace communication is over [7]. And lastly, because of the low frequency nature of TV bands, these bands are best suitable for foliage penetration (FOPEN).

Commensal radars usually use emitters of opportunity consisting of communication systems (e.g. DBBT, FM transmission etc.). In such conventional commensal radars, the communication systems are the main systems and the radar act as a commensal system. However, in the current generation of commensal radars, it is assumed that the communication systems have been designed with no consideration to this emerging use of the system as a potential radar system. This idea can be extrapolated to a system where the communication systems have been designed to support their commensal use as a radar system. One of the potential use of such a system is in the field of Whitespace communication. Whitespace communication is the first communication standard to leverage on the emerging research in the field of cognitive radio. Whitespace communication has several merits as a communication system. First of all because the bandwidth is in the zone of VHF, the cell size will be much larger than conventional cell size. Secondly, because of lower frequencies they will have some amount of foliage penetration capabilities. This makes them suitable to be used in sparsely populated and forest areas. Recently the author's group has developed a hardware module which can be used as a whitespace communication node with capabilities for a commensal radar usage. The operation and the system requirements of unlicensed devices for setting up of broadband networks within the TV whitespace spectrum have been discussed in [7]. The TV band signals, having a broad bandwidth as well as long distance propagation capabilities without much signal loss compared to standard wireless communication signals which operate at much higher frequencies, provide us with an opportunity to tap its potential for networked radar which can be used in remote areas, where there may not be any access to wired networks. There have been studies regarding the utilization of communication signals for radar functionality as well. [8]–[10] discuss the use of OFDM signals used in communication, for various radar applications.

The above described benefits of a whitespace radio are also applicable to the commensal radar which may build upon whitespace communication network. One of the major advantages of such a system will be its foliage penetration (FOPEN) capability. In this paper we shall examine the FOPEN capabilities of such a commensal radar system built upon a whitespace radio network. The major challenges to be examined will be the analysis of the whitespace standards and to investigate how much of FOPEN (in terms of radar usage) is achievable within the specifications of the communication standard. Given that whitespace communication may become one of the major technologies of choice for sparsely populated areas, and the fact that such areas are mostly the areas (hilly and forest terrains) where we seek FOEPN capabilities, this investigation is very pertinent and practical in nature.

The current work has two major contributions. First of all we propose a system which integrates communication systems to work as a radar network. Secondly we investigate the possibility of whitespace radio for possible FOPEN radar applications.

Rest of the paper is organised as follows. Section II gives a system level description of the proposed integrated communication radar (COMRAD) system. Section III gives simulation support for the claim that whitespace radio will have enough power to be operated as a radar. We conclude the paper in Section IV.

II. System level operation

IEEE Whitespace Standard IEEE802.22 is an open standard [11] which *specifies the air interface, including the cognitive medium access control layer (MAC) and physical layer (PHY), of point-to-multipoint wireless regional area networks comprised of a professional fixed base station with fixed and portable user terminals operating in the VHF/UHF TV broadcast bands between 54 MHz to 862 MHz.* The standard caters for high speed internet service to upto 512 users within a radius of 30km (upto 100km with special scheduling). Few salient features of the proposed system are as follows. The modulation scheme for the signal will be OFDM using QPSK or QAM. Secondly, the transmitters for the Whitespace communication will be able to support monotonic power level control over a range of at least 60 dB, with a resolution (step size) of 0.5 dB. The receiver sensitivity is expected to be around -90dBm. And, lastly the video bandwidth to be supported in this standard will be few MHz.

The above figures suggest that the use of such a system can be made as a Radar system as well. However, the main challenges are two fold.

1. The Radar functionality of the system will be secondary. Hence, a single base station can not be relied upon.

2. The bandwidth available is not sufficient for range resolution required for reliable detection and tracking of air-crafts.

