Power Efficient Technique for MIMO radar using Co-operative and Non co-operative game theory in Wireless Applications

T. Harikala, RVS SatyaNarayana

Abstract: ***Multiple Input Multiple Output (MIMO) is receiving the massive attention in the field of communication. MIMOradars aresimultaneously transmitted multiplelinearly independent wave form and receive their reflected signals. In MIMO communications, Radar offers as a paradigm for signal processing research.The power allocation is the major concern in the MIMO radar network. In this paper, the game theory of Nash equilibrium and Pareto optimality is introduced for non-cooperative and cooperative network of distributive clusters respectively. Based on the distance analysis, the MIMO radar network is decided either it is a non-cooperative or cooperative. These power allocation strategies are introduced to allot the specified power for each antennas within the cluster. The clustering of the network is occurred by using K-means clustering. The proposed method is named as Cooperative and Non Cooperative Game Theory based Power Allocation (CNCG-PA) in MIMO radars. The performance of the CNCG-PA is analysed by the power consumption and it is compared with GNG PA method. Assume both the GNG PA method and CNCG-PA methods have 3 clusters and 3 users in each clusters. The power consumption of cluster 2 of the GNG PA of 0.1191 is more when compared to the CNCG-PA of 0.1167.***

Keywords: ***MIMO radar, power allocation, Nash equilibrium and Pareto optimality game theory, Power consumption.***

I. INTRODUCTION

Multiple Input Multiple Output (MIMO) is the advanced communication in the past decades. Then the MIMO radar is investigated from the inspiration of MIMO structure. The MIMO radar enhances the system performance via diversity [1-2]. Using spatial diversity, The MIMO radars are separated transmitting and receiving waveform when the target is located at different aspects simultaneously for improving radar detection performance.[3]. Compared with traditional phased array radar, which transmits scaled version of a single waveform, MIMO radar offers enhanced capabilities through waveform diversity [4]. MIMO radar is divided into two kinds. MIMO Radar can be categorized as Collated antenna MIMO and multi-static MIMO. For a system with more number of transmit or receive elements has high SNR value and a system with less number of transmit/receive elements has low SNR value [5-6]. The main feature for MIMO radar system is to localize, track targets and using distributed antennas enhanced the localization capabilities of target using increased spatial spread.

This MIMO radar is used for the active localization and also it improves the target detection and localization capability by exploiting the spatial diversity of target's radar cross section (RCS) [9]. The conventional methods used for power allocation and target tracking is given as follows: A joint beam selection and power allocation (JBSPA) strategy is developed for multiple target tracking in netted colocated multiple-input multiple-output radar system [10].In MIMO radar system design, the power allocation problem is generally arises due to uneven distribution of power in wireless sensor network. Thus the MIMO based Two Person Zero Sum game employs an interaction between the target and MIMO radar which are grouped into three cases such as unilateral, hierarchical and symmetric based on the information of each player, the power is allocated [11]. Tracking algorithms based on kalman filter and particle filter processes the interactive signal for a non-coherent MIMO radar target tracking [12]. A novel water filling method is introduced between the MIMO radar and target for removing the clutter in the Stackelberg game. WF is applied to distribute the jamming power and signal power [13].

The major contribution of this research paper is stated as follows:

- Here the clustering of the MIMO radar network is performed by using K-means. Based on distance analysis of the network, the primary and distributive clusters over the radar are separated.
- The power allocation performed only in the distributive clusters. Because, the primary clusters have enough energy to transmit the information to the target. The Nash equilibrium and Pareto optimality is applied based on the threshold calculation.
- The power allocation through the MIMO radars are mainly depends on two values such as current power value of all the MIMO radars and distance from the radar to the target.

This research work is composed as follows, Section-2 presents an extensive survey recent papers based on MIMO radar network. In the section-3, briefly described the power allocation in MIMO radar network using Nash equilibrium and Pareto optimality. The section-4 describes about an experimental result of a proposed method along with the comparison of proposed method with conventional method. The conclusion of this research work is given in the section-5.

