

REPUBLIC OF TURKEY
YILDIZ TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**SHARING OF NETWORK RESOURCES IN NEXT GENERATION
WIRELESS COMMUNICATION SYSTEMS**

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DOCTOR OF PHILOSOPHY THESIS

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Dedicated to my family

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I hope that this thesis would be helpful to researchers working on PHY and MAC layers Game Theoretical-Based in Ad Hoc Networks.

Ali Kamil KHAIRULLAH

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LIST OF SYMBOLS

C_q	Action regard to the player q
F_q	Antenna gain for the receiver
∂_q	Available codebook of q^{th} node pair
t_1	Beamformer for one q^{th} node pair
$t_q^{M,m}$	Beamformer of m^{th} node in cluster M
t_q and w_q	Beamformer pair
$\emptyset, T$	Beamforming set
$\mathbf{B}_i$	Best response
$a_{k(t)}$	Channel condition
CCE	Coarse correlated equilibrium
b_q	Complex symbol stream
$R(t)$	Cooperation decision probability
CE	Correlated equilibrium
R_i	Data transmission rate
β	Discount factor
$Z_{(t)}$	Empirical frequency vector
Φ	Empty set
G	Game
G^+	Identical interest gam

I	Identity Matrix
$R_q(\emptyset_{-q}, E_{-q})$	Interference and noise covariance of q^{th}
A_S	Joint action space
L	Left side
$U_{q,j}$	MIMO channel of j^{th} and q^{th} nodes
σ_i	Mixed strategy of player i
S^*	Nash equilibrium for G
$U_{\text{net}}(t, E)$	Network utility
a'_i	New action of player i
j	Node other than q
π	Normal form game
W_q	Normalized w_q at the q^{th}
M	Number of clusters
Υ	Number of codebook
A_k	Number of cooperation attempts
N	Number of nodes
N	Number of players in a game
γ^N	Number of searching profile space
$\emptyset^*$	Optimum beamformer
S_i^*	Optimum choice of player i
O	Overhead
α	Path loss exponent
$C, D \text{ and } T$	Player strategy
σ_i	Power of background noise
$E_q^{m,m}$	Power of node pair q in cluster m

E_q	Power of node q
$F(s)$	Potential function
$t_q^{\bar{t}^q}(k)$	Probability distribution of regret vector
Z^{RL}	Probability distribution over joint action RL
Z^{LR}	Probability distribution over joint action LR
Z^{LL}	Probability distribution over joint action LL
Z^{RR}	Probability distribution over joint action RR
Z	Probability distribution over joint action space
p_1^L	Probability distribution player 1 over action L
p_2^L	Probability distribution player 2 over action L
p_1^R	Probability distribution player 1 over action R
p_2^R	Probability distribution player 1 over action R
$p_i^{a_i}(t)$	Probability of p_i for $a_i \in A_i$ at t
a_i	Pure strategy of player i
$\mathbf{R}$	Real number
R_q	Received signal vector of node q
$\mathcal{r}$	Reinforcement signal
$R_i^{a_i}(t)$	Regret of p_i for $a_i \in A_i$ at time t
$r_{k,A_k^{(n_k)}}(n)$	Regret of player k selected an action in A_k at time n
$Re_q^{\hat{\partial}_q}(k)$	Reward of q^{th} for action $\hat{\partial}_q$ at k^{th} iteration
R	Right side
sgn	Signnum function
τ_q	Signal to interference noise ratio of q
$\boldsymbol{\tau}$	Smoothing vector

T^c	Solution time
S^c	Solving time
τ	Specific time
$z_{-i}^{-a}(t)$	Stage's percentage of selecting action a_{-i}
s_i, s'_i	Strategies of player i
$S, P \text{ and } Q$	Strategy set
A_i	Strategy space of player i
a_{-i}	The opponent players
γ_0	Threshold value of SINR
A	Total number of antennas
k	Total number of iterations
$E_q^{M,m}$	Transmission power of m^{th} node in cluster M
ID_q^m	User belonging to q^{th} of m^{th}
U_1	Utility function of the player 1
u_i	Utility function of the player i
$\{F_q\}_{q=1}^N$	Utility of players associating with their strategy
σ^2	Variance noise power
V_t	Value function
w_i	Weighted potential game vector

LIST OF ABBREVIATIONS

AP	Access point
ACK	Acknowledgment
ABS	Almost blank sub-frame
AI	Artificial intelligence
BBU	Baseband unit
BS	Base station
BF	Beam-forming
BR	Best response
BRD	Best response dynamic
BER	Bit error rate
CSMA/CA	Carrier sense multiple access with collision avoidance
CSI	Channel state information
CTS	Clear to send
CG	Cluster gateway
CH	Cluster head
CM	Cluster member
CMI	Cluster member information
CB-	Cluster-based
CCE	Coarse correlated equilibrium
CDMA	Code division multiple access
COPMA	Cooperative power minimization algorithm
CoMP	Coordinated multi point
CE	Correlated equilibrium

DR	Data rate
DS	Distribution system
ECOPMA	Enhanced cooperative power minimization algorithm
ϵ -greedy	Epsilon greedy
e-NB	Evolved node B
FP	Fictitious play
FDMA	Frequency division multiple access
GSM	Global system for mobile
Het-Nets	Heterogeneous networks
IEEE	Institute of electrical and electronics engineers
LAN	Local area networks
LTE	Long-term evolution
LTE-U	Long-term evolution unlicensed
MUE	Macro cell user equipment
MAC	Medium access control
MSE	Mean square error
MANET	Mobile ad hoc network
MIMO	Multiple input multiple output
MUI	Multi user interference
Mu-MIMO	Multi user-Multiple input multiple output
NE	Nash equilibrium
NP-hard	Non-deterministic polynomial-time hardness
OSI	Open Systems Interconnection
OFDMA	Orthogonal Frequency division multiple access
PHY	Physical

PCUE	Pico cell user equipment
PG	Potential game
PC	Power control
PDF	Probability density function
PMF	Probability mass function
QAM	Quadrature amplitude modulation
QoS	Quality of Service
ReTCl	Registration to cluster
RM	Regret matching
RMGS	Regret matching game selective
RL	Reinforcement Learning
RLPBA Algorithm	Reinforcement Learning based Power allocation and Beam-former
RTS	Request to send
SIFS	Short inter-frame space
SINR	Signal-to-interference-plus-noise ratio
SNR	Signal-to-interference noise ratio
TDMA	Time-division multiple-access
UE	User equipment
VANET	Vehicular ad hoc network
WCDMA	Wideband Code division multiple access
WiFi	Wireless fidelity
ZF	Zero forcing

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Sharing of Network Resources in Next Generation Wireless Communication Systems

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Department of Electronics and Communication Engineering

Doctor of Philosophy Thesis

Advisor: Prof. Dr. M. S. Ufuk TÜRELİ

Recent years have witnessed many research in the area of wireless networks. The goals can be divided into two main categories: improving network performance and energy efficiency. Game theory is widely used to relate the behavior of the users therefore, the cooperation among nodes can be achieved and network performance can be improved when the game theory is utilized. The applications of mathematical analysis to the study of wireless ad hoc networks have met with limited success due to the complexity of mobility and traffic models, the dynamic topology, and the unpredictability link quality that characterize such networks. The ability to model individual, independent decision-makers whose actions potentially affect all other decision-makers renders game theory particularly attractive to analyze the performance of the ad hoc networks. The cooperative approach with the use of game theory can achieve power minimization, yet presents overheads, while non-cooperative solutions utilizing the game theory reduce overhead, yet taking more iterations as well as power for convergence. The dissertation suggests a new game theory-based algorithm for achieving trade-offs between communication overhead and the power control with regard to multiple antenna enabled wireless adhoc

networks that operate in multiple-user interference environments. Enhanced joint iterative power adaptations in addition to the beamforming approach has been developed for minimizing mutual interferences at each one of the wireless nodes along with constant received Signal to Interference Noise Ratio (SINR) at each one of the receiver nodes. The performance optimization method has presented the comparison between suggested algorithms and COPMA and Regret Matching based joint transmit beamformer and power Selection Game (RMSG) is provided. Furthermore, simulation results related to the two approaches proving effective power adaptations as well as beamforming with regard to large and small networks with minimum interferences and overheads in comparison to modern approaches. Complexity analysis is presented, the comparison between different games are presented.

Keywords: Ad hoc wireless networks, beamforming and power adaptation, interference, game theory, reinforcement learning

Yeni Nesil Kablosuz İletişim Sistemlerinde Ağ Kaynaklarının Paylaşımı

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Son yıllarda kablosuz ağlar konusunda çok fazla araştırma yapıldı. Hedefler iki ana kategoriye ayrılabilir: ağ performansını ve enerji verimliliğini artırmak. Oyun teorisi, kullanıcıların davranışlarını ilişkilendirmek için yaygın olarak kullanılmaktadır, bu nedenle, oyun teorisi kullanıldığında, düğümler arasındaki işbirliği sağlanabilir ve ağ performansı geliştirilebilir. Kablosuz ad hoc ağların çalışmasına matematiksel analiz uygulamaları, hareketlilik ve trafik modellerinin karmaşıklığı, dinamik topoloji ve bu ağları karakterize eden öngörülemez bağlantı kalitesi nedeniyle sınırlı bir başarı ile karşılaştı. Eylemleri diğer tüm karar vericileri potansiyel olarak etkileyen bireysel, bağımsız karar vericilerin modellenenebilmesi, oyun teorisini geçici ağların performansını analiz etmek için özellikle çekici kılmaktadır. Oyun teorisinin kullanımı ile işbirlikçi yaklaşım güç minimizasyonu elde edebilir, ancak genel giderler sunarken, oyun teorisini kullanan işbirlikçi olmayan çözümler genel giderleri azaltırken, daha fazla yineleme ve yakınsama gücü de alır. Tez, çoklu kullanıcı etkileşimli ortamlarda çalışan çoklu anten özellikli kablosuz Adhoc ağları ile ilgili olarak iletişim yükü ve güç kontrolü arasındaki dengeyi sağlamak için yeni bir oyun teorisi tabanlı algoritma önerir. Işın oluşturma yaklaşımına ek olarak gelişmiş eklem iteratif güç adaptasyonları, alıcı düğümlerin her

birinde sabit alınan Sinyal-Parazit Gürültü Oranı (SINR) ile birlikte kablosuz düğümlerin her birinde karşılıklı etkileşimleri en aza indirmek için geliştirilmiştir. Performans optimizasyonu yöntemi, önerilen algoritmalar ile COPMA ve Regret Matching tabanlı ortak iletim hüزمةleyici ile güç Seçim Oyunu (RMSG) arasındaki karşılaştırmayı sunmuştur. Ayrıca, modern yaklaşımlara kıyasla asgari parazit ve ek yükleri olan büyük ve küçük ağlar için ışıın şekillendirmenin yanı sıra etkili güç adaptasyonlarını kanıtlayan iki yaklaşımla ilgili simülasyon sonuçları. Karmaşıklık analizi sunulur, farklı oyunlar arasındaki karşılaştırma sunulur.

Anahtal Kelimeler: Tasarsız kablosuz ağlar, beamforming ve güç paylaşımı, girişim, oyun teorisi, ek öğrenme

1.1 Literature Review

With regard to the present wireless communication systems, radio spectrum as well as infrastructure have been utilized, in a way that the interference will be avoided through exclusive allocation regarding the frequency bands as well as using the base stations. Also, the resource sharing will show the way that equal priority resource sharing with regard to the wireless networks enhance the spectral efficiency, improve coverage, improve user's satisfaction, result in more revenue for the operators, as well as decreasing capital and the operating expenditure.

The major approach related to physical resource sharing might be specified with the use of Figure1.1. There has been general set that is related to the common resources that are divided in to 2 classes, referred to as spectrum as well as infrastructure. Player's set includes users and operators. There have been no other stakeholders such as vendors, spectrum brokers, content providers, manufacturers, service providers, as well as central network controllers involved. Each one of the players has set of the private information, also operators having business models in addition to revenue strategies, also the user has private interest and partially private state information involving mobility, traffic, as well as channel parameters. Such aims as well as parameters have been typically not indicated to the others.

Constraints have been divided in to 2 areas, referred to regulatory as well as environmental constraints. They might partially overlap as in the condition related to spectrum masks in addition to the power constraints that have been environmental and regulatory. The major difference between such 2 areas is that the regulatory constraints include fairness as well as social welfare or certain legal issues, while the environmental constraints involve certain fundamental limitations which are induced via physics.

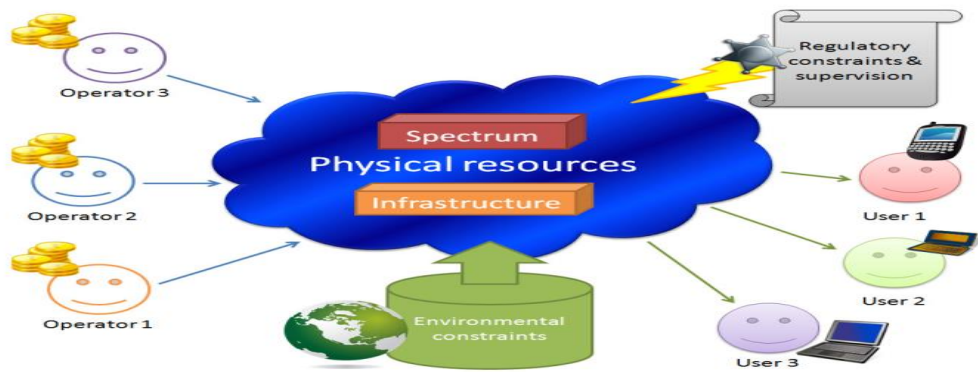


Figure 1.1 Conceptual overview of spectrum and infrastructure sharing

Resource sharing problems have been interdisciplinary as well as requiring regulatory in addition to certain political bodies, market and business specialists. Also, network and communication engineers are providing technical input. Current discussion related to spectrum commons resulting majorly from market as well as regulatory perspective. Yet, development in the communication systems (interference cancellation, adaptive receivers, multi-antenna systems, software-defined-radio, as well as multi-carrier systems) have been specified for having solid effect due to the fact that they are enabling effective as well as concurrent use regarding the spectrum [1]. Also, technical requirements related to the IMT-Advanced as indicated before including the technologies of next-generation mobile radio which might be enabling effective resource sharing.

With regard to the perspective of communications engineering, there are a lot of orthogonality types in the frequency, space, time or the coding domain have been utilized for the resource allocation based on the interference type: With regard to the users in single cell that is operated through single operator (intracell interference) TDMA along with the FDMA (applied in the systems of GSM) or the CDMA (along with the TDMA/FDMA in the systems of 3G) has been utilized for separating the signals at receiver. With regard to various cells or sectors, intercell interference has been managed via utilizing various frequency reuse factors [2]. Currently, the techniques related to separating the transmissions from various operators (the inter-operator interferences) with no orthogonal resource allocations have been designed: The first flexible resource sharing methods have been designed and the results indicating that the system's overall efficiency might be enhanced through sharing various resources in network between distinctive operators [3].

Share infrastructure or spectrum end up in developing *interferences on physical layer*. Thus, MAC and physical layer optimization with regard to the resource sharing is studied extensively. The competitions between the operators and service providers has been modelled with the use of game theory [4]. Also, there has been a lot of studied related to game theory to the spectrum conflict in the wireless systems, although such field has been fairly novel preliminary researches related to spectrum sharing problem from the viewpoint of the game theory indicated in searching for efficient, fair, as well as self-enforcing protocols. Furthermore, spectrum sharing problem in terms of cognitive radio was formulated as dynamic (repeated) and static Cournot4 game [4]. Non-cooperative and co-operative approaches related to power control optimizations in the interference networks were suggested [5]. Also, the co-operation was utilized for agreeing on the spectrum's fair allocation [6].

