SIGNAL SYNTHESIS AND MIMO RADAR DETECTORS DESIGN: MORE ANTENNAS MEANS BETTER PERFORMANCE

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ABSTRACT

The MIMO (multiple-input multiple-output) systems have gained popularity and attracted attention of late for their ability to enhance all areas of system performance. Inspired by the success of MIMO systems in communications, several publications have advocated the concept of new MIMO emerging active sensing radar technology from the system implementation point of view, as well as for signal processing techniques for target detection and parameter estimation. Reaping the full benefit of the superior performance enabled by the MIMO radar which exploits the special diversity of target scattering to improve detection performance over other types of array radars due to absence of target fades and analyse various topologies of multiple antenna systems in radars. In this paper, the present different digital arrays radar concepts are summarized, and performance is analyzed based on different modulation techniques to improve the resolution of the target parameters identifiability. This paper explores how transmit diversity can improve the direction finding performance of a radar utilizing an antenna array at the receiver and focuses on improving the performance of the signal detection.

Keywords*:* *MIMO, AWGN, SNR, SER, BPSK, QPSK, 16-QAM.*

1. INTRODUCTION

Radar theory and radar system have developed a lot for the last 50 years or so. We are proceeding towards a broadband age both for the communication as well as remote sensing. Digital communication using MIMO processing has emerged as a breakthrough for revolutionary wireless systems. Inspired by the success of MIMO systems in wireless communications, a new emerging concept in array radar has been introduced recently by the MIMO radar which is capable of transmitting arbitrary waveform [1][2] from each antenna element and allows the multiple antennas to transmit arbitrary waveforms. Like MIMO communications, MIMO radar offers a new paradigm for signal processing research. MIMO radar possesses significant potentials for fading mitigation, increased diversity of the target information, increase the spatial diversity of the system [3][4][5]**,** resolution enhancement, and excellent interference rejection capability[6][7], improved parameter identifiability [8], and enhanced flexibility for transmit beam pattern design[9][10][11], exploiting RCS diversity [12], handle slow moving targets[13][14] by exploiting Doppler estimates from multiple directions , and support high resolution target localization[13] [15], and jamming suppression. Fully exploiting these potentials can result in significantly improved target detection, parameter estimation, target tracking and recognition performance. The degrees of freedom introduced by MIMO radar improve the performance of the radar systems in many different aspects. The main contribution of this paper is to study the signal processing issues in MIMO radar for different modulation techniques utilising novel algorithms for improving the performance of MIMO radar system.The different types of radar concepts focus on improving the different radar performances with respect to different modulation techniques. One concept is to improve the performance of the signal detection, and other is to reduce the SER.

2. SYSTEM MODEL

The MIMO radar scheme is based on a system with M transmitting radars and N receiving radars, widely distributed. It is assumed to be both time and phase synchronized. MIMO radar offers the potential for detection/estimation performance through diversity gain and resolution performance through spatial resolution gain. The performance enhancement of the different radar signal detection is considered from an aspect of improving the SNR, and is to utilize the best modulation techniques for only AWGN channel over the whole process. The rank of the channel matrix can be used to determine the number of dominant scatterers or the number of targets in the range resolution cell. With suitable processing, this property of MIMO radar can be applied to enhance radar resolution by allowing the measurement of one scatterer at a time.

