

TARGET LOCALIZATION ACCURACY USING WIMAX RADAR NETWORKS

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ABSTRACT

Scientists have explored that WiMAX has the potential to enhance the performance of the radar networks. With the idea of implementing MIMO (multi-input multi-output) communication technology for overcoming the challenges offered by hostile channel and environmental effects. It leads the technocrats to utilize this technology in radar operations. WiMAX MIMO can exploit the range of WiMAX and the spatial diversity of MIMO radar. A WiMAX based MIMO radar system is introduced in this paper. In conventional radar, the target's radar cross section (RCS) measurement at very low SNR level is very difficult and degrades the overall radar performance under mobile condition. This paper focuses on WiMAX-based passive radar design based on a MIMO-OFDM testbed for getting information about the nearby target vehicle. It also explores potential of MIMO radar regarding the probability of target detection in low signal to clutter ratio (SCR) level.

Keywords: *WiMAX, MIMO, SCR, MISO, ITS*

1. INTRODUCTION

Passive radar systems utilize broadcast, communication or radio-navigation transmission as their illuminating signals in bistatic (or multistatic) radar geometry. Over the past decade or more, there have been emerging interests in the employment of illuminators of opportunity for passive radar, such as FM radio, television, digital radio and television (DAB,DVB), cell phone downlink, and satellite broadcast or radio navigation signals [1-4]. Such signals, however, are not optimized for radar purposes, and so it is necessary to analyze their behaviors in order to understand their performance and to choose which signals to be used and how best to process them. The passive radar is, essentially, receiver-only radar that usually dissociates the receiver antenna away from the transmitter. Containing no transmitter, the benefits that passive radar can offer are numerous. Most importantly, passive radar is virtually undetectable to surveillance receivers and there is no constraint

in spectrum allocation. Passive radar is smaller, easily portable and more effectively used for target detection as compared to conventional active radar. In fact, it is the reuse of communication technology to characterize the target. However, testbed for passive radar is composed of a communication transmitter and a communication receiver modified for radar operation which are also commercially available for testing the target. Two different applications can then be thought of:

Application 1: The passive radar to detect and characterize the target. Here, radar carrier frequency is 3.5 GHZ maximum and is limited by the maximum carrier frequency used by commercial WiMAX transmitter. WiMAX waveform is relatively new for such application. MIMO is mandatory.

Application 2: The test bed including both the transmitter and the receiver to detect and characterize the target.

The WiMAX testbed can be used for applications like ITS and others. WiMAX in its standard form using MC-CDMA waveform is relatively new and

popular digital communication technology using 3.5 GHz carrier for WMAN. WiMAX technology is based on IEEE 802.16 standard and it is a telecommunication protocol offering full access to mobile internet across cities and countries with a wide range of devices. WiMAX supports multipath, offers very high speed, reliable and secure broadband access to mobile internet, it also supports time division duplexing (TDD) and frequency division duplexing (FDD). With an intention of utilizing WiMAX at millimeter wave, the author is willing to explore WiMAX at 60 GHz millimeter wave carrier for vehicular application. While unlicensed spectrum around 2.5 GHz and 5 GHz is also available internationally, the amount of available 60GHz bandwidth is much higher than that around 2.5GHz and 5GHz. Unlicensed spectrum surrounding the 60 GHz carrier frequency has the ability to accommodate high-throughput wireless communications [5][6][7]. It is highly directive and can be used for long and directed link. 60GHz system enjoys the size reduction and cost reduction advantages. Additionally, due to availability of 5GHz bandwidth the data-rate for communication is more interesting. Many commercial products have been developed facing these challenges. Developmental efforts towards individual and separate communication and radar systems are progressing a lot for utilization in vehicular application. Research trends are initiated towards combined use of inter-vehicle communication and radar ranging [8]-[9]. With an intention of utilizing WiMAX at millimeter wave, the author is willing to explore WiMAX at 60 GHz millimeter wave carrier which can be utilized for vehicular application. Unlicensed spectrum surrounding the 60 GHz carrier frequency has the ability to accommodate high-throughput wireless communications [5][6][7]. It is highly directive and can be used for long and directed link. 60GHz system enjoys the size reduction and cost reduction advantages.