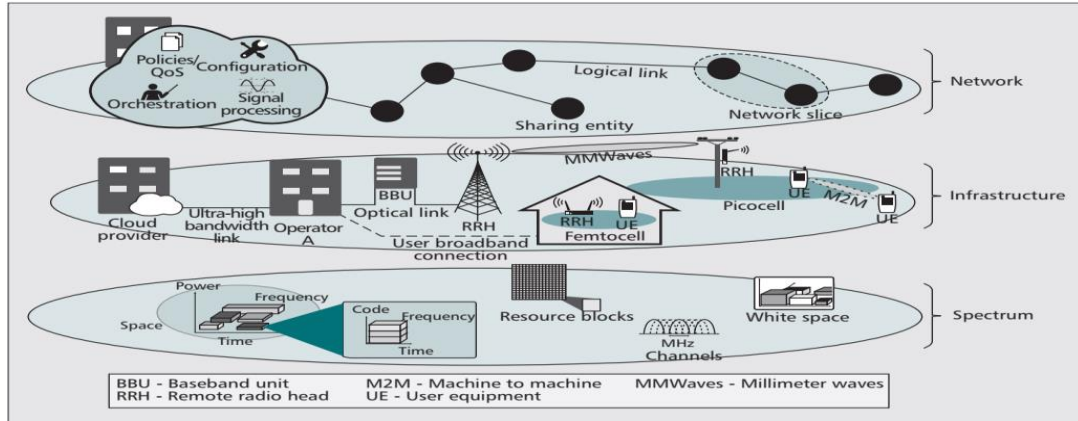


Figure 1.2 Resource sharing in HetNets-cloud radio access networks

Thus, the network sharing is focusing to manage the available resources, in spite of their physical representation (infrastructure and spectrum), as can be seen in the Figure1.2. With regard to such level, BBU might be processing all network configurations, orchestrations, signal processing, as well as accounting regarding the policies/QoS requirements [7].

The presented work will be suggesting 2 approaches RLPBA and ECOPMA for addressing the problems related to power minimization with the least interferences as well as communication overheads with the guaranteed QoS that is related to multiuser MIMO adhoc systems with constant constraints of the SINR in the first part, while, second part of this thesis was consider varies SINR amounts. Furthermore, ECOPMA has been on the

basis of possible cooperative games with the use of binary weight books instead of utilizing complex Grassmannian weight book for the purpose of reducing communication overheads. Also, ECOPMA has been comparable to COPMA [8] with the inclusion that is related to binary weight books. RLPBA has been considered as non-cooperative games-based power allocations as well as beamforming approach comparable to RMSG [8] with using reinforced learning for reducing power consumptions as well as the number of iterations to converge.

Ad Hoc MIMO communication systems are considered to be the foundation of next generation of the wireless communication systems Massive MIMO. Furthermore, the Multiuser-MIMO (MU-MIMO) boosting development and design regarding the Massive MIMO technology [9]. Also, the efficiency of MIMO communication systems depending on adaptability regarding the transmit parameters like the modulation methods, transmit power, beamformer selection, transmission rate, and so on. Beamformer selection's design is of high importance in adaptive wireless communication systems. With regard to MIMO, the approaches of beamforming have been developed for various network types like ad hoc, cellular, as well as point-to-point [10]. A lot of the beamforming approaches were developed for addressing challenges associated to all of these networks. Furthermore, conventional approach of beamforming showing throughput maximization, power control, as well as capacity enhancement particularly with regard to the cellular and point-to-point networks. With regard to the MIMO adhoc networks, distributed beam-forming solutions are showing system throughput enhancements as well as energy minimization, yet suffering from interferences as well as communication overheads. A lot of distributed beamforming techniques have been developed for minimizing interferences as well as communication overheads in literature.

As indicated before, there have been 3 categories where beam-forming solutions provided for the MIMO. Furthermore, the communication-based point-to-point MIMO beam-forming solutions which have been specified in [11]-[14] also beam-formers as well as the linear pre-coders (i.e. Eigen-coders) suggested for the point-to-point MIMO communication in [15]-[16]. Also, beam-forming algorithms have been developed for cellular networks in [17]-[18] reducing power as well as improving capacity related to single antenna mobile transmitters in addition to the array-equipped base stations. Power control and beamforming with regard to point-to-point as well as the cellular MIMO

networks has been accomplished minimum overheads as well as challenges of interferences. Yet, ad hoc MIMO networks operating with no centralized controller as well as the moving nodes. With regard to MIMO ad hoc networks, distributed beamforming approaches enhancing the throughput of network as well as minimizing energy consumptions [19]-[20]. The main challenge with the use of optimization-based solutions with regard to the ad hoc networks has been systematic as well as adequate research is required for examining overheads provided via beamforming algorithms that impacts the performance related to MIMO ad hoc networks. The distributed spatial beamforming approaches have been provided in [21]-[22] with regard to multiuser ad hoc MIMO networks within conditions of channel reciprocity. Yet, in these approaches, transmission overhead has been provided throughout power control, also at each one of the iterations. Yet, trade-offs related to overhead as well as performance isn't accomplished with these approaches in addition to convergence related to iterative algorithms wasn't totally examined.

Game theory has been significant mathematical tool to study the environments in which multiple players have been making decisions and interacting, sometimes talking about the rational players (they are attempting for optimizing their interests) [23]-[24]. Also, the game theory-based solutions were suggested convergence investigation with regard to significant problems in the wireless communications such as the joint code-division multiple access [25], the algorithms of the distributed power control [26], as well as strategies of the optimum transmission signaling [27]-[28]. The game theory-based beamforming as well as the power adaptation approaches developed for the multiuser ad hoc MIMO network communications might be achieving power efficiency with the minimal overheads. In a study conducted by [29]-[30], initial cooperative as well as the non-cooperative game theory-based approaches related to the joint channel as well as the power control regarding the wireless mesh networks, as well as channel allocation, also the beamforming with regard to ad hoc networks has been examined. Yet, decrease related to the power utilizing distributed algorithms as well as the transmit beamformer selections has been complicated tasks, and thus it is difficult for formulating beamforming games with regard to the multi-user wireless communications, a study conducted by [31]-[32]. Reinforcement learning (RL) based-algorithms has been utilized for determining the adequate policy with regard to the selections between 2 distinctive approaches, the first

has been beamforming, whereas the other has been power control with regard to sensor array networks, through using individual features regarding each one of approaches depending on (SINR) threshold. The main problem related to RL has been selecting the action of (PC or BF) on the basis of learning state with regard to (SINR), which has been satisfied with system requirements. The Q-learning with epsilon greedy (ϵ -greedy) policy has been utilized in RL which has been trained with the use of offline approach. AI approaches were specified as well as utilized in problems related to beamforming, power control as well as the MIMO wireless communication systems [33]-[36].

Recently, a study conducted by [37] explored the considerable diversity in the (MIMO) wireless systems requiring complete channel knowledge or knowledge regarding optimal beamforming vector; the two are difficult to realize. Therefore, quantized maximum (SNR) Grassmannian beamforming as well as Binary Grassmannian beamforming with regard to the MIMO Wireless Systems have been suggested in which the receiver just send label regarding best beamforming vector with the use of pre-determined codebook to transmitter. The Grassmannian weight-book providing optimum performances even in high noise environments. The developed binary weight-book providing same performance like Grassmannian weight-book, yet with minimum complexity.

They were specified as binary weight-book as well as Grassmannian weight-book design with regard to the systems of MIMO beamforming utilizing the quantized feedback on the basis of the beam-forming criterion of Grassmann. With the use of weight-book, computational complexity for finding optimal beam-forming weight vector as well as storage requirement related to weight-book could be decreased. They indicated that Grassmannian criterion related to the binary weight-book design is maximizing minimum Hamming distance regarding equivalent block code [38]. Therefore, block code which as large minimum Hamming distance has been of high importance to the binary weight-book design with regard to the systems of MIMO beamforming utilizing quantized feedback [38].

On the other hand, and especially in a clustering [40], the mobile nodes are divided into different virtual groups and they are allocated geographically adjacent into the same cluster according to some rules with different behaviors of nodes. Clustering [39] is a promising approach for enhancing the scalability of mobile ad hoc networks (MANETs) in the face of frequent topology changes mainly due to the host mobility. Clustering not

only makes a large MANET to appear smaller, but more importantly, it makes a highly dynamic topology to appear less dynamic [40]. Cluster structure makes Ad hoc networks to be appeared as smaller and more stable. Clustering helps to improves routing at the network layer by reducing the size of the routing tables and by decreasing transmission overheads of routing tables after topological changes. Clustering contains three types of nodes such as Cluster-Head [39], Cluster Gateway, and Cluster Member. Figure 1.3 shows the architecture of clustering [41].

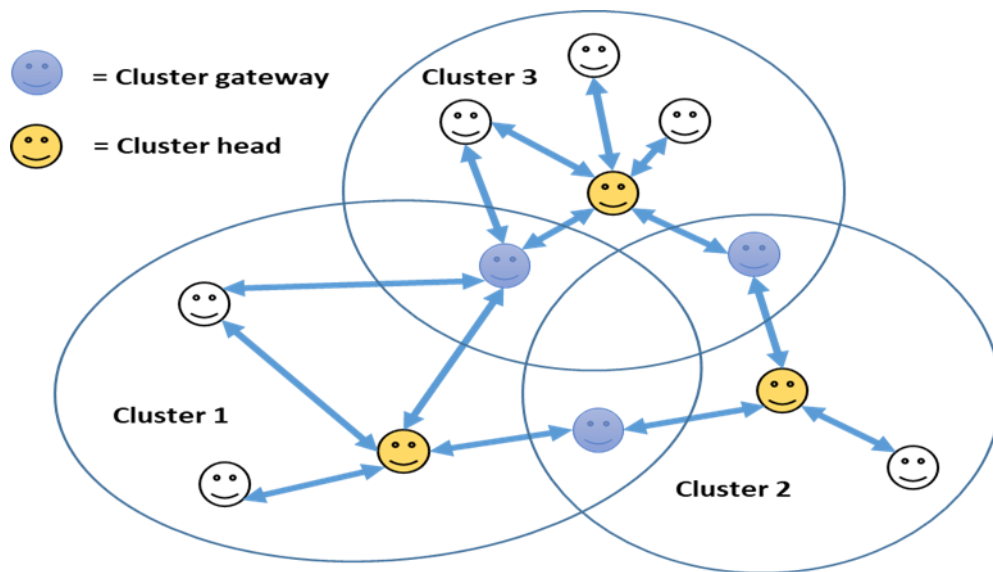


Figure 1.3 Clustering architecture

1.2 Objective of the Thesis

The objective of this study was exploring different concerns that are related to resource utilizations. Considerable performance gains can be achieved in case of handling this procedure with taking under consideration the main parameters of the performance. Which is why, the main concerns are:

1. What is the way of reducing the general delay of the network for increasing the efficiency of the network?
2. What is the way of fulfilling different users' needs for the bandwidth with an insufficient amount of the resources?

3. What are the ways of increasing the life-time of the network via enhanced energy utilization? Matrices mainly concerned with the general gains of the system, different strategies will be discussed,

In the present thesis, it has been considered that the games' players use equipment like mobiles ad hoc network. Interactions between the mobiles naturally exist in the wireless networks, due to the fact that there is usually interference and that the common resources have to be shared. Wireless devices are in a non-cooperative network or cooperative some time according to a specific condition. Our goal here to minimize transmission power by reduce the interference with the maximal throughput in the realistic environment according to the rules of the economic incentives, this goals will reach by define common communication and application that allow us for using some conventional cellular networks (Het-nets, LTE and 5G) for improving power efficiency and traffic offloading in next generation wireless communications systems. The main purpose of this thesis will be the deployment of strategy in wireless networks and proposing new model based power efficiency and optimal utility Furthermore, we want to explore the advantages of Resource sharing, including cooperative and non-cooperative networks, beamforming, spectral efficiency, coverage, low power consumption, reliable transmission and cost.

For driving this study to the abovementioned aim, the operational aims below were specified:

1. Carefully research the existing solutions for solving similar issues.
2. Improving the effectiveness of the approaches that have already been developed: such as, reducing the network overhead, the communication delay and increasing the communications' throughput, as well as convergence rate.
3. Develop transparent algorithms with suitable structure so they can be researched, used and/or modified subsequently by any researcher or developer, either for bringing them some benefit or for applying their implemented tools.

In this part, we discussed the past studies found in literature. Since our dissertation is focusing on resource sharing and allocation with efficient power usage for next generation wireless communication networks, we consulted papers and textbooks in line with the scope of the thesis and put together all necessary details, such as techniques, types and theoretical approach that can guide us in the evolution of our thesis.

The main contribution and algorithms of this thesis summarized as follows:

In chapter 2: The game theory and its application especially in the wireless communication networks field were presented briefly with recent literature from an economic and engineering point of view.

In chapter 3: A journal article published in International Journal of Computational Intelligence Systems with this contribution.

In chapter 4: A conference article published in IEEE Engineering International Conference with this contribution.

In chapter 5: Result, discussion and future work suggestion with this contribution.

1.3 Hypotheses

In order to have useful applications, communication between Ad hoc nodes and existing networking infrastructures should be reliable and efficient. Cooperative communication is capable of increasing the reliability of the communication link through the mitigation of the impairments of the wireless channel which result from the mobility in the Ad hoc networks. two game theory based algorithms to optimize the performance of ad hoc wireless MIMO systems for joint transmit power and transmit beamforming with minimum power consumption and overhead. We presented cooperative (ECOPMA) solution using clustering and binary codebook and non-cooperative (RLPBA) solution using the distributed reinforce learning in this thesis. One more way, the cluster-based communication is capable of improving the communication reliability through the formation of a cluster with a neighboring node that is very closed. The optimum transmit beamformers can be chosen through a predefined codebook in order to decrease the entire power, by using a cooperative fashion (Potential game), for cluster-based -Network topology. Thus, Bit Error Rate (BER) and power can be minimized and convergence rate can be increased (the steady-state spot i.e. Nash Equilibrium) of beamformer games to enhance the whole system performance (i.e. Data Rate), can be guaranteed throughout the iterations, taking into account the receiver nodes minimum requirement QoS (SINR threshold) in intelligent system computational design.

The rest of this thesis has been organized as: performance modeling and analysis game theory and its application in telecommunication networks are presented in Chapter 2.

Optimized Intelligent Design for the Smart Systems Hybrid Beam-forming and Power Adaptation Algorithms for Sensor Networks Decision-Making Approach is proposed in Chapter 3. Low Complexity Power Reduction and Beamforming Selection: An Intelligent System for Cooperative Game Approach in MU-MIMO Wireless Sensor Networks is provided in Chapter 4. Concludes and summarizes of this dissertation are presented in Chapter 5.

2.1 Introduction

Game theory a mechanism by which mathematical models can be constructed concerning non-cooperative and cooperative intelligent rational decision makers [42].