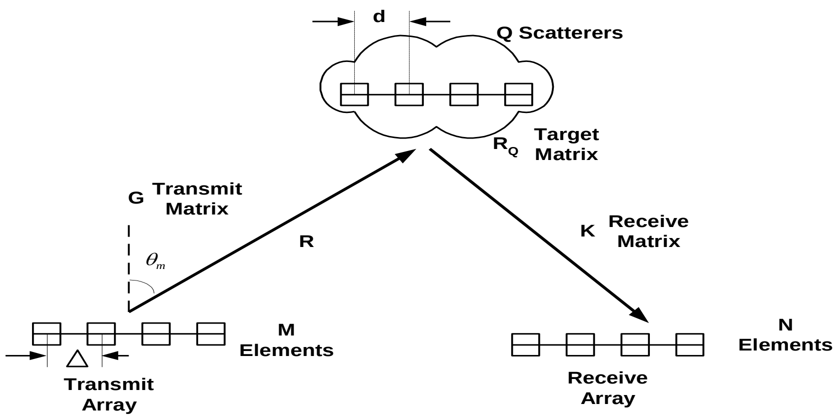


Fig.1: MIMO radar channel

For the SIMO system, we have N antennas at receiver and only one at transmitter. If the signals received on these antennas have on average the same amplitude, then they can be added coherently to produce an N^2 increase in the signal power. On the other hand, there are N sets of noise that are added incoherently and result in an N-fold increase in the noise power. $(SNR)_{SIMO} \approx \frac{N^2[Power\,]}{N[Noise\,]} = N.SNR_o \ldots..(1)$, where, SNR_o is the SNR of the SISO system. The SNR of the SIMO system is improved by N times comparing with the SISO system. In the case of multi-input single-output (MISO) system, the transmitter utilizes M antennas, and the transmitted power is distributed into M antennas. So $(SNR)_{MISO} \approx \frac{M^2[\text{Power }/M]}{[\text{Noise }]} = M.SNR_o \ldots\ldots(2)$ is improved by M times comparing with the SISO system. In case of MIMO system can be view in effect as a combination of the SIMO and MISO channels.

$$(SNR)_{MIMO} \approx \frac{N^2M^2.\,signal\;power}{N.M.(noise)} = M.N.SNR_o \ldots\ldots(3)$$

The SNR of the MIMO is improved by *M.N* times comparing with the existing SISO system.

3. CONVERGENCE BETWEEN MIMO COMMUNICATION AND MIMO RADAR SYSTEM

The convergence of MIMO communication to MIMO radar is already developed at the laboratory [16] by assuming that no direct path exists between transmitter(T_x) and receiver (R_x) only modulating element for the radar signal is the target. In absence of target, noise is received by the received antenna (Fig. 2). Using the distances and the coordinates of the target Where, h_b is the channel just before hitting the target, h_a is the channel after heating the target, h_R is the channel just before reaching the receiver, ω is the angular frequency of the transmitted signal, T_1 and T_2 is the time taken for the signal to reach the target from the transmitter and target to receiver respectively, $r_1^{\rightarrow}$ and $r_2^{\rightarrow}$are the distances from T_x to target and target to R_x.

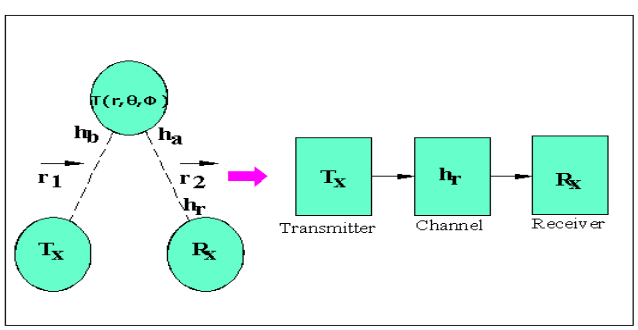


Fig.2 : Block diagram of analogous communications system for radar

Now **e**fforts are also put to extend the above MIMO communication system towards MIMO radar. The MIMO radar complexity is involved in its signal processing. Therefore, works have been imparted towards processing of MIMO radar and its performance analysis for tracing probability of detection, SER(symbol error rate), PSD(power spectral density).