2. DEVELOPMENT OF WIMAX MIMO RADAR

MIMO radar can improve detection performance by spatial diversity. In MIMO radar, transmit/receive array is commonly formed by multiple Omni-directional beam sub-arrays with different phase centres. Furthermore, the transmitted signals of all sub-arrays are orthogonal time-domain waveform and separate with each other. The system can acquire much spatial diversity gain but no spatial

coherence gain. The received signal of the n th antenna can be expressed as below.

$$B_k(t) = \beta y(t) \exp\left(j \frac{2\pi}{\lambda} dk \sin \theta\right) + u(t) \dots (1)$$

for $k = 0, 1, 2, 3, \dots, Q-1$, where, Q is the number of antennas, $\lambda = c/f_c$ is the wavelength of the signal, $y(t)$ is the signal envelope, β is the amplitude response and $u(t)$ is the additive noise. The phase difference term $\exp\left(j \frac{2\pi}{\lambda} dk \sin \theta\right)$ comes from different travelling distances to different antennas.

To extract signal from θ we can linearly combine the received signals [6] and obtain the following $s(t)$.

$$s(t) = \sum_{k=0}^{Q-1} z_k b_k(t) \dots \dots \dots (2)$$

$$= \beta y(t) \exp\left(j \frac{2\pi}{\lambda} dk \sin \theta\right) + \sum_{k=0}^{Q-1} z_k u(t) \dots (3)$$

Where, z_k is the weighing coefficient corresponding to the k th antenna. From the above equation, we see that the signal coming from different angle θ , has different gains also depending upon the value of θ . Again we can say that the summed signal can be controlled by the weighting coefficients z_k . Note that we have $\omega = \frac{2\pi}{\lambda} d \sin \theta$, in the above equation. If $d > \lambda/2$, there will be multiple values of θ mapping to the same ω . Thus aliasing effect arises. To get rid of this, we choose $d \leq \lambda/2$. In practice, the spacing between antennas is about half of the wavelength. In this case, $-\pi \leq \omega = \frac{2\pi}{\lambda} d \sin \theta = \pi \sin \theta \leq \pi$ and if so, there will be no aliasing in the incoming plane wave pattern to the radar receiver.

Each antenna in a MIMO radar system transmits orthogonal (or incoherent) waveforms. A set of matched filters is used at the radar receiver to extract the waveforms returning back from the target. At the time of propagation, the individual waveform faces individual path effect. So, the extracted components at the receiver side, contains the information of an individual path. Two different kinds of approaches are taken for further using this information. First, the spatial diversity can be increased. In this scenario, the transmitting antenna elements are widely separated such that each views a different aspect of the target. Consequently the target radar cross sections (RCS) are independent random variables for different transmitting paths. Second, a better spatial resolution can be obtained. In this scenario, the transmitting antennas are colocated such that the RCS observed by each transmitting path are identical. The components extracted by the matched filters in each receiving antenna contain the information of a transmitting

path from one of the transmitting antenna elements to one of the receiving antenna elements. By using the information about all of the transmitting paths, a better spatial resolution can be obtained.

Let us consider that total P no. of transmitter and Q no. of receivers are used. If the transmitting waveform from the j^{th} transmitting antenna is represented by $\phi_j(t)$, then the emitted waveforms are orthogonal and thus we can write

$$\int \phi_j(\Omega) \phi_j^*(\Omega) d\Omega = \delta_{jq} \dots \dots (4)$$

So, at the receiver side, we need to extract these orthogonal signals and the number of Matched Filters required is P. Hence, the total number of signals extracted is Q.P if we consider a far-field point target. At the n^{th} receiving antenna, the m^{th} Matched Filter [6] contains the Target information which can be mathematically expressed as

$$s_{k,j}^{(t)} = \sigma_t \exp \left(j \frac{2\pi}{\lambda} p_t^B (A_{B,j} + A_{D,k}) \right) \dots \dots (5)$$

Where p_t is the unit vector pointing towards the Target from the radar transmitter, σ_t is the amplitude of the Target reflected signal.