Game theory is considered discipline of applied mathematics. It has been significant tool to study daily life and public life. The moves or actions related to situations depend not just on what individuals are doing, but also on what other individuals are doing. A few examples of the "games" in the game theory have been negotiations regarding price with the seller, votes at presidential elections, participations in internet auctions, even attempts at finding seats on a bus. Other major games have been monopoly, football, chess, and so on. Thus, individuals are having interactions between them with regard to the situations. The decisions of individuals in day-to-day problems are based on their own preferences as well as the actions of the other individuals, thus they are interdependent. After that, *game* includes 2 players or multiplayer, also they might have common or conflicting interests. Furthermore, all players have strategies which determine their moves in the game. Also, game theory provides mathematical processes regarding choosing optimum responses to the players for facing opponent ones. Thus, definition related to the *Game Theory* might be in the following way: set related to the tools designed for analyzing interactions among the multiple agents for achieving their objectives. Furthermore, game theory was utilized in many fields like computer science, biology, sociology, law, as well as philosophy. Lately, game theory has been gradually utilized in the computer sciences, also in AI, networks, as well as cybernetics. Utilizing game theory, one can model the cases where there have been no centralized entities with the partial/full information network conditions. Therefore, significant interests indicated to solve network as well as communication problems. The major interests for research with the use of game theory

in such problems: adaptive interference avoidance, power control, flow control, routing, as well as congestion control.

2.2 Cooperation in Wireless Networks

Recently, the wireless industries are going through unique progress in the number of applications, subscribers, and services which should receive support via next-generation systems of mobile communications. The more and more diffusion related to novel services including multimedia communication and mobile television highlights the requirement for developed wireless networking which might be increasing the performance of the system [8]. In such regard, co-operation between wireless network's devices was specified as a major technology enabler needed for facilitating the next-generation systems of wireless communications. In the last 10 years, a lot of studies assumed point-to-point communications between centralized and terminal access points or the point-to-multipoint communications between terminals and central entity. The wireless users might be engaging in co-operative behavior, leading to enhanced performance of the network. Also, the co-operation between devices might be coexisting with the centralized infrastructures, for instance, cellular networks, yet it is of high importance as well in ad-hoc autonomous networks.

One of the basic examples related to wireless network's cooperation has been relay channel, initially presented in [43]. The relaying specifies that certain wireless helper-node might be assisting the other nodes to transmit their data to destination. Therefore, it was indicated that the nodes and network might be witnessing improvements of the performance at various levels including elevated throughput, improvement of the bit error rate, coverage extension, and so on [44]. A few of the single-antenna nodes might be cooperating for the purpose of exploiting the benefits of multiple-input-multiple-output (MIMO) systems with no requirement for the physically-present multiple antennas on devices [45]-[46]. Also, beyond physical layer, the co-operative systems were examined at upper layers including network and MAC layers. For instance, through co-operating at MAC layer, access points in wireless LAN might be achieving decreased interference and high throughput [46]. It was indicated that through co-operating in the packet forwarding, nodes in the ad hoc wireless networks might be improving the network's connectivity via suitable cooperation decisions [47].

2.3 Cooperative Games

With regard to the game theory, cooperative games are considered as games in which group of players might be enforcing cooperative behaviors, such group might be referred to as coalition. Yet, a competition take place between those coalitions, instead of between the individual players, also there have been 2 types related to the cooperative games, therefore coalitional games as well as bargaining games, cooperative games are focusing on efficiency and fairness. Furthermore, its cooperative games might be also specified as games which group of the players might be enforced for working together for minimizing their payoff. After that, there have been competitions between the groups of the players, instead of the individual players. With regard to cooperative networks, agents have been included in cooperative games. With regard to cooperative game theory, the users (wireless agents) in network agrees with how effectively and fairly sharing provided spectrum resources [48].

Coalitional game theory [49] is majorly dealing with cooperative group's formation, for instance, coalitions, which enable cooperating players in strengthening their position in certain game. The current interests in wireless network's cooperative paradigms, indicated that using coalitional games-based techniques is somewhat natural. In such regard, the coalitional games are tools of high importance to design effective, robust, fair, and practical cooperation plans in the communication networks. Yet, the majority of researches in wireless communities is focused on either the games which are non-cooperative [50] or utilizing methods and models of standard coalitional game theory for examining the extremely limited factors related to network cooperation, including the stability within fairness or ideal cooperation. This has been majorly because of the sparse literature which is tackling the coalitional games as the major pioneer game theoretical reference like [51] focusing on the non-cooperative games.

Coalitional games are classified via authors to 3 unique classes to excellently identify the possible wireless as well as communications applications [52]:

1. **Class-I:** Canonical coalitional games.
2. **Class-II:** Coalition formation games.
3. **Class-III:** Coalitional graph games.

The major aspects of such classes have been indicated in the Figure. 2.1.

The coalitional game theory is presenting [49] significant framework which might be utilized to model different factors of cooperative behavior in the wireless networks of next- generation. Also, for optimum co-operation, one might be using different solution ideas related to canonical coalitional games to study the fairness and stability to allocate utilities in the case of cooperation between all network's users.

At the same time, in the case when there is benefit-costs tradeoffs for the co-operation, one might be reverting to class related to coalitional games, referred to as coalition formation games, to derive algorithms and models which might be helping to analyze cooperating groups which is going to arise in certain wireless network.

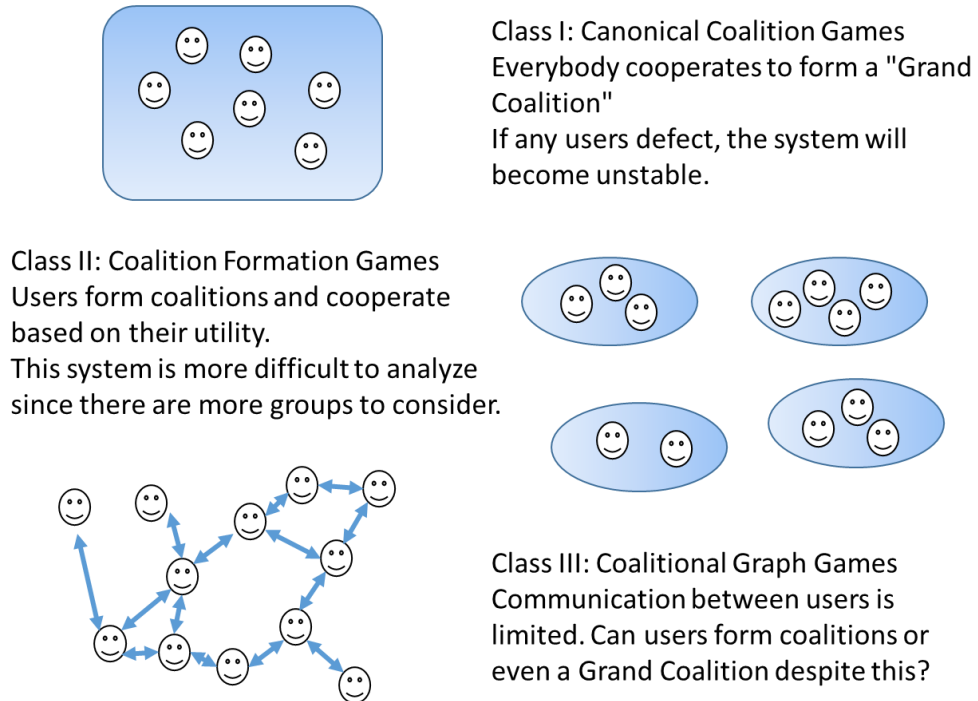


Figure 2.1 Classes of coalitional game theory

In his work, [53] provides informative similitude between attempt for providing micro-foundations to the macro-economic as well as Nash program, with the goal of “bridge the gap between both the counterparts of game theory (i.e. the cooperative and the non-cooperative)”, such comparison has been adequate for shedding some light on the topic's significance.

In [54] stated that there are weaknesses to both non-cooperative and cooperative approaches. Particularly, the latter was lacking some strategic foundation, while the former was depending heavily on the choices related to game's extensive form as well as adopted equilibrium concept, choices which have been far from being generally approved. Other issue related to non-cooperative approaches is the equilibria's multiplicity which could result in [51]. Therefore, their combination might be significant operation for overcoming each side's flaws.

For the purpose of understanding the approach, where one might be strengthening the other, it has been required for totally comprehending what the 2 methods are in addition to their dissimilarities. A study conducted by [55] indicated that the co-operative game theory has been just normative method which is detached from the strategic considerations which pursue the cooperation, also the equity via required desirable axioms has been majorly wrong. The same study indicated that the adequate definition related to cooperative game theory is "of a theory where the coalitions and the set of payoffs which are feasible for every one of the coalitions are primitives". Thus, the coalitional game has been a game of normal form in which set of pay-offs have been provided via the value which each one of the coalitions is dependently attached on each of the coalition structures (game in the partition function form) or in an independent manner (game in the characteristic function form). Also, the cooperative game theory is operating a simplification to omit the game's extensive form for its desired strategic and normal form [56].

However, the things which are lost in the richness, will be obtained in sharpness, as it is restricting the focus on major features of strategic situation. Also, there is importance in indicating that a few of the solution concepts arise in the games which are in partition function form have been modifications or extensions related to concepts which are initially envisaged for the games which are in characteristic function form. For instance, the study of [57], which is extending the **Shapley value** to partition function games, also the study of [58], also [59], with the aim of proposing **Core** for the setting.

2.4 Non-cooperative Games

With regard to non-cooperative networks, there are agents which have been concerned with non-cooperative games. The major element related to non-cooperative game theory

has been Nash Equilibrium (NE) [60], that has been considered as strategy profile like that no one of agents could reduce their individual costs through unilaterally change the strategies. With regard to distinctive case strategic game in the case when NE exists, also in the case when strategic game can be specified as pure strategy, as well as when specified as mixed strategy. There might be incomplete or complete information in the game. Furthermore, a might be static that indicates that players might not be having over a single move. Yet the game might be dynamic, and that indicates that players might be observing the former moves or the data, also following making new decisions for moving. Thus, dynamic games have been specified as general game models. This study will be provided certain cases which might be ensuring the equilibrium's uniqueness. Also, a game might be having more than single equilibrium, after that there have been certain conditions for the purpose of selecting such equilibrium.

Mixed Strategies: With regard to pure strategies, players are deciding between behaviors [61]. Whereas in mixed strategies, players might be deciding in playing those pure strategies with various likelihoods. The mixed strategy will be defined as follows: [61]. Mixed strategy σ_i (a_i) otherwise σ_i related to the player i has been considered as probability distributions over the pure strategies $a_i \in A_i$. Assuming that Σ_i has been mixed strategy space that is related to the player i , in which $\sigma_i \in \Sigma_i$. Also, the profile's notion has been specified via probability distribution allocated through each one of the players to their pure strategies, i.e. $\sigma = \sigma_1, \dots, \sigma_N$. Furthermore, the strategy profile that is related to opponent players has been referred to as σ_{-i} . Utility to the profile σ with regard to player i has been specified as follows:

$$u_i(\sigma) = \sum_{a_i \in A_i} \sigma_i(a_i) u_i(a_i, \sigma_{-i}) \quad (2.1)$$

Extensive Form: The players in a game might be having sequential interactions, indicating that one player's move depends on the other player's move. These games have been indicated as dynamic games, also might be specified in the extensive form. Furthermore, extensive form game has been considered as game tree. Such tree has been rooted one in which each one of the non-terminal nodes representing a choice must be taken via the player, also each one of the terminal nodes giving payoff to players. Extensive form game could be directly analyzed or might be converted in to equivalent strategic form. Also, the extensive form might be divided in to 2 categories, extensive

form with the imperfect information as well as the extensive form with the perfect information. In the latter, each one of the players at all points is alert of the other player's former choices. Players are having sequential interactions, indicating that just single player will be move in one time. Such games could be analyzed through backward induction. Such method solving the game through specifying game's last likely choices.

2.5 Nash Equilibrium (NE) & Existence

NE of strategic game with the components u_i , A_i , and N has been profile $a' \in A$ related to actions in a way that $\forall i \in N$ then

$$u_i(a'_i, a'_{-i}) \geq u_i(a_i, a'_{-i}) \quad \forall a_i \in A_i \quad (2.2)$$

In which a_i representing the strategy related to the player i , also a_{-i} representing strategies related to all the players apart from the player i .

NE will be defining optimum response strategy regarding each one of players. Therefore, no one of players could be enhancing their payoffs through unilateral deviations from NE, with the assumption that the other players adopting NE. Furthermore, the Kakutani's Fixed Point Theorem has been indicating next theorem with regard to NE's existence in the strategic game [62].

Theorem: Strategic game which has the components N , A_i as well as u_i will have NE in the case when $\forall i \in N$, set $A_i \neq \emptyset$ has bene compact convex sub-set related to Euclidian space as well as payoff function u_i has been continuous as well as quasi-concave on the A_i . Mixed strategy NE that is related to the strategic game has bene NE in which the strategies of players are non-deterministic, yet being regulated through the probabilistic rules.

Theorem: [Nash 1951]: Each one of the finite strategic games has mixed strategy NE.

Theorem: [Kuhn 1953]: Each one of the finite extensive games related to perfect information has pure strategy NE.

Thus, all correlated **equilibria**, and consequently Nash equilibria, are actually coarse correlated [63] equilibria as can be seen in the Figure2.2. In the case when all the players are independently selecting their actions, such as the conditions in defining Nash equilibrium, after that the definition related to correlated, coarse-correlated, as well as Nash equilibria will all be equivalent.

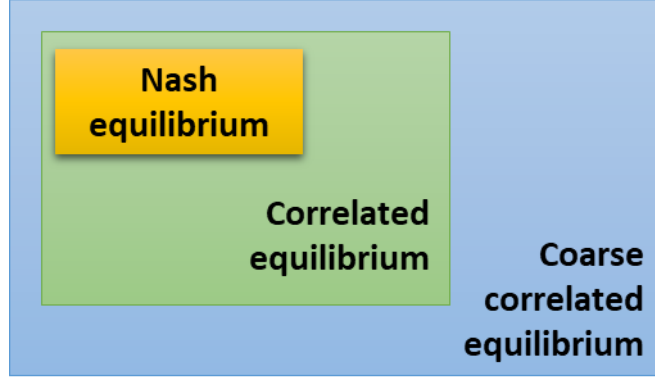


Figure 2.2 Relationship between Nash, correlated, and coarse correlated equilibria

Let us consider the next the two-player game along with the payoff matrix in Fig 2.3. With regard to any of the joint actions, the first entry can be defined as player 1's payoff, while the second entry is player 2's payoff. For instance, $U_1(L, L) = 1$ and $U_2(L, L) = 1$. Assuming $z = \{ z^{LL}, z^{LR}, z^{RL}, z^{RR} \}$ is the probability distribution over the joint action space $A = \{LL, LR, RL, RR\}$.

		P2	
		L	R
P1	L	1,1	0,0
	R	0,0	1,1

Payoff Matrix

		P2	
		L	R
P1	L	z^{LL}	z^{LR}
	R	z^{RL}	z^{RR}

Joint Distribution

Figure 2.3 Example of an identical interest game

$$p_1^L = p_2^L = 1/2 \text{ and } p_1^R = p_2^R = 1/2 .$$

In such instance, there are two strict Nash equilibria, (L, L) and (R, R). Also, there exists a single mixed Nash equilibrium. The joint distribution z has been specified as correlated equilibrium in the case when off-diagonal probabilities are not exceeding diagonal probabilities, for instance, set related to correlated equilibria has been considerably large in comparison to set of Nash equilibria.

$$\max \{ z^{LR}, z^{RL} \} \leq \min \{ z^{LL}, z^{RR} \}.$$

2.6 Potential Game

The attractiveness of potential games is depending on their significant features related to attainability and existence of their Nash equilibria. There are direct consequences related to such properties: straightforward application related to equilibrium-seeking dynamic to potential game's gameplay might result in Nash equilibrium solution. Yet, prior to having the ability for effectively applying rewarding results to the practical problems, there is a requirement for answering significant questions related to the way of identifying if the game is considered as potential one. Put differently, the way of formulating problem in a way that the resulting game might be potential one [64].