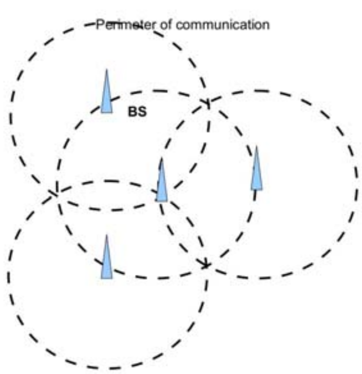

Fig. 1. An optimal positioning of the network of BS

Hence, as a solution we propose to use a network of base-stations, each with commensal capabilities to be used both as a Whitespace communication BS as well as a Radar node.

Figure 1 shows an optimal positioning for the proposed net-work of base stations. This solution solves both the challenges listed above.

1) Every location in the field of interest is covered by at least two BS. This gives the added reliability required to track aircrafts.

2) A network of BS work as a network of multistatic Radars. In such a case, even though the range resolution is low, reliable tracking is possible using the Doppler information only.

A. System Architecture

Figure 2 represents the block level diagram of the proposed system. Figure 3 represents the block level diagram of each node.

In Figure 2, each base station sends a time stamped Radar data to the central processor. It should be marked here that all the communication processing is done in each individual node. This is because communication is the primary function of the system. Secondly, if we try to add all the Radar processing to each node, this will make it bulky and more power consuming. In the central processor, the first task done to be done is to combine information from all the bands. Whitespace communication may not be able to get sufficient continuous band width. Hence, this block combines information from different bands to a single range resolution profile. There are many algorithms to do this, and worth mentioning is reference [12]. The next block applies some constant false alarm rate (CFAR) algorithms on the data. The third step is to extract the range resolution profiles and the Doppler profiles. The last step is to use the Doppler profiles along with position information of each BS to track the targets.

Figure 3 shows the block diagram of each base station. Transmitter and receiver antenna are connected to the RF front end, which in turn are connected to a digitiser. Because of the current surge in the field of software defined radio (SDR) and the success of the SDR platform developed in-house [**Error! Reference source not found.**3], each BS will use an SDR platform. A customised SDR platform for Whitespace Radar, is currently under development in our group. The received signal is processed in two independent chains, one for Radar and one for communication. The Radar chain is computationally light. It mainly does cross-correlation with the transmitted waveform. Then it adds the position and band-information with it and the data is then sent to the central processor. The communication chain strictly follows the Whitespace communication standard of IEEE 802.22

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III. The Signal to Noise Ratio (SNR) vs. Radar Range

We have done simulations for different Radar cross section (σ), duty factors (τf_p) and the number of pulses integrated (n) values using the Radar range equation [**Error! Reference source not found.**] as given in Equation 1.

$$R_{max}^4 = \frac{P_{av} G \sigma n}{16\pi^2 kTB \frac{S}{N} \tau f_p}, \qquad (1)$$

where,

- P_{av} is average power transmitted;
- G is antenna gain;
- σ is radar cross section (RCS);
- n is pulse integration factor;
- k is Boltzmann constant;
- T is noise temperature;
- B is signal bandwidth;
- $\frac{S}{N}$ is signal to noise ratio, SNR;
- τ is pulse width; and
- f_p is pulse repetition frequency.

We use a dummy variable *ID* defined by

$$ID = \frac{1}{\tau f_p}. \qquad (2)$$

In these simulations, the only channel effect being considered is the thermal noise. Hence a further degradation of the range and correspondingly, the required SNR, is expected. These other conditions are clutter effects, environmental effects like attenuation, dispersion, and target effects like fluctuation losses etc. Since, we have not parameterized the further environmental losses and distortions, the calculations are simplistic. Figures 4, 5, and 6 show the SNR vs Range plots at various values of *ID* and *n*. Figure 7 shows the comparison of plots of the test cases 5, and 6. The range values at 0 dB SNR have been tabulated in Table I.