3. SIMULATION MODEL OF WIMAX MIMO

An end-to-end simulation block diagram of the system is shown in Fig.1. The system consists of transmitter, receiver and the target section. Pulse Barker code is used here as transmitted data. Then the OFDM is carried out to get two independent streams of data which are up converted to IF and RF individually and finally transmitted towards the cluttered environment.

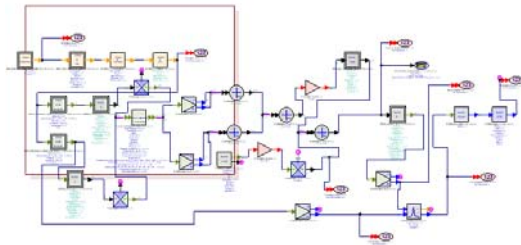


Fig.1: The simulation model for WiMAX MIMO radar

The correlation MIMO channel is inserted in the simulation where the 2×2 configuration has been considered. The cluttered transmit signal propagating through two independent paths/streams are merged so that it can reach the target and while

reflecting back from the target, it is down converted and passed through the cross-correlation API provided by the SystemVue. The transmitter end OFDM frame has been taken as the reference of the correlator. The correlated output is passed through the CFAR so as to achieve the target peaks shown below at different input SCR at radar receiver front end. The results are depicted below one after one. SCR is measured using a spectrum analyzer where the sharper peaks are clutter and broad spectrum is the signal while output SCR using an oscilloscope connected at the output of the WiMAX final receiver output.

4. WIMAX RADAR TEST BED USING AWG AND VSA

The heart of the WiMAX testbed is the two equipments namely Tektronix arbitrary waveform generator (AWG, PXI-5014C) and Agilent vector signal analyzer (VSA, PXI-U1065A) connected at the transmitter and receiver end in a Master-Slave configuration. AWG and VSA will be useful for data spread at the transmitter and de spread operations at the receiver respectively. The AWG and VSA together will enhance the flexibility in radar operation and will definitely, boost the radar performances. The radar circuit is finalized including those two equipments. The baseband designs are done in SIMULINK and SystemVue.

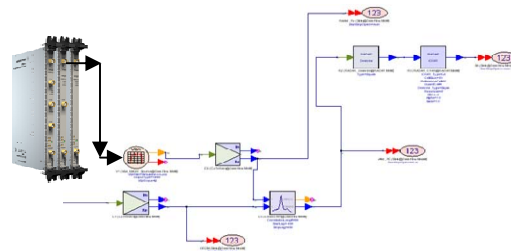


Fig. 2: VSA acts as the WiMAX receiver and received data processing

5. RESULTS

The generated 11-Bit Barker code pattern from the Ioutput of the AWG is shown in fig. 3. Here the Barker code pattern is: -1-1-1+1+1-1+1+1-1+1. The output result at the VSA is also shown in fig. 4.



Fig. 3: Generated 11-Bit Barker Code Pattern at the output of the AWG

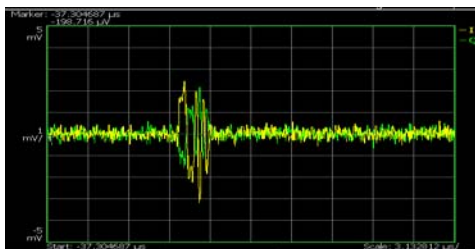


Fig.4: Received pulse Barker waveform at the VSA

5. PERFORMANCE ANALYSIS OF THE SYSTEM

The performance of the Radar is determined by measuring the value of SCR. In case of conventional radar if the Clutter level is greater than the signal level then the target detection is almost impossible. Though the clutter level is higher than the signal level, target can be detected. Here lies the essence of the proposed model Fig. 5 depicts target detected at negative input SCR and target position is set at 10Km. whereas Fig. 6 shows the characteristics of receiver front end.

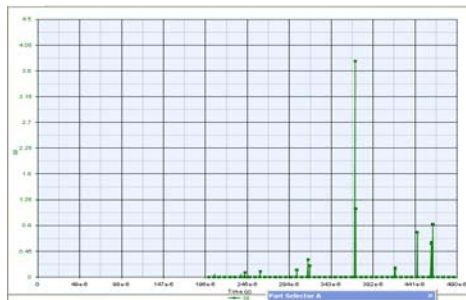


Fig. 5: Target detected at negative input SCR (= -3.383 dB) and target position is at 10Km (371.4 microseconds).