Mathematically, potential games might have many types. In all such game's types, the general thread is the presence of related to function (*potential function*) which is mapping the strategy space S of a game to real number R space. The classifications are on the basis of certain relation between the utility function and potential function of players. Therefore, the latter is the major significant in the researches of potential games. The source related to the term "potential" has been taken from analogies to comparably-termed idea of potential in the analysis of the vector field, with major examples including gravitational potential as well as the electric potential in physics.

A study conducted by Monderer and Shapley [65] provided 4 types related to potential games: *generalized ordinal potential games, weighted potential games, ordinal potential games, and exact potential games*.

2.6.1 Exact Potential Games

Definition 2.1 (Exact Potential Game). Game G is considered as an exact potential game in the case when potential function $F(S) : S \rightarrow R$ existing in a way that, $\forall i \in N$:

$$U_i(T_i, S_{-i}) - U_i(S_i, S_{-i}) = F(T_i, S_{-i}) - F(S_i, S_{-i}) \quad (2.3)$$

$$\forall S_i, T_i \in S_i; \forall S_{-i} \in S_{-i}$$

With regard to such potential games, changes in single player's utility because of their strategy deviations lead to precisely the same amount of changes in the potential function. Supposing that every one of the strategy sets S_i has been continuous interval related to R , also each one of the utility functions U_i has been differentiable and everywhere continuous, it must be indicated that G has been continuous game. The game will be an exact potential one, a definition which is equivalent to (2.3) will be as follows:

$$\frac{\partial U_i(S_i, S_{-i})}{\partial S_i} = \frac{\partial F(S_i, S_{-i})}{\partial S_i}, \forall S_i \in \mathbf{S}_i; \forall S_{-i} \in \mathbf{S}_{-i}, \quad (2.4)$$

From the many potential game's type, the exact potential games were the ones with a definition requiring strictest conditions related to exact equality. Other potential game's type has been specified via loosening such condition. However, the exact potential games have been the major significant and receiving high interests in practical applications and theoretical researches [66], also there are other extensions presented in literature. The highly important ones in such monograph the best-response potential games suggested [67], as well as the pseudo-potential games suggested [68]. The definitions related to all such potential game's types will be presented.

Example2.1. Prisoner's dilemma is considered as a precisely potential game. Pay-off table is re-produced in Figure 2.4 right side as well as corresponding potential function will be provided in the same figure left side. There is a difficulty in verifying this through stepping via all potential unilateral strategy change. For example, switching from (C, C) to (D, C) because of 1,

	C	D
C	-1, -1	-6, 0
D	0, -6	-4, -4

Payoff Matrix

	C	D
C	1	2.0
D	2	4

Potential Function

Figure 2.4 Prisoners dilemma with payoff matrix and a potential

$U_1(C, C) - U_1(D, C) = (-1) - 0 = -1$. Similarly, $F(C, C) - F(D, C) = 1 - 2 = -1$. The other strategy might be similarly verified. It must be noted that the potential function isn't unique.

2.6.2 Weighted Potential Games

For the definitions and explanation in the following section, the reader is referred to [106].

Definition2.2 (Weighted Potential Game). Game G is considered as weighted potential game in the case when potential function $F(S) : \mathbf{S} \rightarrow \mathbf{R}$ existing in a way that, $\forall i \in N$:

$$U_i(T_i, S_{-i}) - U_i(S_i, S_{-i}) = w_i(F(T_i, S_{-i}) - F(S_i, S_{-i})), \quad (2.5)$$

$$\forall S_i, T_i \in \mathcal{S}_i; \forall S_{-i} \in \mathcal{S}_{-i}$$

In which $(w_i)_{i \in N}$ constituting vector related to positive numbers, referred to as weights.

With regard to the weighted potential games, changes of players in the payoff because of their uni-lateral strategy deviations has been equal to changes in potential function (referred to as w-potential function in [67]) yet scaled via factor of weight. Each exact potential game has been weighted potential games with all the players have identical weights equal to 1. Comparably, (2.3) has been similar to the next condition for the continuous games.

That is, $\forall i \in N$:

$$\frac{\partial U_i(S_i, S_{-i})}{\partial S_i} = w_i \frac{\partial F(S_i, S_{-i})}{\partial S_i}, \quad \forall S_i \in \mathcal{S}_i; \forall S_{-i} \in \mathcal{S}_{-i}, \quad (2.6)$$

Even though being separately defined, the weighted potential games in addition to the exact potential games might be similar through appropriately scaling the utility functions.

2.6.3 Ordinal Potential Games

Definition 2.3 (Ordinal Potential Game). Game G is considered to be weighted potential game in the case when potential function $F(S) : \mathbf{S} \rightarrow \mathbf{R}$ existing in a way that, $\forall i \in N$:

$$U_i(T_i, S_{-i}) - U_i(S_i, S_{-i}) > 0 \leftrightarrow (F(T_i, S_{-i}) - F(S_i, S_{-i})) > 0 \quad (2.7)$$

$$\forall S_i, T_i \in \mathcal{S}_i; \forall S_{-i} \in \mathcal{S}_{-i}$$

It must be indicated that (2.7) might be equivalently rewritten in the following way.

$\forall i \in N$:

$$\text{sgn}[U_i(T_i, S_{-i}) - U_i(S_i, S_{-i})] = \text{sgn}[F(T_i, S_{-i}) - F(S_i, S_{-i})], \quad (2.8)$$

$$\forall S_i, T_i \in \mathcal{S}_i; \forall S_{-i} \in \mathcal{S}_{-i}$$

In which $\text{sgn}()$ representing signum function.

Dissimilar to the exact potential games, the ordinal ones might just be requiring that changes in potential function because of uni-lateral strategy deviations must be of the same sign as changes in utility function of the player, in a way that if the player i is gaining worse (better) utility from switching the strategies, this might result in decline (increase) in potential function F, and conversely.

$$\text{sgn} \left[\frac{\partial U_i(S_i, S_{-i})}{\partial S_i} \right] = \text{sgn} \left[\frac{\partial F(S_i, S_{-i})}{\partial S_i} \right], \forall S_i \in \mathbf{S}_i; \forall S_{-i} \in \mathbf{S}_{-i}, \quad (2.9)$$

2.6.4 Generalized Ordinal Potential Games

These games are considered as extension from the ordinal ones, as specified in [67].

Definition 2.4 (Generalized Ordinal Potential Game). Game G will be specified as weighted one in the case when potential function $F(S) : \mathbf{S} \rightarrow \mathbf{R}$ existing in a way that, $\forall i \in N$:

$$U_i(T_i, S_{-i}) - U_i(S_i, S_{-i}) > 0 \rightarrow (F(T_i, S_{-i}) - F(S_i, S_{-i})) > 0 \quad (2.10)$$

$$\forall S_i, T_i \in \mathbf{S}_i; \forall S_{-i} \in \mathbf{S}_{-i}$$

Majorly, decrease (increase) in the utility of a player because of their uni-lateral strategy deviations implying a decrease (increase) in potential function. Yet, the reverse isn't correct, dissimilar to the ordinal potential games.

2.6.5 Best-Response Potential Games

These games have been provided in [80].

Definition 2.5 (Best-Response Potential Game). Game G is considered as weighted one in the case when potential function $F(S) : \mathbf{S} \rightarrow \mathbf{R}$ existing in a way that, $\forall i \in N$:

$$\mathbf{B}_i(S_{-i}) = \arg_{S_i \in \mathbf{S}_i} \max F(S_i, S_{-i}), \forall S_{-i} \in \mathbf{S}_{-i} \quad (2.11)$$

In which $\mathbf{B}_i(S_{-i})$ representing the player i's best-response correspondence.

It must be indicated that the equality in (2.11) must be interpreted as 2 sets which have been equal.

2.6.6 Pseudo-Potential Games

The concepts related to these games [81].

Definition 2.5 (Pseudo-Potential Game). Game G is considered to be weighted one in the case when potential function $F(S) : \mathbf{S} \rightarrow \mathbf{R}$ existing in a way that, $\forall i \in N$:

$$\mathbf{B}_i(S_{-i}) \supset \arg_{S_i \in \mathbf{S}_i} \max F(S_i, S_{-i}), \forall S_{-i} \in \mathbf{S}_{-i} \quad (2.12)$$

Thus, it must be indicated that the group of the maximizers which are related to function F in terms with the strategy related to player i , whereas the opponent's strategies are constant, has been included in the best-response correspondence of player i . For the purpose of player i obtains one of their best responses, they must do this via maximizing pseudo-potential function F .

2.6.7 Nash Equilibrium Existence

The major concept is showing that the Nash equilibrium is existing in the potential games and has been an observation that *the group of the equilibriums in this type of games is tied to that of a similar interest game*, in which each of the players is maximizing the common potential function.

Theorem 2.1 [65]. In the case when potential function with regard to the ordinal potential game $= [N, S, \{U_i\}_{i \in N}]$, the set related to Nash equilibria of the G is coinciding with the group which is related to the Nash equilibriums for the identical interest game $G^+ = [N, S, \{F\}_{i \in N}]$.

$$\text{NEset}(G) \equiv \text{NEset}(G^+) \quad (2.13)$$

In which NEset representing the set of Nash equilibria related to the game.

Proof. Initially, assuming that S^* representing Nash equilibrium for G . Then, $\forall i$:

$$U_i(S_i^*, S_{-i}^*) - U_i(S_i, S_{-i}^*) > 0 \quad S_i \in S_i. \quad (2.14)$$

Through definition regarding the ordinal potential game (2.7), this result in, $\forall i$:

$$F(S_i^*, S_{-i}^*) - F(S_i, S_{-i}^*) > 0 \quad S_i \in S_i. \quad (2.15)$$

Therefore, S^* representing Nash equilibrium the for G^+ and, $\text{NEset}(G) \stackrel{a}{=} \text{NEset}(G^+)$ and conversely. In the case when F has maximum point in the S , then G has pure-strategy Nash equilibrium.

Theorem 2.2. *The next statements have been true.*

- *Each one of the finites (ordinal) potential games admit minimum single pure-strategy Nash equilibrium.*
- *Each one of the continuous (ordinal) potential games with strategy space S that is compact (bounded and closed) as well as potential function F is continuous admit*

minimum single pure-strategy Nash equilibrium. Also, in the case when F is strictly concave, Nash equilibrium will be distinctive.

2.6.8 Nash Equilibrium Convergence

Before, the presence of minimum single pure-strategy Nash equilibrium was established. The presented section is presenting how a player will be achieving Nash equilibrium in the potential games. The major concept is through sequential decision dynamics where the players are taking turns for acting in *sequence or in round-robin way*. Each one of the players will be selecting (in turn) novel approach on the basis of some decision rule, therefore create unilateral strategy deviations as well as inducing corresponding changes in potential function. In the case when the changes are representing improvements in the function's value, one is expecting *series of improvements which is driving the game towards one of its equilibria* [69].

2.6.9 Considerations of the Utility Function

A number of the characteristics are defined to be beneficial to construct the games utility functions turning out to be potential games. They are *separability, symmetry of observations* in addition to the *linear combinations amongst the utility functions*.

2.6.9.1 Separability

It must be observed that in the case when each utility function of the player has been separable in multiple terms with some structures, the game might be indicated for being exact potential game. The first idea related to separability is the *strategic separability*, indicating that the utility function might be decomposed to summation related to a term solely contributed via own strategy, also other term solely contributed via the joint strategy of opponents.

Definition 2.7. Game G has been strategically separable in the case when $\forall i \exists P_i : S_i \rightarrow \mathbf{R}$ as well as $\exists Q_i : S_{-i} \rightarrow \mathbf{R}$ in a way that:

$$U_i(S_i, S_{-i}) = P_i(S_i) + Q_i(S_{-i}). \quad (2.16)$$

Theorem 2.3. In the case when G has been strategically separable. Then, it might be considered as exact potential game with the next potential function

$$F(S) = \sum_{i \in N} P_i(S_i). \quad (2.17)$$

Proof. With regard to any of the unilateral strategy deviations related to arbitrary player i from S_i to T_i , we have

$$\begin{aligned} U_i(T_i, S_{-i}) - U_i(S_i, S_{-i}) &= P_i(T_i) + Q_i(S_{-i}) - P_i(S_i) - Q_i(S_{-i}) \\ &= P_i(T_i) - P_i(S_i). \end{aligned} \quad (2.18)$$

At the same time,

$$\begin{aligned} F(T_i, S_{-i}) - F(S_i, S_{-i}) &= P_i(T_i) + \sum_{j \neq i} P_j(S_j) - P_i(S_i) - \sum_{j \neq i} P_j(S_j) \\ &= P_i(T_i) - P_i(S_i). \end{aligned} \quad (2.19)$$

Ence, $F(S)$ is a potential function for G .

2.7 Reinforcement Learning

Through which players reach a desirable point (e.g., a Nash)

- Multi-agent or reinforcement learning are disciplines on their own
- Game theory is one of their major application
- Introduced by Auman in the 70s (Nobel prize)
- Generalization of a Nash equilibrium
- An arbitrator or coordinator exists and sends (private or public) signals to the players, helping them in picking their strategies
- Arbitrator need not be a smart entity, just a “signaling” point
- Correlated Equilibrium (CE) includes Nash and could be more efficient
- Loosely, CE now generates random joint probabilities rather than the conventional individual mixed strategies [25], [70].

The correlated equilibrium will be specified as correlated strategy such that

$$\sum_{s_{-i} \in S_{-i}} p(s_i, s_{-i}) [u_i(s'_i, s_{-i}) - U_i(s_i, s_{-i})] \leq 0. \quad (2.20)$$

For all $i \in N$, $s_i, s'_i \in S_i$, and $s_{-i} \in S_{-i}$

expected payoff received by a player i choosing strategy s_i at the correlated equilibrium has been over or equal to its expected payoff for choosing any other strategies' i . The set related to correlated equilibria has been closed, non-empty, as well as convex in each of

the finite games. Learning is essentially an iterative process occurs over time, players take actions at each time slot.

Every learning algorithm has 3 general phases:

- 1- Observing the environments at iteration t , that is providing a concept to the players on the way they are played in previous iterations, enhancing strategy $pk(n)$ on the basis of present observation.
- 2- Selecting action $ak(n)$ according to strategy $pk(n)$.
- 3- Learning ends when the strategy vector converges to equilibrium following finite number of iterations Best response dynamics are the simplest form of learning.

2.7.1 Best response

is useful to find a pure strategy Nash, Iterative process (parallel or sequential). Every player observes actions of other players, Player choose the action $ak(n)$ that is optimizing its utility, providing the actions of players in parallel case, players optimize given the actions at time $n-1$.

2.7.2 Fictitious play

Is the simplest form of learning for mixed strategies? At each iteration n , player observes the past actions of all other players at $n-1$. Empirical frequency (belief) updates (basically count how many times an action has been used). Using the beliefs, each one of the players will be choosing actions that are maximizing the expected utility in terms of other player's beliefs. Can be sequential or parallel.

2.8 Regret matching

Does not follow the utility maximization rules of FP and BRD. The players now “minimize” the regret of not playing a certain action:

$$r_{k,A_k^{(n_k)}}(n) = \frac{1}{n-1} \sum_{t=1}^{n-1} (u_k(A_k^{(n_k)}, \mathbf{a}_{-k}(t)) - u_k(a_k(t), \mathbf{a}_{-k}(t))). \quad (2.21)$$

Player is assumed to be able to measure or evaluate the utility under different actions at time n . The action taken is according to the probability distribution found by normalizing a ‘regret vector’ [82] [83].

There must be a representation related to matrix game with n-player $p := \{p_1, \dots, p_n\}$. Finite action set A_i with regard to each one of the players $p_1 \in p$, as well as utility function $U_i : A \rightarrow \mathbf{R}$ for each one of the players set A_i for each player $p_1 \in p$, in which $A := A_1 \times \dots \times A_n$.