3.1 MIMO RADAR CHANNEL

MIMO radar architecture is shown in Fig.1 employs multiple transmit waveforms and has the ability to jointly process signals received at multiple antennas ,independent waveforms are omnidirectional beam pattern and diverse beam patterns created by controlling correlations among transmitted waveforms. Antenna elements of MIMO radar can be co-located or distributed. In deterministic MIMO channel matrix is assumed to be non random, quasi-static and frequency non-selective. The channel for a MIMO system can be represented by

$$H = \begin{bmatrix} h_{11} & \cdots & h_{1M} \\ \vdots & \ddots & \vdots \\ h_{N1} & \cdots & h_{NM} \end{bmatrix} \ldots\ldots\ldots\ldots (4)$$

Where h_{ij} is the complex channel path gain between transmitter j and receiver i. The elements of the matrix H are unknown/ uncorrelated but their statistics are known. Received signal of MIMO radar for point target located at a distance X is given by $r_i(t) = \sqrt{\frac{E}{M}}\sum_{j=1}^{M} h_{ij}\ (X) s_j\,(t - \tau_{ij}\,(X)) + n_i(t) \ldots\ldots (5)$

Where, E= signal energy, M and N= Number of transmit and receive antennas, $n_i(t)$= white Gaussian noise. For MIMO radar transmitted waveforms $s_j(t)$ are known to the receiver but channel coefficients are unknown.

3.2 MIMO Communication Channel

Received signal of MIMO communication is given by

$$r_i(t) = \sqrt{\frac{E}{M}}\sum_{j=1}^{M} h_{ij}\ s_j\,(t - \tau) + w_i(t) \ldots\ldots..(6)$$

Detection of space-time coded digital symbols $s_j(t)$ and channel coefficients h_{ij} known/estimated by coherent communication.

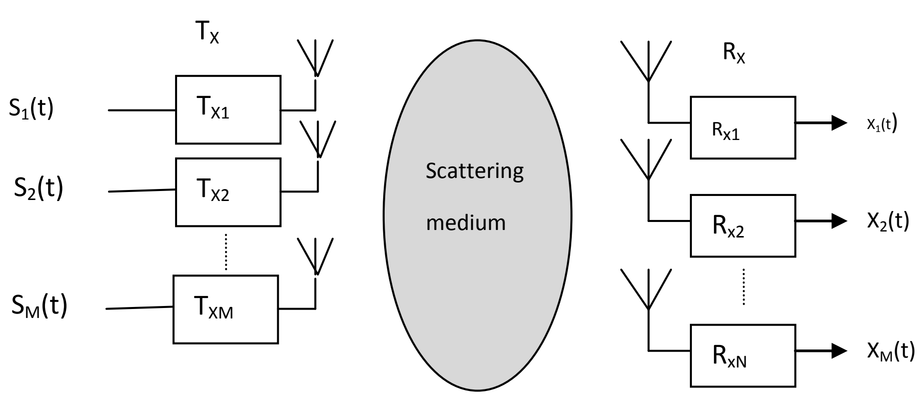


Fig.3: MIMO communication channel

So for MIMO communication antennas are co-located and scatterers are separated but for MIMO radar antennas are separated and scatterers are co-located which is depicted in Fig.3 and Fig.1.

4. RESULTS AND SIMULATIONS

4.1. SYMBOL ERROR RATE

Using this model, the 1 × 1 SISO radar has only one channel in the analogous communication system. The 2×1 MISO and the 1×2 SIMO radars have two channels each and the 2 × 2 MIMO radar has four channels and so on. This leads to the expressions for the received signal-to-noise ratios (SNRs) of each of these radars in terms of the respective channels:

$$(SNR)_{SISO} = (H)^2 \frac{E_m}{\sigma_n^2} \ldots\ldots\ldots(7), \qquad (SNR)_{MISO} = \frac{1}{2}(H)^2 \frac{E_m}{\sigma_n^2} \ldots\ldots\ldots(8)$$

$$(SNR)_{SIMO} = (H)^2 \frac{E_m}{\sigma_n^2} \ldots.(9) \qquad , \ (SNR)_{MIMO} = \frac{1}{2}(H)^2 \frac{E_m}{\sigma_n^2} \ldots\ldots(10)$$