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II. LITERATURE SURVEY

A.Panoui*et.al* [14] presented the distributed waveform design for multi static radar networks. The main objective of this technique to improve the signal to disturbance ratio of the cluster by selecting the appropriate waveforms. As a result, the best waveform for an each cluster is determined. The performance of the radar is improved by establishing an interaction and determining the equilibrium between all radars. Each clusters has two radars. However if the number of clusters increases, the interference induced in the network also increases which in turn reduces the SDR values for all the clusters.

Nguyen Duy Duong *et.al* [15], introduced the power allocation of two tier networks for stackelbergbayesian game. The main purpose of this technique is to increase the transmission capacity of the femtocell networks by guaranteeing that interference at macro base station does not exceed the interference constraint. The major advantages of this technique are low cost, low power, short range,improved quality of services, extended battery life, etc. However the computation cost is high and complex.

Wang.*et.al* [16] has introduced the robust jamming power allocation strategies forradar system. Theoretical analyses shows that the MMSE- and MIMO based jamming power allocation strategies are different. In addition, the radar waveform uncertainty does not affect the MMSE-based robust jamming result when the radar waveform power and the target power spectral density (PSD) were lies in the bounded uncertainty sets. Therefore, it is not important for the jammer to estimate the accurate radar waveform information under specific case.

She*et.al* [17] has proposed a joint sensor selection and power allocation algorithm for multiple-target tracking in a radar network based on low probability of intercept (LPI). It is found that the algorithm can minimize the total transmitted power of a radar network on the basis of a predetermined mutual information (MI) threshold between the target impulse response and the reflected signal. The MI is required at the radar network system to estimate target parameters, and it can be calculated predictively with the estimation of target state. This algorithm is only applicable for less number of users.

Deligianni*set.al* [18] has introduced a distributed beamforming and resource allocation technique for radar system in the presence of multiple targets. At first, The authors studied an SNG, without any coordination among the radars/players. Thus each player greedily decides its optimal beamformers and power allocation.Nash equilibrium in a non-cooperative, distributed, multiuser power control problem. Since each player greedily optimizes its utility function, the equilibrium might not be the Pareto-optimal solution.

III. PROPOSED SYSTEM FOR EFFECTIVE POWER ALLOCATION

The major limitation in MIMO radar system is distributive power allocation, In order to overcome that, a Nash equilibrium and Pareto optimality game theory based power allocation scheme is introduced for a multistatic multiple-input multiple-output radar network. The overall process of this proposed scheme is given in the flowchart as shown in Figure.1.

The steps of this proposed methodology is given as follows:

- Initially, the MIMO radar users are randomly deployed in the interested area.
- K-means clustering is applied in the MIMO radar to cluster the network into a primary and distributive clusters.
- Initial Power is allocated to the MIMO radar users.
- The target detection is happened by generalized likelihood ratio test (GLRT). Then the radars are clustered into primary and distributive cluster based on the distance from the target and energy consideration.
- The power allocation of the distributive radars are performed by using Nash equilibrium for non-cooperative network and Pareto optimality for cooperative network.

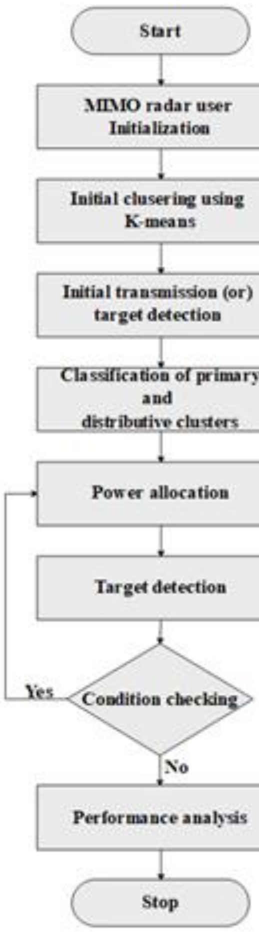

Figure.1. Flowchart for the proposed system.