Regret matching must be introduced, from [71], where players are choosing their actions on the basis of their regret for not selecting specific actions in past steps.

Defining the regret related to player p_i for action $a_i \in A_i$ at time t as

$$R_i^{a_i}(t) = \frac{1}{t} \sum_{\tau=1}^{t-1} (U_i(a_i, a_{-i}(\tau)) - U_i(a(\tau))). \quad (2.22)$$

Put differently, average regret of player p_i 's for $a_i \in A_i$ might be representing average enhancements in the utility in the case when selecting $a_i \in A_i$ in all the past steps as well as the actions of other players when un-altered.

Each one of the players p_i use the regret matching computes $R_i^{a_i}(t)$ with regard to each one of the actions $a_i \in A_i$ with the use of recursion.

$$R_i^{a_i}(t) = \frac{t-1}{t} R_i^{a_i}(t-1) + \frac{1}{t} (U_i(a_i, a_{-i}(t)) - U_i(a(t))). \quad (2.23)$$

It must be inodiated that at each one of the steps $t > 0$, player p_i is updating all the entries in the average regret vector $R_i(t) := [R_i^{a_i}(t)]_{a_i \in A_i}$. For updating the mean regret vector at time t . it has been adequate for player p_i to observe (along with actual utility that is received at time $t-1$. $U_i(a(t-1))$) his hypothetical utilities $U_i(a_i, a_{-i}(t-1))$, for all $a_i \in A_i$, that might be received in the case when he had selected a_i , (rather than $a_i(t-1)$), also all the other actions of other players $a_{-i}(t-1)$ are unaltered in step $t-1$.

With regard to the regret matching, a player p_i is computing the average regret vector, $R_i(t)$., then choosing action $a_i(t)$, $t > 0$, on the basis of probability distribution $p_i(t)$ specified as:

$$p_i^{a_i}(t) = \Pr[a_i(t) = a_i] = \frac{[R_i^{a_i}(t)]^+}{\sum_{\tilde{a} \in A_i} [R_i^{\tilde{a}}(t)]^+} \quad (2.24)$$

For any of the $a_i \in A_i$, indicating that the above-mentioned denominator has been positive; or else, $p_i(t)$ has been uniform distribution over the A_i ($p_i(0) \in \Delta(A_i)$ remains arbitrary). A player that applies regret matching is selecting specific action at any one of

the steps with the probability considered to be proportional to average regret for not selecting the certain actions in past steps. In the case when all players are using regret matching, empirical distribution which are related to joint actions converge to the set related to coarse correlated equilibria (comparable results hold to various regret-based adaptive dynamics); see [71]. It must be indicated that this doesn't mean that the action profiles $a(t)$ are going to be converging, nor indicating that the empirical frequency values of $a(t)$ is going to converge to point in $\Delta(A)$.

2.8.1 Coarse Correlated Equilibriums and No-Regret

The connection of the set of coarse correlated equilibrium to notion of regret is strong, since the percentage at which all the players select joint action profile $a \in A$. Up to time $t - 1$, i.e.,

$$z^a(t) = \frac{1}{t} \sum_{\tau=0}^{t-1} I\{a(\tau) = a\}. \quad (2.25)$$

Assume that $z(t)$ indicates empirical frequency vector that is created via components $\{z^a(t)\}_{a \in A}$. The dimension of $z(t)$ representing the cardinality of set A , i.e., $|A|$. And $z(t) \in \Delta(A)$.

Comparably, assuming $z_{-i}^{a_{-i}}(t)$ is the stage's percentage at which players other than, player p_i selected joint action profile $a_{-i} \in A_{-i}$ up to time $t - 1$, i.e.,

$$z_{-i}^{a_{-i}}(t) = \frac{1}{t} \sum_{\tau=0}^{t-1} I\{a_{-i}(\tau) = a_{-i}\}. \quad (2.26)$$

Which, given $z(t)$, might be specified in the following way:

$$z_{-i}^{a_{-i}}(t) = \sum_{a_i \in A_i} U_i(a_i, a_{-i}) z^a(t), = \frac{1}{t} \sum_{\tau=0}^{t-1} U_i(a_i, a_{-i}(\tau)). \quad (2.27)$$

That is the average utility which the player p_i received up to time $t - 1$. Also, the expected utility regarding player p_i for any action $a_i \in A_i$ is as follows:

$$z_{-i}^{a_i}(t) = \sum_{a_{-i} \in A_{-i}} U_i(a_i, a_{-i}) z_{-i}^{a_{-i}}(t), = \frac{1}{t} \sum_{\tau=0}^{t-1} U_i(a_i, a_{-i}(\tau)). \quad (2.28)$$

That has been the average utility which player p_i might receive up to time $t - 1$ in the case when player p_i played the action a_i , then all the previous time periods indicated that all

actions of other players are un-altered. Thus, regret of the player p_i for action $a_i \in A_i$ at time t might be indicated as follows:

$$R_i^{a_i}(t) = (U_i(a_i, z_{-i}(t)) - U_i(z(t))). \quad (2.29)$$

In the case when all the players are using regret matching, then the empirical frequency $z(t)$ of the joint actions converge just about to the group of the coarse correlated equilibria. In the case when $z(t)$ representing coarse correlated equilibrium. Then, for any of the players $p_i \in p$ and any of the actions $a_i \in A_i$.

$$(U_i(a_i, z_{-i}(t)) \leq U_i(z(t)) \rightarrow R_i^{a_i}(t) \leq 0. \quad (2.30)$$

Thus, specifying that the empirical frequency concerning joint actions converges to the set regarding the coarse correlated equilibria corresponds to specifying that the average action of the player for any of the actions is going to asymptotically vanish.

Finally, in reinforcement learning, player follow a certain behavioral rule. Action set is assumed to be finite, achieved utility has been bounded. Each one of the players might be periodically observing their achieved utility. The concept of RL is that the action which lead to high utility observation in the stage n is granted with high probabilities in game stage $n + 1$, and conversely. JUSTE-RL: utility as well as actions are estimated based on Observations. BRD, FP, and RM, the players must be able to observe. ALL actions of other players => large overhead, particularly in a wireless network. This is where RL and JUSTE-RL have an advantage: they only need an observation /estimate /measurement of the utility and they do only algebraic computations. BRD, FP, and RM need to solve an optimization problem, so they are computationally more demanding [25].

2.9 Actor-Critic Approaches

The actor-critic approach is a type of Temporal Difference (TD) learning. They are characterized by a distinct memory structure for explicitly representing the policy apart from the value function [70]. The policy structure is referred to as the actor, since it is utilized for selecting actions, while the estimated value function referred to as the critic, since it is criticizing the actor's actions. The learning remains an on-policy: the critic should be learning about the critique in the case when the policy is followed by the actor. The critique takes the form of TD error, such scalar signal is the critic's sole output and drive all the learning in critic and actor, as indicated in Figure 2.5.

Actor-critic approaches have been considered as natural extension related to the concept of gradientbandit approaches to the TD learning as well as to full reinforcement learning issue. Generally, critic representing state-value function. Following every one of the action selections, critic will be evaluating the new state for determining if things worse or better than anticipated, such estimation is TD error:

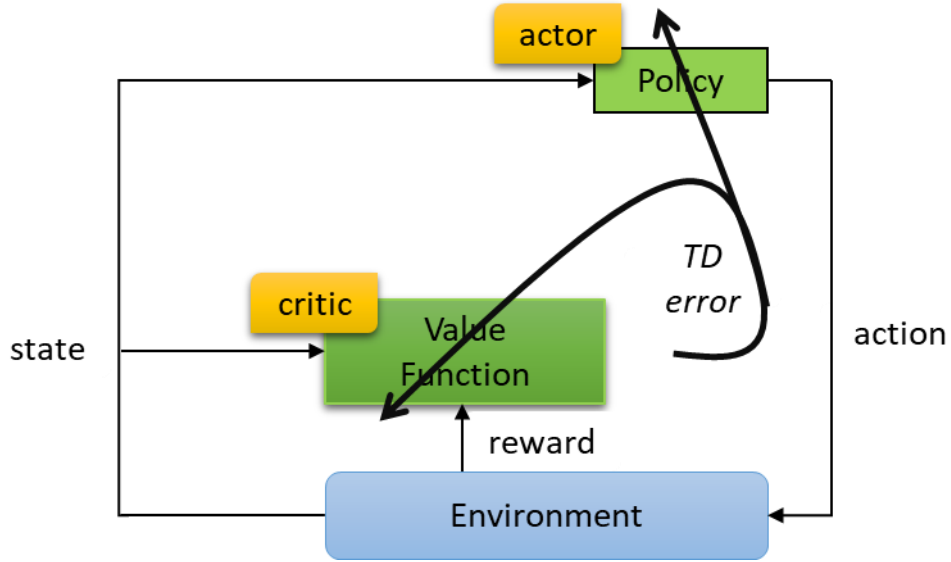


Figure 2.5 The actor-critic architecture [70]

$$\delta_t = R_{t+1} + \gamma V_t(S_{t+1}) - V(S_t), \quad (2.31)$$

In which V_t represent the value function achieved via critic at time t . The TD error might be applied for evaluating the selected action, the action A_t taken in state S_t . In the case when TD error has been positive, it is suggesting that the tendency for selecting A_t must be strengthened for the future, while in the case when TD error has been negative, it is suggesting that the tendency must be weakened. Assuming that the actions will be created via Gibbs softmax approach:

$$\pi_t(a|s) = \Pr\{A_t = a \mid S_t = s\} = \frac{e^{H_t(s,a)}}{\sum_b e^{H_t(s,b)}}, \quad (2.32)$$

In which $H_t(s, a)$ have been value at time t regarding actor's modifiable policy parameters, specifying a tendency for selecting each of the actions a in the case when each one of the states (s) at time t . After that, the weakening or strengthening indicated earlier might be achieved through decreasing or increasing $H_t(S_t, A_t)$, for example, by

$$H_{t+1}(S_t, A_t) = H_t(S_t, A_t) + \beta \delta_t \quad (2.33)$$

In which β represents a positive step-size parameter.

2.10 The Association between Wireless Networks and Games

Game theory can be categorized as non-cooperative or cooperative. With regard to non-cooperative games, agents are making independent decisions with coordinating their plans. Each one of the non-cooperative games includes set of the players, selfish utility function with regard to each one of the players and set regarding feasible strategy space also related to each one of the players. For solving problems in such theory, a study will be made for uniqueness, existence, stability within different strategies as well as gap of optimality. The major element related to non-cooperative game theory has been Nash equilibrium [72]. Therefore, with regard to the non-cooperative networks, agents have been included in non-cooperative games.

Cooperative games are games which are grouping of players which might be enforced for working together for minimizing their payoffs. After that, there has been competitions between player's coalitions, instead of between the individual players. With regard to cooperative networks, agents have been involved in cooperative games. With regard to cooperative game theory, network's wireless agents (users) are having agreements on the way of effectively and fairly sharing provided spectrum resources [73]. Wireless network's optimization has been extensive research area. The telecommunication systems like WLANs, LTE systems, cellular networks, as well as the cognitive radio systems were developed with the use of layered architecture-based models. OSI layers and connections with matching application fields have been: Wireless network's components could specify as game's components, figure 2.6 showing such connection.

Table 2.1 The layers of OSI and the connection with the corresponding application

Layer	Application Field
Transport	Call admission control, Load Control, Cell selection
Network	Routing
Data Link	Medium Access Control
Physical	Power control, Access Control, Cooperative Communication, MIMO System, Noise

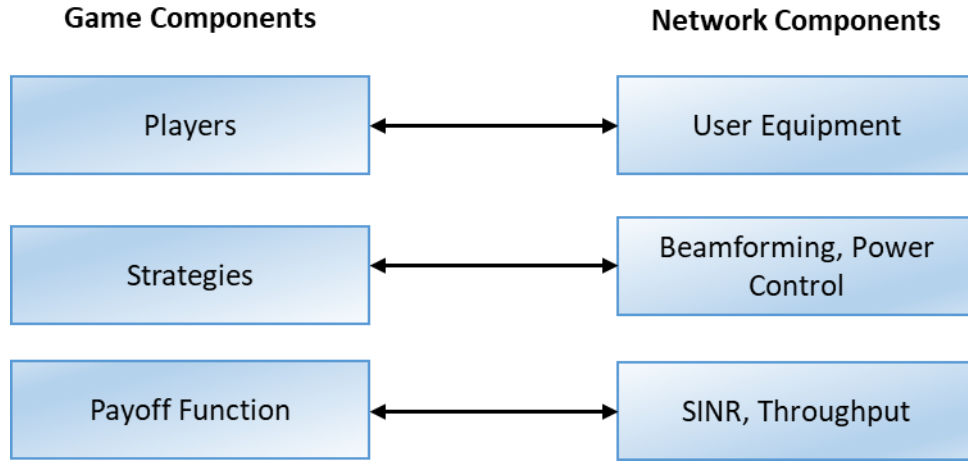


Figure 2.6 The connection between of the game theory and the wireless networks

Generally, the game theory could be specified in to 2 branches: non-cooperative as well as cooperative [25]-[74]. The non-cooperative study the strategic choices caused by interactions between the competing players, in which each one of players independently choosing their strategies to enhance their performance (utility) or to reduce their losses (costs). With regard to solving the non-cooperative games, a lot of concepts are presented like celebrated Nash equilibrium [75]. Also, the mainstream related to current study in the communication networks focusing on utilizing non-cooperative games in a lot of applications like the distributed resource allocations [76], congestion controls [77], power controls [78], as well as sharing of the spectrum in the cognitive radio, and so on. This requirement for the non-cooperative games result in a lot of books and tutorials specifying its usages and concepts in the communications, for instance, [79] as well as [80]. Whereas non-cooperative branch study the competitive scenarios, the cooperative branch will be providing analytical tools for studying the behavior related to the rational players in the case when cooperating. The major branch related to the cooperative games describing the formations related to the player's cooperating groups, indicated as coalitions [52], which might be strengthen the positions of player in the game. With regard to such tutorial, the attentions will be limited to the coalitional game theory, although a few of the other references might be involving other game types, like bargaining, within umbrella related to the cooperative games. Also, the coalitional games were extensively studied in various disciplines like political science or economics. Lately, cooperation has been novel networking paradigm which has dramatic impact on enhancing the performances from

physical layer [81]-[82] up to networking layers [83]. Yet, achieving cooperation in the largescale communication networks facing a lot of issues like fairness, efficiency, modeling, as well as complexity.

2.10.1 Game Theory for Telecommunications

With the fast evolution of internet and the deregulation related to companies of telecommunications, the area of research related to networking and telecommunications has been developed rapidly. The internet facilitated the possibility for a lot of geographically distributed autonomous units for interacting with each other as well as providing a lot of services. Furthermore, up-to-date telecommunication methods must be dealing with heterogeneous, large networks where a lot of autonomous agents are interacting. The game theory is applied to a lot of class relations for including non-humans and humans, such as the intelligent network devices.