$$\text{Where, } H = \sum_{i=1}^{M}\sum_{j=1}^{N}|h_{ij}| \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where, h_{ij} are the channels that are set-up in the respective analogous communication system and E_m is the signal power while σ_n^2 is the noise power spectral density. The SER of each of these systems is found using BPSK, QPSK and 16-QAM modulation schemes. In BPSK with an additive white Gaussian noise (AWGN), the SER is given by,

$$P_b = Q\left(\sqrt{\frac{2E_m}{\sigma_n^2}}\right) \ldots(12), \qquad P_b = Q\left(\sqrt{\frac{E_m}{\sigma_n^2}}\right) \ldots\ldots(13), \qquad P_b = \frac{3}{4}Q\left(\sqrt{\frac{E_m}{10\sigma_n^2}}\right) \ldots\ldots(14)$$

Where, equation (13) and (14) are the SER of QPSK and 16 – QAM for AWGN respectively.

$$\text{Where, } Q(x) = \frac{1}{2}\, erfc(x/1.414) \ldots\ldots\ldots\ldots(15)$$

The target can occupy any position in space defined by azimuth-elevation space $\theta = [0, \pi]$ and $\varphi = [0, 2\pi]$. Let $p(\theta, \varphi)$ be the probability density function of the target positions. Then the SERs of each of the four radar systems using BPSK are given by,

$$P_{SISO} = \int_0^{2\pi}\int_0^{\pi} Q\left(\sqrt{2(H)^2\frac{E_b}{N_0}}\right) P(\theta,\varphi)\sin\theta d\theta d\varphi \ldots(16), \qquad P_{MISO} = \int_0^{2\pi}\int_0^{\pi} Q\left(\sqrt{(H)^2\frac{E_b}{N_0}}\right) P(\theta,\varphi)\sin\theta d\theta d\varphi \ldots(17)$$

$$P_{SIMO} = \int_0^{2\pi}\int_0^{\pi} Q\left(\sqrt{2(H)^2\frac{E_b}{N_0}}\right) P(\theta,\varphi)\sin\theta d\theta d\varphi \ldots(18), \quad P_{MIMO} = \int_0^{2\pi}\int_0^{\pi} Q\left(\sqrt{(H)^2\frac{E_b}{N_0}}\right) P(\theta,\varphi)\sin\theta d\theta d\varphi \ldots(19)$$

By assuming uniform probability distribution for the target and an arbitrary fading probability distribution for the radar target reflectivity over all the azimuth-elevation space, the integrals in the above equations are evaluated numerically. Similar expressions can be derived for QPSK and 16-QAM modulation schemes. Fig. 4 shows the results of SER performances. For all SNR levels, MIMO system has the least SER and hence the highest probability of detection because the lower the error in the received signals, the higher is the detection.