A. System model

Consider the network has numerous MIMO radars and this radar network is clustered into K-clusters by using K-means clustering. The K clusters are represented as $D = \{D_1, D_2, \dots, D_k\}$ as well as the clusters from the K-means clustering contains T MIMO radars. The set of radars which

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belongs to the cluster is denoted as $D_k = \{M_{rk1}, M_{rk2}, \dots, M_{rkT}\}$. The major process of the clusters of MIMO radars has to operate in power constraints. The goal of the clusters from the network is to utilize the minimum transmission power while generating the waveform. Here, the clusters of the network are processed independently that is in non-cooperative behaviour. But, the one cluster members do not affect the performance of other cluster members means, the clusters are do not interfere any of other clusters. It occurs only inside the system. The typical MIMO radar network is illustrated in the Figure.2.

A signal return samples (n) are received by radars and the hypothesis testing is used for making the decision in the presence of target in each time step.Based on the transmitted signals from radars within the same cluster says all clusters are present only in the cluster. These transmitted signals are orthogonal to each other and also the waveforms from the different clusters are not in orthogonal manner. The cluster k gain of the ith radar to hth radar is $\alpha_{kih} \sim \mathcal{CN}(0, f_{kih}q_i)$. The signal propagation loss and transmission power is represented as f_{kih} and q_i respectively. The cross channel gain among hth radar in the cluster k and ith radar in the cluster l is denoted as $\beta_{likh} \sim \mathcal{CN}(0, \mu_{likh}p_{kh})$. The inference of M_{rkh} from the other clusters is given in the equation (1).

$$I_{kh} = \sum_{\substack{l=1 \\ l\neq k}}^{K} \sum_{i=1}^{T} \beta_{likh} s_{li} \quad (1)$$

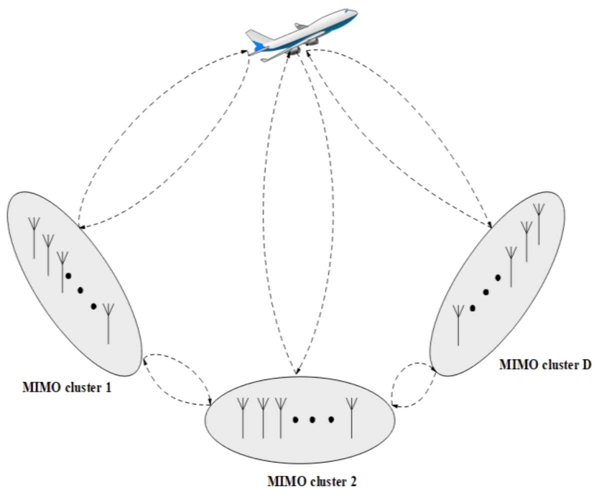

Figure.2. Example for MIMO radar network

Then the noise and signal echoes of the clutter is denoted as $d_{kh} \sim \mathcal{CN}(0, u_{kih}q_{ki} + \sigma_m^2)$. Where the kth cluster to the radar M_{rkh} is expressed as $u_{kih}q_{ki}$ and the noise power is σ_m^2. The hypothesis testing is formed by utilizing the above definitions. Here, the $k = 1.., K$and $h, i = 1, \dots, T$. The hypothesis testing is given in the following equation (2).

$$H_0 : x_{kh} = I_{kh} + d_{kh} (\text{target absent})$$
$$H_1 : x_{kh} = \sum_{i=1}^{T} \alpha_{kih} s_{ki}\, I_{kh} + d_{kh} (\text{target present}) \quad (2)$$

The generalized likelihood ratio test (GLRT) is applied to identify the target. Define $\alpha_{kh} = [\alpha_{k1h}, \dots \alpha_{kTh}]^T$. The probability density functions of x_{kh} hypothesis functions H_0 and H_1 is expressed in equation (3) and (4) respectively.