Particularly, interactions between devices and users sharing common network resource might be modeled as games. Furthermore, the common issues of network management are QoS provisioning, traffic pricing, congestion and flow control, routing, load balancing, and so on, were active field of research regarding the game theoretic researches. With the use of game theoretic formulations, overall network performance might be specified [84]. The game theory can be considered as adequate tool to set the telecommunication networks due to the fact that it is dealing with the distributed optimizations – the individual users, specified for being selfish, making their decisions rather than being controlled via central authority. A lot of issues should be solved in the communication systems have been indicated for being NP-hard; thus, to solve such optimization problems centrally has been computationally impractical with the increase in network sizes. Due to the fact that game theory focusing on using distributed solutions to the system problems, the systems developed with the concerns about game-theory have been extremely scalable. Furthermore, the game theory assuming that all the players are seeking to maximizing their utility functions in a way that effortlessly rational. In the case when game players are computerized agents, there must be an assumption that the device is going to be programmed for maximizing anticipated value related to certain utility function. Therefore, strong rationality assumptions are considered to be extra reasonable with regard to the network devices in comparison to individuals. Thus, game theory was

adequate for solving the communication problems- in which ‘agents’ have been possibly to be computerized network devices – rather than solving the human problems [85].

2.10.2 Game Theory for analyzing Ad Hoc Networks

The mathematical analysis application on studying the wireless ad hoc networks was met with a limited degree of success as a result of the dynamic topology, complexity of traffic models and mobility, and the link quality unpredictability characterizing this type of networks [86]. The capability of modeling independent, individual decision makers who can act in possibly affecting all of the rest of the decision makers makes the game theory specifically useful for the analysis of ad hoc networks’ performance. In the present study, a wireless ad hoc network has been identified by a dynamic, distributed, self-organizing model. Every one of the network’s nodes has the ability to independently adapt its operations according to the current environment based on pre-determined protocols and algorithms. The analytical models for the evaluation of ad hoc networks’ efficiency were scarce as a result of the dynamic and distributed nature of this type of network. Game theory presents a set of the tools which can be efficiently utilized to model the interactions amongst the separate nodes in the ad hoc network.

In the game, the player can be considered as an independent decision maker, whose pay-offs are dependent on the actions of other players. Ad hoc network nodes are identified with the same characteristic. Such similarity results in strong mapping between the elements of the conventional game theory and the ad hoc network components. Table 2.2 includes a list of the characteristic ad hoc network game elements. The concepts of the game theory may be implemented for modeling the ad hoc network at the link layer (media access control), physical layer (wave-form and distributed power control adaptation), and the network layer (i.e. the forwarding of the packets). Applications at transport layer and above are present as well, even though they are less pervasive in literature.

An interesting question in all of these cases is how to achieve the provision of suitable incentives for discouraging the selfish behavior. In general, selfishness is disadvantageous for the general performance of the network; for example, an increase in the power of the node with no regards for the interferences that it can cause on the neighboring nodes (layer 1), a node’s immediate retransmission of a frame in collision

cases with no case of going through a phase of the back-off (layer2), or the node's refusal in forwarding the packets for the neighbors (layer3). In the following section, game-theoretic models for those 3 layers will be outlined. However, first, some advantages and drawbacks in the application of the game theory for studying ad hoc networks will be discussed.

Table 2.2 The layers of OSI and the connection with the game theory

Component of a game	Element of an ad hoc network
Players	Nodes in the network
Strategy	Action related to the functionality being studied
Utility function	Performance metrics

A question of interest in all those cases is that of how to provide the appropriate incentives to discourage selfish behavior. Selfishness is generally detrimental to overall network performance; examples include a node's increasing its power without regard for interference it may cause on its neighbors (layer 1), a node's immediately retransmitting a frame in case of collisions without going through a backoff phase (layer 2), or a node's refusing to forward packets for its neighbors (layer 3). In the next section, we outline game-theoretic models for these three layers. Before that, however, we discuss some of the benefits and common challenges in applying game theory to the study of ad hoc networks.

2.10.2.1 Advantages of the application of game theory in the ad hoc networks

The area of game theory presents some advantages as one of the tools of the analysis of the distributed protocols and algorithms for the ad hoc networks, 3 of those advantages have been highlighted below:

- i. Distributed system analysis: Game theory has allowed investigating the presence, distinctiveness and convergence to an operating point of the steady state in the case where the nodes of the network carry out independent types of adaptation. Which is why, it plays the role of a strong tool for the rigorous distributed protocol analysis.

- ii. Designing incentive models: the design of the mechanism is a game theory field which is concerned with the way of engineering the incentive mechanisms which will be leading self-interested, independent participants in the directions of the required results from a system-wide viewpoint.
- iii. Cross layer enhancement: usually, in the ad hoc network games, the decisions of the nodes at a specific layer are taken while aiming to optimize the efficiency at some other layers. With the suitable action space formulation, the game theoretic analysis is capable of providing the insights about the cross layer enhancement methods.

2.10.2.2 Difficulties in applying the game theory to the ad hoc network

Using game theory in the analysis of ad hoc networks' efficiency has a set of difficulties. Three especially challenging aspects have been discussed below:

- i. **Rationality Assumption:** Game theory has been based upon the theory that the player acts in a rational manner, in the sense which every one of the players has objective function which it attempts at optimizing, considering the imposed restrictions on its options of the actions with the conditions in game. Even though the nodes in the ad hoc networks may be programmed for the purpose of acting rationally, the outcomes of the steady state of the rational behaviors do not require being socially favorable. In fact, one of the main game theory contributions is the fact that it strictly illustrates that the objective-maximizing, individually rational behavior doesn't have to result in the socially optimum states.

The theory of the perfect rationality, on a few of the practical cases, doesn't provide a precise reflection of the empirically observed behaviors (for instance, widespread availability of the peer-to-peer networks of file sharing with the unavailability of any schemes of punishment/reward). The study which has been presented by [87] has considered a NE extension idea for the purpose of the accurate modelling of the nodes slightly deviating from the projected optimum behaviors. Such weakened rationality form is referred to as the near rationality.

- ii. **Utility functions option:** It is hard assessing the way the node values various performance levels and the tradeoffs that it is prepared to be making. The issue

has been worsened by the insufficiency of the analytical models mapping every node's available actions to the metrics of the higher layer like the throughput.

- iii. The rational cases need complicated models: The ad hoc networks' dynamic nature results in noise or imperfection in the actions which are observed by the node. This type of imperfection requires being modeled with rationally complicated imperfect information games and/or imperfect monitoring games. Moreover, wireless channel model modeling and the interactions amongst the protocols at various layers includes complicated and, in some cases, nonlinear mathematical analyses.

2.10.2.3 Physical layer

Selecting a suitable signaling wave-form and the distributed power controls are adaptations of the physical layer which could be adopted by nodes. From the viewpoint of the physical layer, the efficiency is, in general, an effective signal-to-interference-plus-noise ratio (SINR) function at node(or nodes) of the interest. In the case where the network's nodes respond to the variations in the perceived value of the SINR through the adaptation of the signal, an interactive decision making procedure of the physical layer takes place. Such adaptation of the signal may take place in the level of the transmit power and the wave-form of the signaling (i.e. frequency, modulation, and band-width). The precise adaptation structure is affected as well by various factors controllable in an indirect manner at physical layer, which includes the environmental losses of the path and the processing abilities of node (or nodes) of interest.

2.10.2.4 Power control

Although tightly relate to the cellular network types, the power control is often applied to the ad hoc network because of the possibly important gains of efficiency which have been accomplished in the case where the nodes restrict their levels of power [88]. The discussion below can be applied to a number of the suggested models of the distributed power controls. Even though not all of those works have adopted a game theoretic method, the various suggested algorithms' distributed nature lends itself to game theory applications.

In the study which has been conducted by [89], an algorithm for the performance of the distributed power controls in the networks of 802.11 has been explained. The authors have permitted using 10 various levels of power and incorporating the important signaling to the RTS-CTS-DATA-ACK frame exchanges. Every one of the nodes performs the communication with the neighboring ones and selects a transmission level for every one of the neighbors in a way that minimal signal power which is necessary for the adequate performance has been accomplished. In such case, every one of the nodes may be modeled as an attempt towards the achievement of a wanted value of the SINR. Even though it has not been taken under consideration in the study conducted by [90], this may be modeled with the use of several scenarios of connection reception as has been proposed in [91], or every one of the connections may be assumed as a separate entity in the scenario of the fixed assignment.

An analogous approach was suggested in [92], in which an extra channel has been included for the power controls. Similarly, in [93] “Noise Tolerance Channels” have been introduced, which are similar to the channel of the power control, however, rather than permitting every one of the nodes to declare its “noise” tolerance amount, the additional interferences which may be afforded with no loss of the currently received signals. Other researches, like [32], additionally refined the issue of the ad hoc power controls through the introduction of the beamforming consideration.

2.10.2.5 Adaptation of the Wave-form

The adaptation of the wave-form in the ad hoc network includes selecting a wave-form by the node in a way that reduces the interference at the receiver. Interference at receiver is a function of user’s wave-form correlation with other users’ wave-forms in the network. In addition to that, generally, individual nodes which play a role in the transmission have little or no knowledge on the interference environment of the receiver. Which is why, for the sake of minimizing the overhead of the adaptation, algorithms of the distributed wave-form adaptations requiring minimum feedback amounts between the receivers and the transmitters require being developed for those types of network. Game theory is capable of providing useful information to such type of scenarios.

Earlier works about the avoidance of the interference has been focused on the systems of the single-receiver. An algorithm of the avoidance of the distributed interference for

synchronous CDMA system up-link with one base-station has been presented by [94]. In such method, every one of the users performs a sequential update of their sequence of the signature for improving its value of the SINR at base-station. The sequences of the signatures represent the code-on pulse spreading codes with the chips which take any value in complicated plane. Such iterative algorithms (in which the user greedily increases his value of the SINR) is converged to a group of the sequences maximizing the system's sum capacity [95]. In addition to that, such method has been generalized to a case in which the nodes are capable of adapting their approaches of modulation/demodulation with the use of a generalized method of the signal space. Other extension types comprise sequence adaptations in the asynchronous systems of the CDMA [96], multi-path channels [97] as well as multicarrier systems [98].

Using the concepts of the game theory provides a more sufficient greedy signature update approach analysis and it is helpful in deriving the conditions of the convergence. The game theory was utilized for showing that for one receiver system with 2 players any mixture of metrics (like the SINR or the MSE) and types of the receivers (like an MSINR receiver or a correlator) result in the game with the convergent solutions of the Nash equilibrium [98]. A framework of the game-theory for the analysis of the signature sequence adaptation and the power control in the synchronous systems of the CDMA has been presented as well by [99]. The characteristics of utility function which is related to every one of the users in network ensuring the presence of the Nash equilibrium for power and game of wave-form adaptation have been characterized, with the SINR which possesses those characteristics.

As a result, the convergent Nash equilibriums appear to be existing in the games of the greedy wave-form adaptation in one centralized receiver scenario. None-the-less, in the networks with several distributed receivers, applying identical methods of the greedy interference avoidance will not result in stable NEs ([100]) because of the mutual interference asymmetry between the users at various receivers (for example, the user will cause greater interferences at the neighboring receiver compared to it at a farther receiver). Which will lead to the user to adapt the sequences in the conflicting manners. Which will show that the greedy methods of the interference can't be extended to the ad hoc networks in a direct manner. Frameworks which are based upon the possible game theory like the theory which has been described in this study may be utilized for the

construction of the games of the convergent wave-form adaptation in this type of the scenarios. It is advised referring to [85] for a more thorough discussions. A potential game [65]-[67] is a game of the normal form in a way that all utility function changes of any of the players as a result of the unilateral deviations by that player is reflected in a corresponding manner in global function which is known as a potential function. The presence of such function will make such game type simple for the analysis and giving a framework in which the user is capable of serving the greater good through following their best interests, in other words, they are capable of maximizing global utility through merely attempting at the maximization of their utility types. Which is why, it may result in the simple formulations of the game in which the maximization of the users' utility enhances a measure of the global network efficiency as well. There are numerous various potential game types, of which precise and ordinal possible games have been taken under consideration in the present section. Ordinal and precise potential games have a beneficial characteristic of the convergence: which is, the game players are assured to be converging to an NE through playing their optimal responses.

Mathematical analysis applications to the wireless ad hoc network has been met with a limited level of the success, because of the traffic and mobility models' complexity, in combination with dynamic topologies and link quality unpredictability characterizing this type of the networks. The emerging researches in the game theory which is applied on the ad hoc networks has shown a great deal of potential for helping understanding the complicated types of interaction between the nodes in such highly distributed and dynamic environments. Game theory application for the analysis of the issues at a variety of the protocol layers in the ad hoc networks is at the development stages, with the work bulk which has been performed in the last years. The emphasis was put on the maximization of the throughput with the use of the approaches of the random access for wireless media, and on the development of the robust approaches for dealing with the selfish behaviors of the nodes in the forwarding packets. Other fields to which the game theory was implemented comprise the distributed control of the power as well as avoidance of the interference.

OPTIMIZED INTELLIGENT DESIGN FOR SMART SYSTEMS HYBRID BEAMFORMING AND POWERADAPTATION ALGORITHMS FOR SENSOR NETWORKS DECISION-MAKING APPROACH

3.1 Introduction

Ad Hoc MIMO communication systems are considered to be the foundation of next generation of the wireless communication systems Massive MIMO. Furthermore, the Multi-user-MIMO (MU-MIMO) boosting development and design regarding the Massive MIMO technology [1]. Also, the efficiency of MIMO communication systems depending on adaptability regarding the transmit parameters like the modulation methods, transmit power, beamformer selection, transmission rate, and so on. Beamformer selection's design is of high importance in adaptive wireless communication systems. With regard to MIMO, the approaches of beamforming have been developed for various network types like ad hoc, cellular, as well as point-to-point [2]. A lot of the beamforming approaches were developed for addressing challenges associated to all of these networks. Furthermore, conventional approach of beamforming showing throughput maximization, power control, as well as capacity enhancement particularly with regard to the cellular and point-to-point networks. With regard to the MIMO adhoc networks, distributed beam-forming solutions are showing system throughput enhancements as well as energy minimization, yet suffering from interferences as well as communication overheads. A lot of distributed beamforming techniques have been developed for minimizing interferences as well as communication overheads in literature. As indicated before, there have been 3 categories where beam-forming solutions provided for the MIMO. Furthermore, the communication-based point-to-point MIMO beam-forming solutions which have been specified in [3]-[6] also beam-formers as well as the linear pre-coders (i.e. Eigen-coders) suggested for the point-to-point MIMO

communication in [7]-[8]. Also, beam-forming algorithms have been developed for cellular networks in [9]-[11] reducing power as well as improving capacity related to single antenna mobile transmitters in addition to the array-equipped base stations. Power control and beamforming with regard to point-to-point as well as the cellular MIMO networks has been accomplished minimum overheads as well as challenges of interferences. Yet, ad hoc MIMO networks operating with no centralized controller as well as the moving nodes. With regard to MIMO adhoc networks, distributed beamforming approaches enhancing the throughput of network as well as minimizing energy consumptions [12]-[13]. The main challenge with the use of optimization-based solutions with regard to the ad hoc networks has been systematic as well as adequate research is required for examining overheads provided via beamforming algorithms that impacts the performance related to MIMO ad hoc networks. The distributed spatial beamforming approaches have been provided in [14]-[15] with regard to multiuser ad hoc MIMO networks within conditions of channel reciprocity. Yet, in these approaches, transmission overhead has been provided throughout power control, also at each one of the iterations. Yet, trade-offs related to overhead as well as performance isn't accomplished with these approaches in addition to convergence related to iterative algorithms wasn't totally examined.