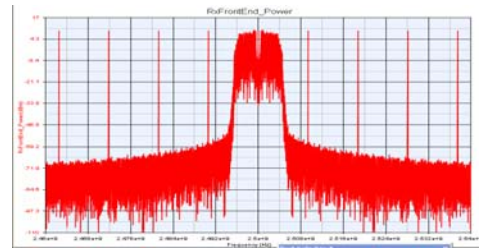


Fig. 6: Receiver front end: Signal level = 6.0 dBm; Clutter level = 9.383 dBm, Input SCR (= -3.383 dB) and target position is at 10Km (371.4 microseconds).

It can be observed from the Fig. 6, that the WiMAX MIMO radar is well working at negative SCR and detecting target distinctly by reducing the clutter level to a satisfactory level.

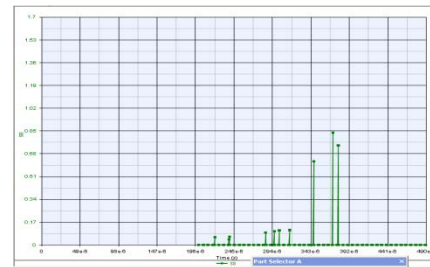


Fig.7: CFAR O/P: Target Level = 0.837 dBm; Clutter Level = 0.743 dBm and O/P SCR (= 2.3826 dB) and Target Position is at 10Km (371.4 microseconds)

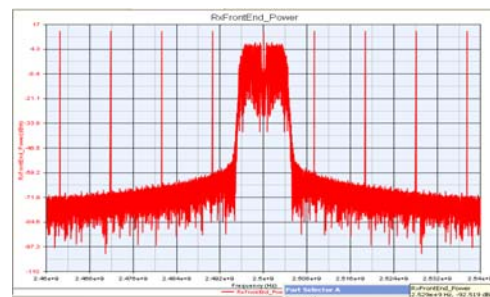


Fig.8: Rx Front End: Signal Level = 6.0 dBm; Clutter Level = 13.664 dBm and I/P SCR (= -7.664 dB) and Target Position is at 10Km (371.4 microseconds)

From Fig. 7 and Fig. 8, we observe that at this level of negative input SCR, the detection capability is 0.837 dBm after CFAR while using WiMAX MISO radar. Hence, it is clearly observable from the above results, the WiMAX MISO radar is well

performing at negative I/P SCR so far as the target detectability is concerned.

6. COMPARATIVE DETECTABILITY PERFORMANCE OF DIFFERENT TYPES OF MIMO RADAR

In Fig.9 performance plot is shown, where the plot is divided into 3 regions marked by two vertical lines and labelled with lower, middle and higher SCR zone. At higher SCR zones, the performances of all the radars are almost same where clutter effects are negligible. At middle and lower SCR zones, the MISO performances are enhanced as compared to SISO with different code variations. Even, MISO radar is workable with large negative SCR values also as noticed in the lower SCR zones. Hence, those curves are the proper justification for MISO/ MIMO radar utilization.

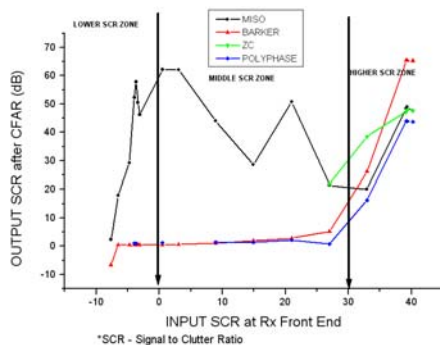


Fig. 9: Comparative performance plot for SISO radar with Barker, ZC and Polyphase code with WiMAX MIMO radar

7. CONCLUSION

WiMAX based digital radar is successfully developed by the authors. The simulation and emulation are completed. A lab prototype of the above system having concurrent communication and safety is thus ready and successfully tested at the laboratory. This concept can be utilized for the realization of E-Vehicle. A field trial will be tried soon after mounting them in two vehicles.

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