$$\phi_{H_0}\left(x_{kh}; \sigma_{H_0}^2\right) = \frac{1}{(2\pi)^{n/2}\sigma_{H_0}^n} e^{-\frac{||x_{kh}||^2}{2\sigma_{H_0}^2}} \quad (3)$$

$$\phi_{H_1}\left(x_{kh}; \alpha_{kh}, \sigma_{H_1}^2\right) = \frac{1}{(2\pi)^{n/2}\sigma_{H_1}^n} e^{-\frac{||x_{kh} - \sum_{i=1}^{T}\alpha_{kih}s_{kh}||^2}{2\sigma_{H_0}^2}} \quad (4)$$

The maximum likelihood estimate for $\sigma_{H_0}^2$ over H_0 is denoted as $\hat{\sigma}_{H_0}^2$, it is given in equation (5). And then $\hat{\sigma}_{H_1}^2$ is given in equation (6).

$$\hat{\sigma}_{H_0}^2 = \frac{||x_{kh}||^2}{n} \quad (5)$$

$$\hat{\sigma}_{H_1}^2 = \frac{||x_{kh} - \sum_{i=1}^{T}\alpha_{kih}s_{kh}||^2}{n} \quad (6)$$

The detection threshold of each radar $h = 1, \dots, T$ in cluster $k$is $\lambda_{kh} \in [0,1]$. The GLRT is expressed in equation (7).

$$\frac{\phi_{H_1}}{\phi_{H_0}} = \frac{\sum_{i=1}^{T}|\alpha_{kih}s_{kh}|^2}{||x_{kh}||^2 n} \gtrless \lambda_{kh} \quad (7)$$

The hth radar of kth cluster signal-to-interference-plus-noise ratio (SINR) is given in equation (8).

$$SINR_{kh} = \frac{\sum_{i=1}^{T} f_{kih}q_{ki}}{\sum_{i=1}^{T} u_{kih}q_{ki} + \sum_{\substack{l=1 \\ l\neq k}}^{K}\sum_{i=1}^{T}\mu_{likh}p_{li} + \sigma_m^2} \quad (8)$$

The miss detection probabilities and false alarm of each radar is given in equation (9) and (10) respectively, which is used to calculate the detection test performance.

$$P_{MD}(\lambda_{kh}) = (1 - \lambda_{kh})^{n-1} \quad (9)$$

$$P_{FA}(SINR_{kh}, \lambda_{kh}) = 1 - \left(1 - \frac{\lambda_{kh}}{1-\lambda_{kh}} \frac{1}{1+nSINR_{kh}}\right)^{1-n} \quad (10)$$

The sum of two probabilities of equation (9) and (10) is less than the ε_{kh}, which is in equation (11).

$$P_{MD}(\lambda_{kh}) + P_{FA}(SINR_{kh}, \lambda_{kh}) \leq \varepsilon_{kh} \quad (11)$$

Where, ε_{kh} is provides upper bound on the probabilities value.

By equating equation (11) to ε_{kh}, the optimum λ_{kh} is obtained that is mentioned as $\lambda^*{}_{kh}$. The optimum $SINR_{kh}$ of each radar is achieved by using the $\gamma^*{}_{kh}$, it is in equation (12).

$$\gamma^*{}_{kh} = \min\{SINR_{kh} | \exists \lambda_{kh} \in [0,1] \text{ s.t.} P_{MD}(\lambda_{kh}) + PFASINRkh,\lambda kh \leq \varepsilon kh\} \quad (12)$$

non-cooperative game theoretic technique:

The game theory is used for analysis the interaction between the radars and also discover the best strategy for each cluster of radars. This theory benefits to each MIMO cluster for processing in a decentralized manner. Here, a game is described as a tuple$< n, \{B_h\}_{h\in n}, \{v_h\}_{h\in n} >$. Where, the set of players is described as n, the set of actions and payoff function is denoted as B_h and v_h respectively. The solution used here is Nash equilibrium is given in equation (13) that is described as the set of actions that is given as follows:

$$(b_1^*, b_2^*, \dots . b_n^*) \in B_1 \times \dots \times B_n, h = 1, \dots n.$$
$$v_h(b_h^*, b_{-h}^*) \geq v_h(b_h', b_{-h}^*), \forall b_h' \in B_h \quad (13)$$