Table 1: Results at 0 *dB* SNR

-	Range (km)	Range (km)	Range (km)
RCS (m^2)	*n* = 1; *ID* = 1	*n* = 100; *ID* = 100	*n* = 1000; *ID* = 100
1	1.4	14	25
5	2.1	21	40
10	2.5	25	42
30	3.1	31	48

To sum up, let us consider an example. Even though we may have, 30 dB (say) of SNR degradation in the real scenario having all forms of distortions, we shall be able to detect a target of RCS $10m^2$ at a distance of around 8 kms by using an *ID* of 100 and an *n* of 1000, Table I.

The above analysis shows that a whitespace based radar network is feasible. This in turn bolsters the claim that whitespace based FOPEN radar can be used for surveillance and home security.

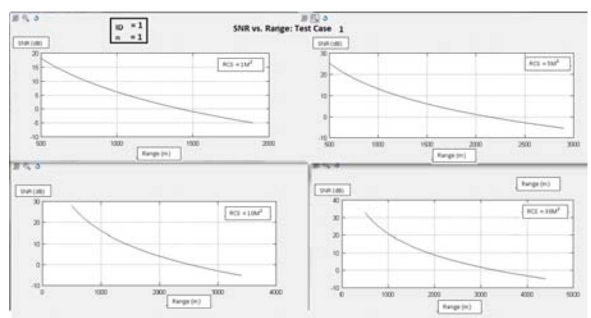

Fig. 4. Results: Test Case - 1 (SNR vs Range at ID = 1 and n = 1)

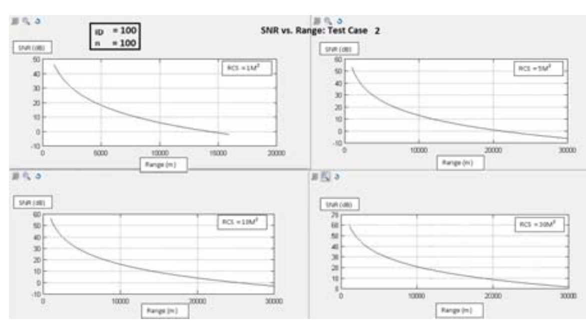

Fig. 5. Results: Test Case - 2, ((SNR vs Range at ID = 100 and n = 100)

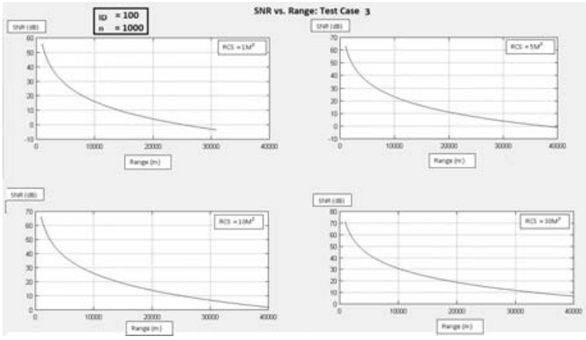

Fig. 6. Results: Test Case - 3 ((SNR vs Range at ID = 100 and n = 1000)

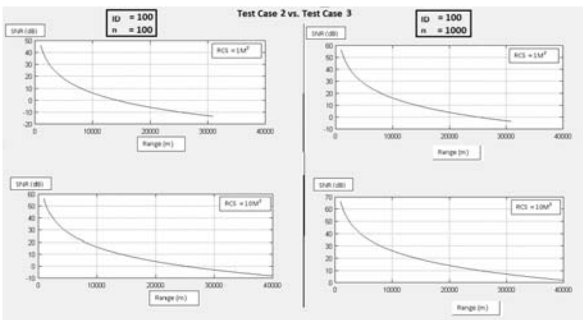

Fig. 7. A Comparison across test cases

CONCLUSION

In this paper we have discussed a novel integrated commensal Radar system which we propose will be based on the Whitespace commensal radio network. The above design has been filed as a South African patent [15]. And a low-cost hardware for each node has already been designed by us [16]. In future we plan to get license to use the spectrum to do some trials and compile the FOPEN performance of the system.

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