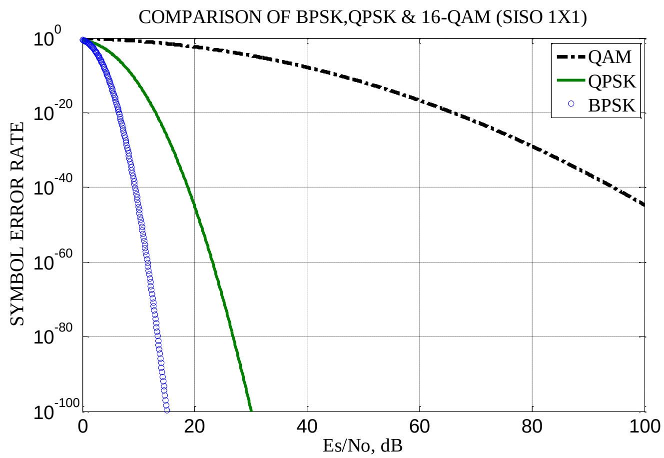
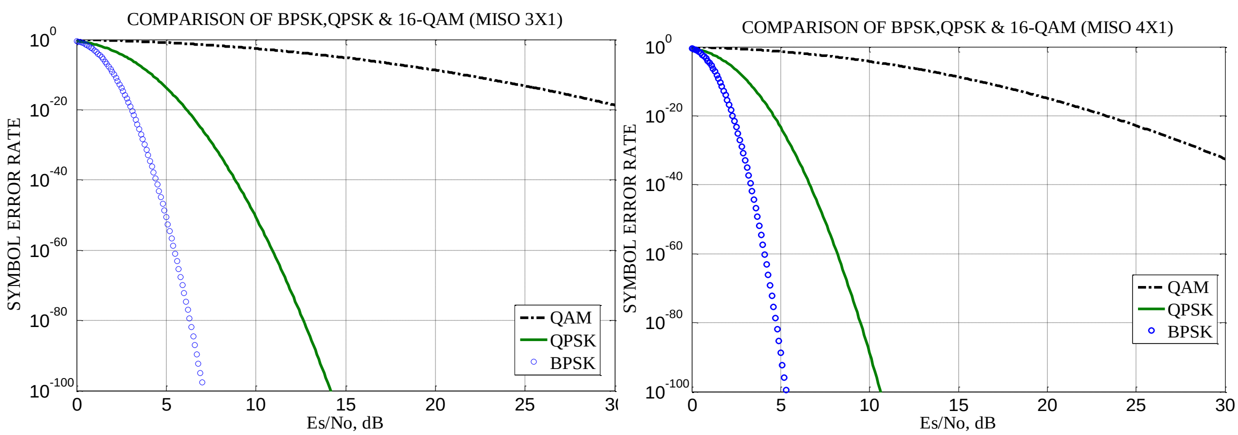


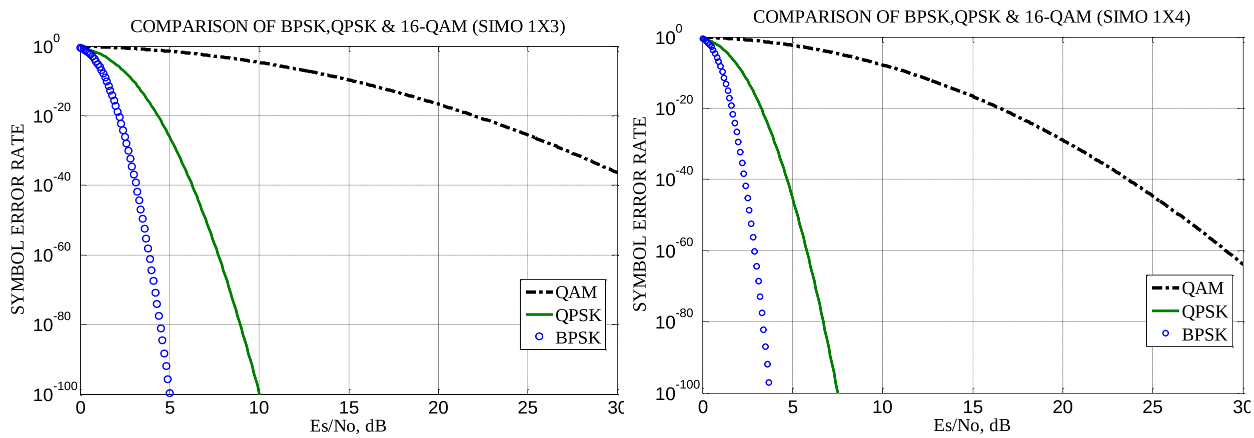
Fig .4: The performance of SISO system with different modulation techniques.

The performance of SISO system with different modulation is shown in fig.4. By consideration of three modulations the performance of QPSK is better than BPSK and 16-QAM, due to phenomenal improvement over the increase in the value of the SNR. .The individual system performance with respect to SER and SNR, BPSK and 16-QAM is better than the rests respectively. But the overall system performance of QPSK system is better with respect to SER and SNR.