The all players excluding player h is denoted as $-h$ as well as in this case of game theory, the game is played between the MIMO clusters of the radar network. The set of players are $D = \{D_1, \dots D_K\}$ and the action set of players are defined as $k \in \{1, \dots K\}$.

$$P_k(p_{-k}) = \{p_k \in [\underline{p}_k, \overline{p}_k] \subset R_+^T \,|\mathrm{SINR}_{kh} \geq \gamma_{kh}, \forall h\} \quad (14)$$

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Where, the power allocated to the radar in the cluster $k$is $p_k = [p_k \in [\underline{p}_k, \overline{p}_k]]^T$, $\underline{p}_k$and $\overline{p}_k$ is the minimum and maximum values of p_k and$\gamma_{kh}$is a fixed value. The following equation (15) shows the utility function.

$$v_k(p_k, p_{-k}) = \sum_{j=1}^{T} p_{kh} \quad (15)$$

Where, the power vector utilized by all clusters except cluster k is p_{-k}. The underlying game is given in the equation (16).

$$\mathcal{G} =< D, \{P_k\}_{k\in\{1,..K\}}, \{v_k\}_{k\in\{1,..K\}} > \quad (16)$$

The best response strategy for the kth player is the solution of the following optimisation that is in equation (17) and (18).

$$\min_{p_k \in P_k(p_{-k})} v_k((p_k, p_{-k})) \quad (17)$$

$$\text{s.t SINR}_{kh}(p_k, p_{-k}) \geq \gamma_{kh}, \forall h = 1, \ldots\ldots T \quad (18)$$

From the above equation (17) and (18).it is clear that the actions of the players are interdependent, since each player's SINR depends on the actions $p_{-k}$of the other players.

$S_k(p_{-k})$denotes the interference plus noise term in SINR_{kh}, which is the last two terms in the denominator of equation (8). This is solved and it is given in equation (19).

$$S_k(p_{-k}) = \widehat{H}_k p_{-k} \quad (19)$$

The $\hat{\gamma}_{kh}$ is the instantaneous of M_{rh}. The optimal solution of equation (17) and (18) is given in equation (20).

$$p_k^* = H_k^{-1} S_k(p_{-k}) \quad (20)$$

This power values are given to the specific radars which doesn't have enough energy for transmitting the information, it is the effective way allocating the power to the MIMO radars for non-cooperative network.

Pareto optimality game theory

The current power of all MIMO radars and distance among the radars to the target is given to this pareto optimality for allocating the effective power allocation to the all MIMO radars of the network. The pareto optimality is takes place in allocating power to the co-operative MIMO radar network. In general, the nash equilibrium (NE) is not corresponds to a socially optimal outcome. In a given game, the costs of the players are improved by collectively allowing to select a strategy differ from the NE. Some players may select to differ from a cooperatively agreed-upon strategy for improving their own cost further at the group's expenses. Here, the Pareto optimal equilibrium defines a social optimum and this optimum is in the sense that is no individual player improves its own cost or lower cost without accomplishing at least one other player worse off. The pareto optimality is not a solution based concept, it is used for identifying the solution which needs to play by players or learn by players. A Pareto optimal solution for which there exists no other solution that gives every player in the game a higher payoff (lower cost). The extracted power from this game theory is allocated to the all MIMO radars which is presented in the co-operative clusters of the network.

IV. RESULTS AND DISCUSSION

The simulation and numerical results are illustrated in this section and this proposed system was implemented by using MATLAB 2018a software tool with i3 processor and 4GB RAM. This proposed method is tested with 32 MIMO radars which is in the network as well as these MIMO radars are clustered by K-means clustering. With the help of this, the primary and distributive type of clusters are extracted based on the distance from the MIMO radar to the target. The target localization of this network is accomplished by using GLRT method. Then the power allocation for the MIMO radar network is done by the nash equilibrium game theory (for non-cooperative network) and Pareto optimality (for cooperative network). The initial amount of energy given to each MIMO radar is 0.5J. The specifications of MIMO radar which is present in the network is given in Table.1.