Game theory can be considered as significant mathematical tool to study environments in which multiple players interact and make decisions, it is frequently talking about rational players (with the attempt of optimizing their interests) [16]-[17]. Furthermore, the game theory-based solutions were suggested convergence investigations with regard to significant problems in the wireless communications such as the joint code-division multi-access [18], distributed power control algorithms [19], as well as the optimum transmission signaling strategies [20]-[21]. Power adaptation as well as the game theory-based beamforming approaches developed for the multi-user adhoc MIMO network communications might be achieving power efficiency with lowest overheads. In a study conducted by [30], initial non-cooperative as well as cooperative game theory-based approaches developed with regard to joint channel in addition to the power control related to wireless mesh networks, also channel allocation in addition to the beamforming

related to the ad hoc networks has been examined. Yet, power reduction with the use of distributed algorithms as well as the transmit beamformer selections has been complicated task and therefore there is difficulty in formulating beamforming games with regard to the multi-user wireless communications. In a study conducted by [8], [32], the first try over the joint discrete transmit beam-forming as well as power adaptations have been developed with the use of non-cooperative and cooperative game theory-based solutions. Furthermore, de-centralized method developed to optimize transmit beamformer as well as the power adapting through the use of the local information with adequate computation burden within certain constraints related to the constant received target (SINR). Yet, to design optimized game theory-based method with regard to power adaptations as well as beamforming in the ad hoc MIMO systems remains complicated research issue. The two solutions were unsuccessful in achieving trade-offs between overhead and power minimization. In a study conducted by [8], first solution cooperative power minimization algorithm (COPMA) were successful in achieving power minimization, yet developed overheads as well as second non-cooperative solutions. Also, the regret-matching-based joint transmission beam-former and power selection game (RMSG) minimizing communication overheads, yet taking more iterations and power to converge. The presented paper will be optimizing RMSG as well as COPMA approaches for minimizing overheads as well as power consumptions. In a study conducted by [33] reinforcement learning (RL)-based algorithm has been utilized for determining the adequate policy to select between 2 distinctive approaches, the first has been the beamforming, whereas the other has been the power control for sensor array networks, through evaluating individual features related to each one of the approaches based on SINR threshold. However, the main obstacle related to RL has been selecting action (PC or BF) based on learning state in such condition (SINR), that has been specified with system requirements. Furthermore, Q-learning with epsilon greedy (ϵ -greedy) policy has been utilized in RL which has been trained with the use of offline technique. The methods of Artificial intelligence (AI) were specified and utilize in the problems related to power control, beamforming, as well as systems of MIMO wireless communications [35]-[37].

The main researches which are related to the presented study are as follows:

Enhanced Co-Operative Power Minimization Algorithm (ECOPMA) with regard to the MIMO Ad hoc networks has been suggested for overcoming the drawbacks of COPMA. This dissertation suggested cooperative approach with the use of potential game method where allocated power as well as beamformer related to each one of the users will be evaluated initially till convergence to steady state on the basis of Nash equilibrium approach. After that, dividing the users in the clusters as well as enabling them to converge at the same time for the purpose of minimizing overhead. Put briefly, in such condition, the users cooperating each other for reducing interference and power with the use of potential game theory as well as the Nash equilibrium.

For reducing ECOPMA's communication overheads, binary weight books have been utilized in spite of complex Grassmannian weight books, as the first one reducing overheads which are incurred through cooperative solutions.

Suggesting Reinforcement Learning based Power allocation and Beam-former Algorithm (RLPBA) that is related to the multi-user ad hoc MIMO systems. With regard to the RLPBA, optimized non-cooperative solutions developed with the use of Reinforcement learning game-based method where local information has been utilized for beamforming as well as the power adaption decisions. Also, reinforcement method has been suggested for reducing the number regarding the iterations, therefore transmit power for the convergence.

Wide-ranging experimental results as well as the comparative evaluations developed for ECOPMA in addition to RLPBA with the centralized and up-to-date non-cooperative and cooperative algorithms.

Section 3.2 will be providing algorithms for RLPBA and ECOPMA in addition to the suggested system model. Simulation results will be discussed in Section 3.3. Ultimately, conclusions and future works have been provided in Section 3.4.

3.2 Methodology

The presented work will be suggesting 2 approaches RLPBA and ECOPMA for addressing the problems related to power minimization with the least interferences as well as communication overheads with the guaranteed QoS that is related to

multiuser MIMO adhoc systems with constant constraints of the SINR. Furthermore, ECOPMA has been on the basis of possible cooperative games with the use of binary weight books instead of utilizing complex Grassmannian weight book for the purpose of reducing communication overheads. Also, ECOPMA has been comparable to COPMA [8] with the inclusion that is related to binary weight books. RLPBA has been considered as non-cooperative games-based power allocations as well as beamforming approach comparable to RMSG [8] with using reinforced learning for reducing power consumptions as well as the number of iterations to converge. Game theory problem and MIMO ad-hoc communication model will be provided in the section 3.2.1. Section 3.2.2 will be presenting the design that is related to centralized beamforming as well as power allocation method. ECOPMA design will be presented in section 3.2.3, while the RLPBA design will be described in the section 3.2.4.

3.2.1 System Model

Figure1 showing system model indicated from [8] that includes wireless adhoc systems with several antenna nodes pair within same channel. Also, interference which has been created via other pairs of nodes that operate on comparable channel. The total N number related to the node pairs with every one of pairs q include single transmit-receive wireless node. Also, each one of receiving and transmitting nodes have been equipped with the A antennas, each one of the nodes have beamformer pair (w_q, t_q) . Furthermore, the complex transmitted symbol stream has been $s_q \in \mathbb{C}$, while the received symbol stream has been $\hat{s}_q \in \mathbb{C}$. Therefore, received signal vector $r_q \in \mathbb{C}$ with regard to the q^{th} receiving node was evaluated as follows:

$$r_q = \sqrt{E_q} U_{q,q} t_q s_q + \sum_{j \neq q}^N \sqrt{E_j} U_{q,j} t_j s_j + n_q \quad (3.1)$$

In which $U_{q,j}$ denoting $A \times A$ MIMO channel which is between j^{th} transmitting node as well as q^{th} receiving node, also it is specified as quasi-static, also E_q has been power related to q^{th} transmission node. Also, additive white Gauss noise terms n_q are having similar co-variance matrices.

The worst condition has been specified in this study, where all pairs often have packets for transmission via wireless channel. Also, the network is specified for being

synchronous. Available codebook beamformers set with regard to q^{th} node pair has been specified via $\partial_q = \{t_q^1, t_q^2, \dots, t_q^Y\}$ with cardinality Y . Furthermore, transmit beam-former from the code-book chosen through receiving nodes as well as feeding back with the chosen beamformer index. Each one of the nodes could choose among the Y transmission beam-formers code-book. Assuming that t_q i. e. ∂_q chosen transmit beam-former that is related to q^{th} node pair. $\emptyset = [t_1, t_2, \dots, t_N]^A$ as well as $E = [E_1, E_2, \dots, E_N]^A$ have been indicated as transmit beamformer selection in addition to the transmission power vectors with regard to N node count. Also, $A \times A$ matrix related to interferences as well as noise covariance at the q^{th} receiving node has been:

$$R_q(\emptyset_{-q}, E_{-q}) = \sum_{j \neq q} E_j U_{q,j} t_j t_j^U U_{q,j}^U + \sigma^2 I \quad (3.2)$$

In which $\emptyset_{-q}$ as well as E_{-q} have been transmit beamformer in addition to the powers related to nodes except q . Also, the normalized receive beam-former at the q^{th} receiving node have been estimated as follows:

$$w_q = \frac{\widehat{w}_q}{\|\widehat{w}_q\|} \quad (3.3)$$

In which $\widehat{w}_q = R_q^{-1} U_{q,q} t_q$. SINR's outcome at the q^{th} receiving node because of required transmitter regarding q^{th} node pair has been:

$$\tau_q = \frac{E_q |w_q^U U_{q,q} t_q|^2}{\sum_{j \neq q} E_j |w_q^U U_{q,j} t_j|^2 + \sigma^2} \quad (3.4)$$

Therefore, the suggested approaches in this study aim for achieving target SINR via transmit powers adjustments. Thus, optimization problem related to this study is specified as follows:

The aim is reducing transmit energy related to all node pairs $q \in \{1, 2, \dots, N\}$ in the network within constraints related to the constant $SINR_{\gamma_0}$. The optimization problem will be defined in the following way:

$$\text{Minimize } (\emptyset, E) \sum_{q=1}^N E_q \quad (3.5)$$

Subjected to $\tau_q \geq \gamma_0$, $\|w_q\| = \|t_q\| = 1$,

In which $E_{min} < E_q \leq E_{max}$, also E_{min} as well as E_{max} have been minimum in addition to maximum transmit power.

Such problem has been specified in game theory method as game's normal form as follows:

$$\pi = (N, C, \{F_q\}_{q=1}^N) , \quad (3.6)$$

In which, N representing set of the players, C representing set related to available actions with regard to all the N players, also $\{F_q\}_{q=1}^N$ representing set related to the utility functions which players associating with their strategy. Actions $c_q \in C_q$ with regard to player q have been selections related to the transmit powers $E_q \in [C_{min}, C_{max}]$ as well as transmit beamformer t_q i.e. ∂_q . Thus, players in the game will be selecting adequate actions for enhancing their utility functions. Also, convergence point in the suggested conditions has been set of the strategies, set related to the beamforming selections $\emptyset = [t_1, t_2, \dots, t_N]^A$ as well as $E = [E_1, E_2, \dots, E_N]^A$ from which there won't be any player that deviate. That set of the strategies will be referred to as the Nash Equilibrium (NE) [30]. Furthermore, NE has been specified as set related to strategy profiles c from which there won't be any player that might be increasing their utility through unilateral deviations. NE utilized for deciding and changing strategy profile, whereas keeping actions related to the other players same. The presented study developed 2 scenarios related to node pairing like the non-cooperative and cooperative for obtaining optimum outcomes for satisfying objective function with definite convergence.

3.2.2 The Centralized Approach

Before specifying de-centralized solutions, the presented section will be formulating centralized solution with regard to the MIMO adhoc systems of communication. With the use of the centralized agents [42], the joint transmits beamformers as well as the matching transmit powers chosen for reducing antennas overall transmit power in the following way:

$$(\emptyset^*, E^*) = \arg \min_{\emptyset, E} \sum_{q=1}^N E_m(\emptyset, E_{-q}) \quad (3.7)$$

In which, $\emptyset^*$ as well as E^* representing optimal transmit beamformer in addition to the power solutions. Also, transmit power (Eq) q^{th} node pair have been evaluated as follows:

$$E_q(\emptyset, E_{-q}) = \frac{\gamma_o}{t_q^U U_{q,q}^U R_q^{-1} U_{m,m} t_m} \quad (3.8)$$

In such condition, centralized agent computers total power of the network which is related to γ^N likely beam-forming vector combination that lead complex tasks with regard to the large scale wireless adhoc networks. Furthermore, sever complexity invalidate centralized approach related to multiuser MIMO ad hoc systems. For solving this kind of tasks, the study will be introducing decentralized solutions.

3.2.3 ECOPMA

ECOPMA can be considered as one of the cooperative game-based solutions, in which nodes might be cooperative each other for the purpose of achieving optimal solution related to the beamforming as well as the adaptive power allocations with regard to the multiuser MIMO adhoc systems. As indicated before, ECOPMA has been comparable to COPMA [8] where utilizing both users paired in the clustering as well as the binary codebook for reducing computational overheads. With regard to this study, binary codebook which has a size 16 (specified as γ) code length as well as 4 (specified as A) has been code's dimensions [101], has been utilized.

With regard to the clustering mode, assuming that node pairs with comparable properties of transmit power have been grouped in to single cluster. Also, mobile users have been clustered for the purpose of enabling them to converge at same time for minimizing overhead and energy. In a study conducted by [102], it has been verified that multi-user case, there are 2 users paired in to the cluster result in transmit beamforming vector sharing as well as improving QoS performances with the minimum overheads as well as power consumptions. With regard to the ECOPMA, the optimum transmits power allocations in addition to the transmit beamformer has been cooperatively enhanced so that power consumptions in network has been reduced. Assuming each one of the users in q^{th} paired specified in to M clusters, in such case they will be sharing common transmit beamforming vector. Furthermore, q^{th} nodes pairs specified that it has been paired to the m^{th} cluster, $m \in [1, 2, \dots M]$. With regard to clustering, assuming that the channel conditions related to receive and transmit beam-forming vectors as: (1) zero-forcing (ZF) pre-coding at every one of the receiving nodes for removing inter-cluster interferences in addition to 2) signal alignment has been carried out at receiver between the users in same cluster. Thus, assuming $E_q^{m,m}$ as well as $\phi_q^{m,m}$ be the transmission power vectors in addition to the transmit beamformer selection vectors related to the q^{th} nodes pair across

m^{th} transmit as well as receive clusters. Therefore, the main functions related to ECOPMA as follows:

$$F_{\text{net}}(\emptyset, E) = - \sum_{m=1, q=1}^{M, N} E_q^{m, m}(\emptyset, E_{-q}^{m, m}) \quad (3.9)$$

Eq. (9) is going to be each one of user utility function

$$F_i(\emptyset, E) = F_{\text{net}}(\emptyset, E) = - \sum_{m=1, q=1}^{M, N} E_q^{m, m}(\emptyset, E_{-q}^{m, m}) \quad (3.10)$$

Special case related to possible games that are modelled in the presented work referred to as identical interest game [8], [42]. Thus, it will be simpler verifying that no less than single pure NE created through all identical interest games that are representing action profiles which are enhancing $F_i(\emptyset, E)$. ECOPMA method will be specified as follows:

Algorithm1: ECOPMA

1. **Inputs:**
 - k : specified iterations count
 - M : clusters count
2. Applying users clustering on every mobile user not considering user pairing
3. **FOR** every one of the clusters m in M ,
4. **Initialize:** For every one of the pairs q , initializing transmit beamforms, also the transmission powers:
 - 4.1. $\|w_q^{m, m}\| = \|w_q^{m, m}\| = 1, q \in N, m \in M$
 - 4.2. $E_q^{m, m} = E_{\max}, q \in N$
5. Repeat: randomly select q^{th} nodes pair with $1/N$ likelihood.
 - 5.1. Set $t_q^{m, m}(n) = t_q^{m, m}(n - 1)$ (current transmission beam-former for q^{th} nodes pair)
 - 5.2. Calculating $E_q^{current}$ with the use of Eq. (8)
 - 5.3. Randomly select transmit beam-former $t_q^{updated}$, also computing equivalent transmit power $E_q^{updated}$ with the use of Eq. (8) needed while utilizing the updated transmit beamformer.
 - 5.4. Form vector $[ID_q^m, E_q^{current}, E_q^{updated}]$ as well as broadcast every other node pair $j, j \in N$.

- 5.5. On receiving vector of data, for every j
- IF (E_j change because of interferences at j^{th} receiver)
- Every other node pairs set $E_j^{current} = E_j^{updated}$,
- Computing new transmission power and set as $E_j^{updated}$
- ELSE
- Unaltered $E_j^{current}$ and $E_j^{updated}$
- ENDIF
- Send back vector $[ID_j^m, E_j^{current}, E_j^{updated}]$ to node pair q
- 5.6. node pair q computers the entire network transmission power as $E_{current} = \sum_{q=1}^N E_q^{current}$ and updated power as $E_{updated} = \sum_{q=1}^N E_q^{updated}$ with $t_q^{updated}$
- 5.7. Update the pair of nodes q select $t_q^{updated}$ with the use of probability according on factor of smoothing ($\tau > 0$) assessed via $1/(1 + \exp((E_{updated} - E_{current})/\tau))$.
- 5.8. q^{th} node pair broadcast decision signal if the new transmitter beam-form has been maintained.
- 5.9. In the case when not kept, each one of other node pair j , $j \in m/N$ keep $E_j^{updated} = E_j^{current}$
6. Until specified iterations steps k count

ENDFOR

The smoothing factors' functionality has been obtained from [8] with the main contribution of that study article. Algorithm1 above illustrates differences between COPMA and ECOPMA with the use of clustering. ID_q^m represents the certain user distinct number belonging to q^{th} pair of nodes and the cluster of m^{th} .