(a) (b)

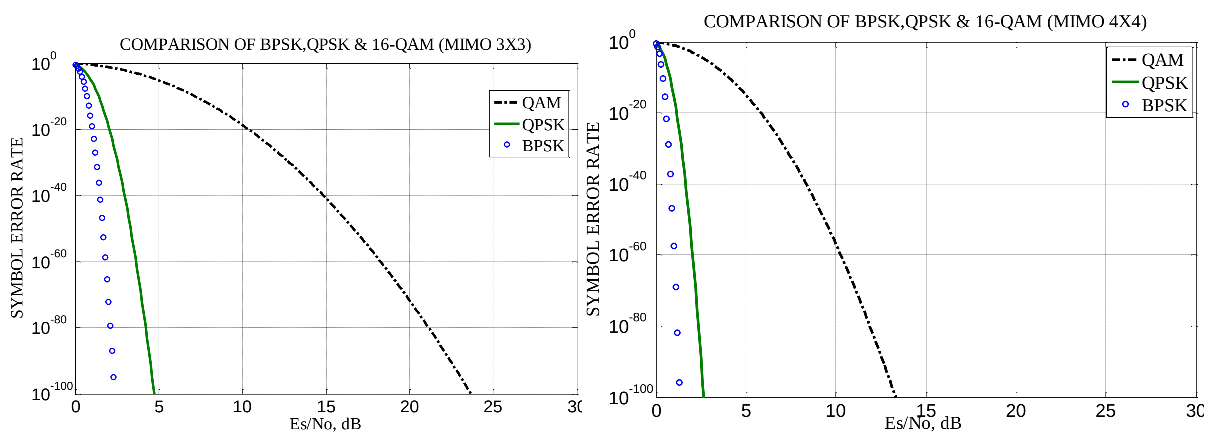
Fig. 5(a) and 5(b): The performance of MISO system with different modulation techniques.



(a) (b)

Fig. 6(a) and 6(b): The performance of SIMO system with different modulation techniques.

The performances of MISO system with different modulation is shown in fig.5(a) and 5(b). By consideration of three modulations the performance of QPSK is better than BPSK and 16-QAM, due to phenomenal improvement over the increase in the value of the SNR. .The individual system performance with respect to SER and SNR, BPSK and 16-QAM is better than the rests respectively. But the overall system performance of QPSK system is better with respect to SER and SNR. For consideration of 8 dB SNR , the performance of MISO system is not only better than SISO but also in MISO, but the overall system performance is also improving due to increasing diversity order of the transmitting antennas. From fig. 6(a) and 6(b) the performance of SIMO is not only better than MISO and SISO but also in SIMO due to its receive diversity.



(a) (b)

Fig. 7(a) and 7(b): The performance of MIMO system with different modulation techniques.

Fig. 7(a) and 7(b) shows the overall system performances of MIMO system is better than other systems for different modulations due to its improvement of transmit and receive diversity. It is noticeable that the overall system performance of QPSK is better compare to other modulation schemes.For all SNR levels, MIMO system has the least SER, and hence the highest probability of detection because the lower the error in the received signals, the higher is the detection. MIMO is followed by SIMO, MISO and SISO with increasing SER.

5. CONCLUSION

We investigated and compared the inherent performance limitations of different modulation techniques for different radar systems. We derived the respective optimal detectors when the target and noise level are either known or unknown. The performance improvement achieved by MIMO radar is not limited to SNR only but also depends on diversity to improve detection and estimation performance. The agreement of the results with established detection theoretic methods provides an easy tool for measuring the performance of different kinds of radars. 4G communication and radar based remote sensing for vehicular safety and communication are synchronized and converged. The system is tested as lab model and results are found to be encouraging in real life vehicular systems and can be simultaneously used for non safety applications too.

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