Table.1. MIMO radar specifications

Initial power	0.5 J
Number of anttennas	4
Motion model	Velocity
Operating frequency	300 MHz
Sample rate	300 kbps
Peak power	2000
Gain	20
Pulse width	6.67e-06
Envelope	Rectangular
Loss factor	0
Temperature	36°C

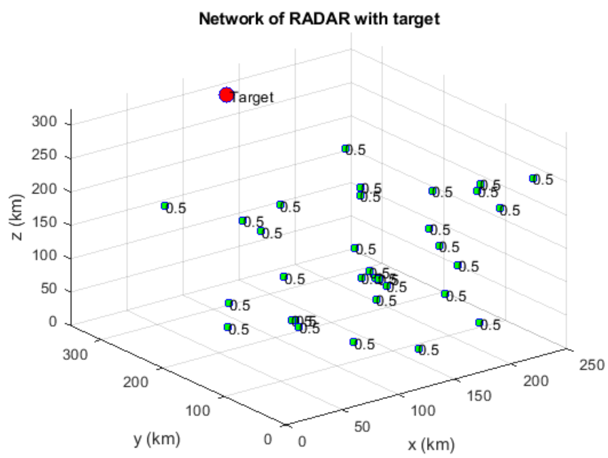

Figure.3. MIMO radar deployment

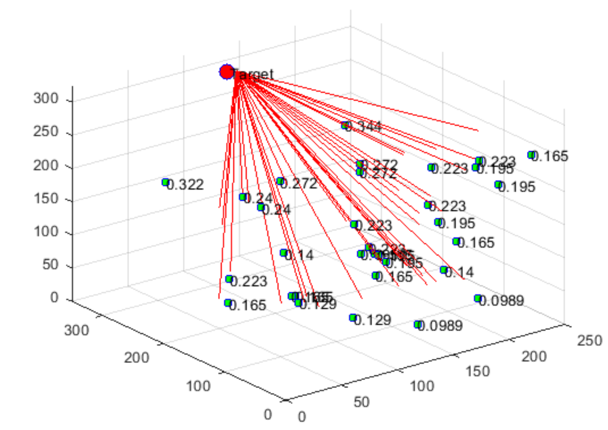

Figure.4. GLRT target detection

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The MIMO radar deployment of the network is shown in Figure.3 and the target detection is shown in Figure.4. The primary and distributive classification of MIMO radars is shown in Figure.5. Based on the distance from the radars to the target, the MIMO radars are classified. From the figure, the MIMO radars which is in blue color are primary cluster as well as the radars which is in green color are distributive cluster. Based on the distance consideration, the primary users are avoided, because they are already satisfied due to its nearer distance to the target.

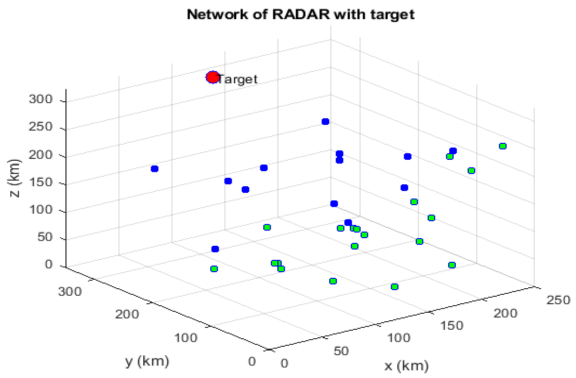

Figure.5. Distance based primary and distributive classification of clusters

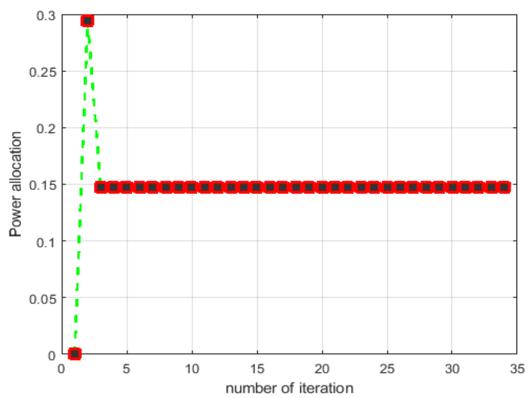

Figure.6. Power consumption of the entire MIMO radar network

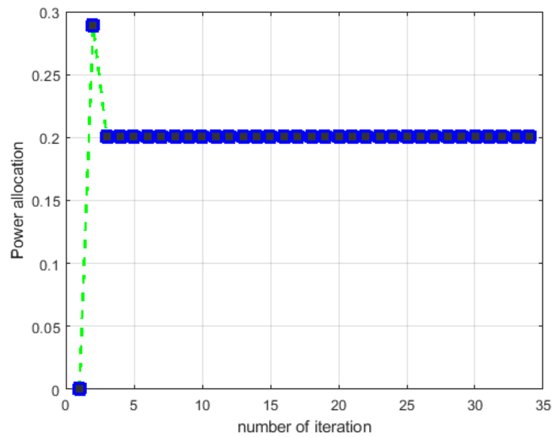

Figure.7. Power consumption of the distributive cluster

Figure.6. shows the power consumption for the both the primary and distributive cluster network. The power consumption of the network is stabled at 0.15J after 5th iteration. Figure.7. shows the power consumption of the distributive cluster and this cluster is obtained based on k-means clustering and distance analysis. The power consumption of the distributive cluster is identified after the power allocation of game theory using SINR measures.

TABLE.2. TOTAL POWER CONSUMPTION IN EACH CLUSTER FOR TWO DIFFERENT SYSTEM REALIZATIONS

	K=2, T=2		K=3, T=3		
GNG PA [19]	0.0763	0.0418	0.0641	0.1191	0.0895
CNCG PA	0.0698	0.0384	0.0599	0.1167	0.0869

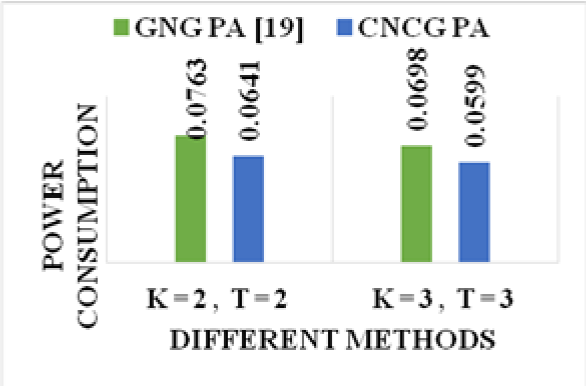

Figure.8. Power consumption comparison of cluster 1

The Table.2 shows the power consumption comparison of different number of clusters and antennas for proposed CNCG-PA to GNG PA [19] method. Figure.8 shows the power consumption comparison at cluster 1. From the analysis conclude that the power consumption of CNCG-PA is less than the existing GNG PA [19]. It is known that the power allocation of nash equilibrium and the pareto optimality gives the optimum power to each MIMO radar in the network.

CONCLUSION

The Nash equilibrium game theory and Pareto optimality based game theory is introduced in the MIMO radar network to allocate the power for each antenna of the distributed MIMO radar cluster. These game theories are applied in the distributive network concurrently, based on the distance from the MIMO radars to the target. If the distance between the radars to the target are in range, the Nash equilibrium is takes place on that time or else the Pareto optimality is takes place when the radars are not in the range. The allocated power value is mainly depends on the distance from the MIMO radars to the target and the power value of each radar (i.e., before power allocation). Based on these values, the optimal power is selected for each antenna and then this power is allocated to the respective MIMO radar. This kind of power allocation leads to minimize the power consumption of the entire network. The proposed CNCG-

PA is compared with the GNG PA in terms of power consumption. The power consumption of the CNCG-PA of cluster 1 is 0.0599, it is less when compared to GNG PA power is 0.0698 at K=3, T=3.

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