3.2.4 RLPBA

The other suggested solution in the present study has been according to non-cooperative game theory-based method with regard to beamforming as well as adaptive power allocations in the multiuser adhoc MIMO systems with the use of reinforcement learning approach. The major goal is examining distributed learning

approach with regard to joint transmits beamformer as well as the power selection approach that requires just local information related to the updates for the systems of adhoc MIMO. Furthermore, the utility function that is related to the non-cooperative users utilized in this condition. In comparison to the cooperative solutions, q^{th} node pair will be only focusing on their power minimizations instead of total network power. Each of utility functions related to players is according to the selection related to the transmits beamformers as well as the power, also other selections of players related to beamformers in addition to transmit power via perceived interferences. The new solution related to the suggested (RLPBA) shows “rewards” related to choosing strategy or action [25], [70]. This work will be formulating non-cooperative game theory method with the use of Actor Critic Learning algorithm which is referred to as the Continuous Actor Critic Learning Automaton in the presented study for predicting and selecting beamformer and thus calculating new transmit power.

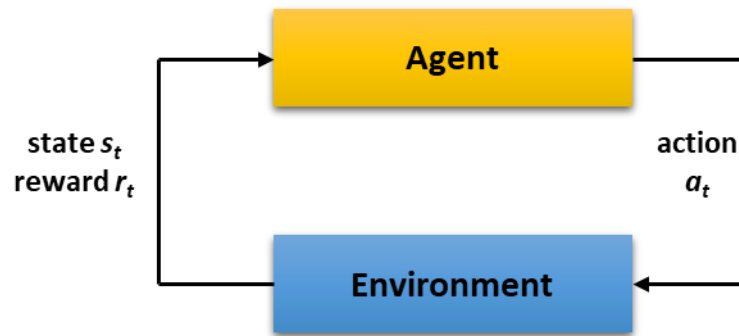


Figure 3.1 Environment and agent system interaction

Significant approach related to Temporal-Difference (TD) techniques has been the Actor-Critic that is according to separated memory structures for the purpose of describing policy independence in comparison to value functions (as contras with reward R_e rather than having short-term returns, value function expected regarding the long-term in addition to decreasing factor), in which the policy structure (action that is used by agent for evaluating next action plan according to current state) has been specified as actor, thus it is applied for choosing actions, and determining the value related to function recognized as critic, that criticize actions which are made

via actor. Also, critic must be observing and justifying if policy has been followed through the approach of actor or not [70].

As can be seen in the Figure 3.1, assuming that S denoting the number of the *states* needed which includes γ number of the transmit beamformer codebooks that is required through each node. Assuming vector $\hat{\partial}_q$ denoting all the *action set* with regard to the user q , i.e. $\hat{\partial}_q = \{t_q^1, t_q^2, \dots, t_q^\gamma\}$, in which $t_q(i)$ denoting transmit beamformer vector chosen via q^{th} users in the iteration i . Defining reward function $Re_q^{\hat{\partial}_q}(k)$ related to the q^{th} user with regard to action $\hat{\partial}_q$ at k^{th} iteration as follows:

$$Re_q^{\hat{\partial}_q}(k) = \sum_{i=1}^{k-1} \mu_q(\hat{\partial}_q, t_{-q}(i)) - \mu_q(t_q(i)) \quad (3.11)$$

Each one of the users q computing $Re_q^{\hat{\partial}_q}$ for each one of actions related to all previous steps in the case when all the other actions of players are unchanged. Each one of users q updating their reward function value related to each one of sets related to action $\hat{\partial}_q$ as follows:

$$Re_q^{\hat{\partial}_q}(k+1) = Re_q^{\hat{\partial}_q}(k) + \mu_q(\hat{\partial}_q, t_{-q}(i)) - \mu_q(t_q(i)) \quad (3.12)$$

Following update, selecting transmit beamformer $t_q(k)$ through evaluating the probability as follows:

$$P_q^{\hat{\partial}_q}(k) = \frac{Re_q^{\hat{\partial}_q}(k)}{\sum_{\hat{\partial}_q \in q} Re_q^{\hat{\partial}_q}(k)} \quad (3.13)$$

Each one of users q selecting strategy or action based on the result of $P_q^{\hat{\partial}_q}(k)$, whereas verifying decision condition as follows:

$$P_q^{\hat{\partial}_q}(k+1) > P_q^{\hat{\partial}_q}(k) \quad (3.14)$$

Based on transmit beamformer $t_q(k)$, new transmit power E_q has been assessed with the use of Eq. (8) on chosen $t_q(k)$. Algorithm 2 showing the already-indicated phases.

Algorithm2: RLPBA

Input
k : pre-defined iterations count
1. FOR $i = 1$ to k 2. FOR $q = 1$ to N 3. Computing reward value utilizing Eq3.11 4. Updating Reward table utilizing Eq3.12 5. Computing likelihood values utilizing Eq3.13 6. Take decision on $t_q(k)$ selection utilizing Eq3.14 7. Computing new transmission power for $t_q(k)$ utilizing Eq3.8 8. ENDFOR 9. ENDFOR

3.3 Results of Simulation and Discussions

The presented section will be providing performance analysis that is related to RLPBA and ECOPMA approaches with modern solutions like centralized optimizations, RMSG, as well as COPMA.

Whereas assessing these approaches, the study developed ad hoc networks with assumptions related to 5 (small) as well as 10 (large) homogenous pairs, while each one of them will have single transmitter as well as receiver node. Furthermore, the complete sets related to parameters have been specified for 5pairs as well as 10 pairs in the tables 3.1&3.2. With regard to COPM, Grassmannian code-book with size of $Y = 16$ with $A = 3$ antennas with regard to all the users, yet since Grassmannian code-book is considered to be complex, with regard to ECOPMA utilized binary code-book with size of $Y = 16$ with $A = 4$ antennas regarding every user in the presented study.

3.3.1 Evaluations of 5-Pair Wireless Ad hoc system

Table3.1 showing parameters of the simulation.

Table 3.1 Simulation parameters with regard to 5-Pairs wireless adhoc MIMO

Parameter	Value
Number of wireless ad hoc pairs	5
Size of network	30m x 30m
Constant Received SINR	10 dB
Grassmannian codebook	($\Upsilon = 16$, $A = 3$)
Binary codebook	($\Upsilon = 16$, $A = 4$)
$E_{\max}$	100 mW
$E_{\min}$	1 mW
Propagation channel	Radio propagation channel (path loss component is 4)
Predefined number of iterations (k)	120
Smoothing factor (For COPMA and ECOPMA)	$0.01/k^2$
Clusters (ECOPMA)	2

Based on table3.1 that has been developed for the small ad hoc network's evaluations. Total power consumption's performance, is demonstrated in the Figure3.2, showing comparative analysis related to the total power that has been consumed through the network with regard to the cooperative approaches COPMA as well as ECOPMA. The main aim of ECOPMA has been reducing overheads through decreasing the number of the iterations in comparison to COPMA that has been achieved in the results as can be seen in the figure3.2. It must be indicated that the performance of ECOPMA settle at global optimum combinations following 87 iterations in comparison to COPMA (with 93 iterations). Also, the decrease in iterations will be reducing communication overheads in addition to network's total power consumptions. ECOPMA performance has been enhanced because of

clustering as well as the simple binary codebook. In similar way, this work assessed non-cooperative distributed learning-based approaches in figure3.3. RLPBA developed for reducing power consumptions with decrease in iterations regarding optimum allocation solutions that are related to the network pairs. This work specified the benefits related to reinforcement learning approach over regret-based learning method in the RLPBA. The results that are related to RLPBA showing that it decreased total transmission powers with regard to the small wireless adhoc MIMO networks in comparison to the RMSG approach. It will be taking 110 iterations for converging the entire network transmission powers in comparison to the RMSG (120iterations).

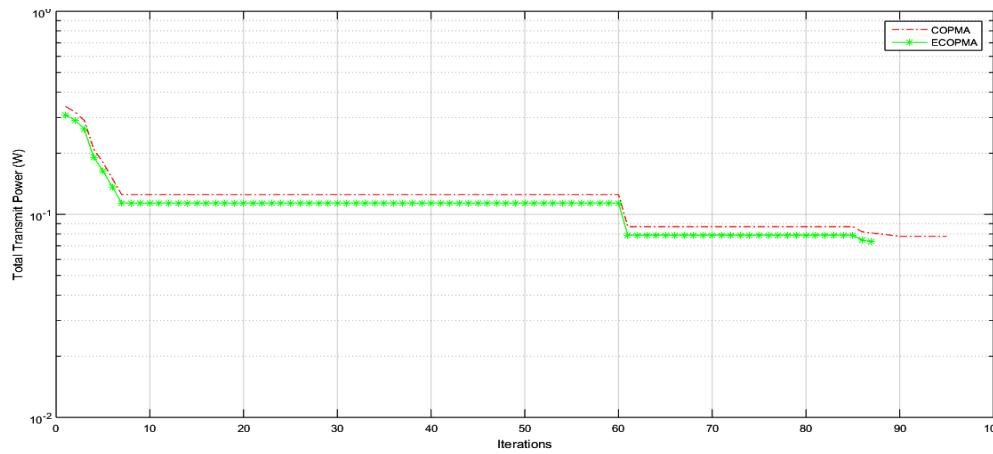


Figure 3.2 Evaluations of the total transmission power vs. iterations (N=5)

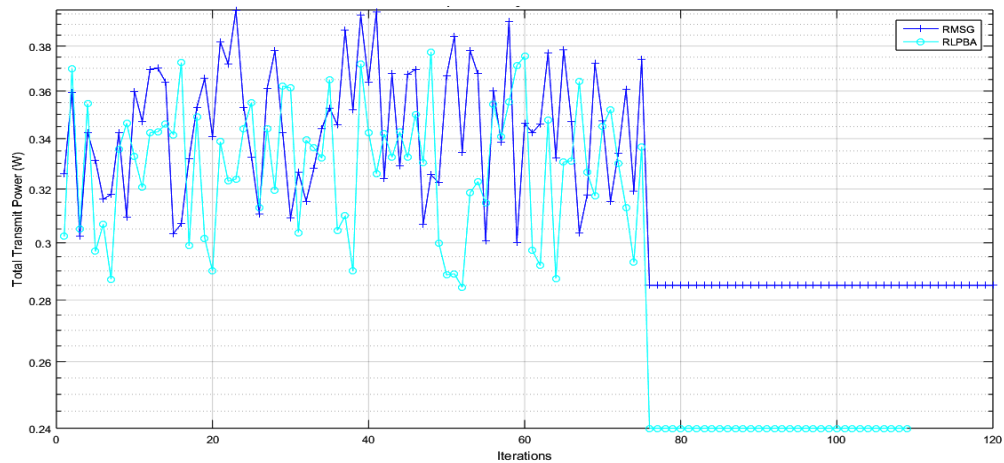


Figure 3.3 Evaluation of the total transmission power vs. iterations (N=5)

Figure3.4 showing comparative study regarding all approaches. It is showing that the network's total power is changing with the use of non-cooperative approaches

over 120 iterations. Furthermore, the cooperative approaches (ECOPMA and COPMA) showed more efficient performance of total transmission power reduction in comparison to the non-cooperative approaches (RLPBA and RMSG). Yet, cooperative approaches provided considerable overhead in comparison to the non-cooperative approaches. Also, updating task will be requiring reduced overhead related to the non-cooperative approaches. The suggested non-cooperative and cooperative approaches showed optimal performances in comparison to current solutions in the study.

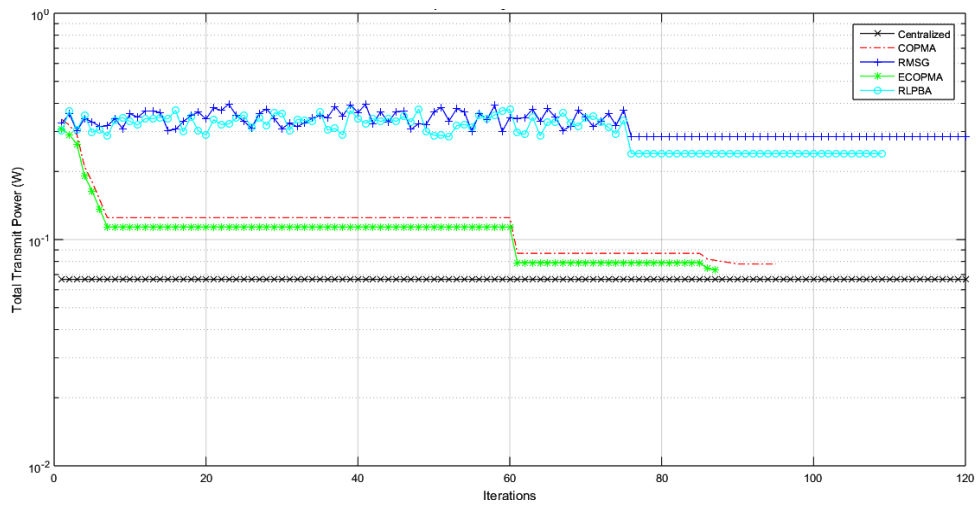


Figure 3.4 Total transmit power vs. iterations (N=5)

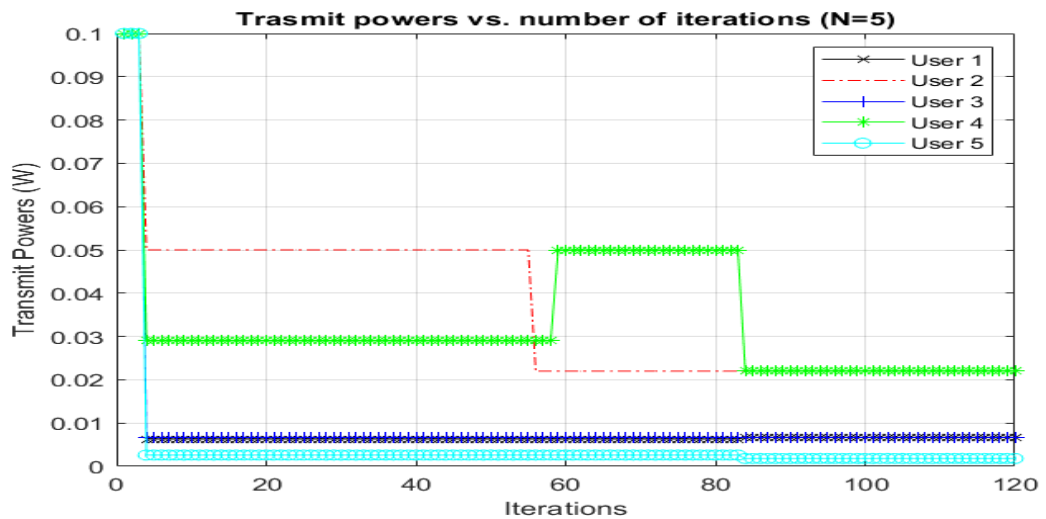


Figure 3.5 Transmit power vs. iterations with N=5

Figure 3.5 showing power trajectories in the ECOPMA with regard to each one of network's user pairs. As indicated in the Figure 3.5, each one of users will be starting

with highest power levels, at first (100mW), and after that iteratively updating the power according to ECOPMA's behavior until achieving NE.

Figure 3.6 showing changes in the probability mass function (PMF) that is related to the RLPBA approach evaluated via Eq. (3.13) following the iterations 1, 12, 50, as well as 100 related to single user. Initially, a user will select transmit beamformers that are having equal probability, after that changes based on working reinforcement learning.

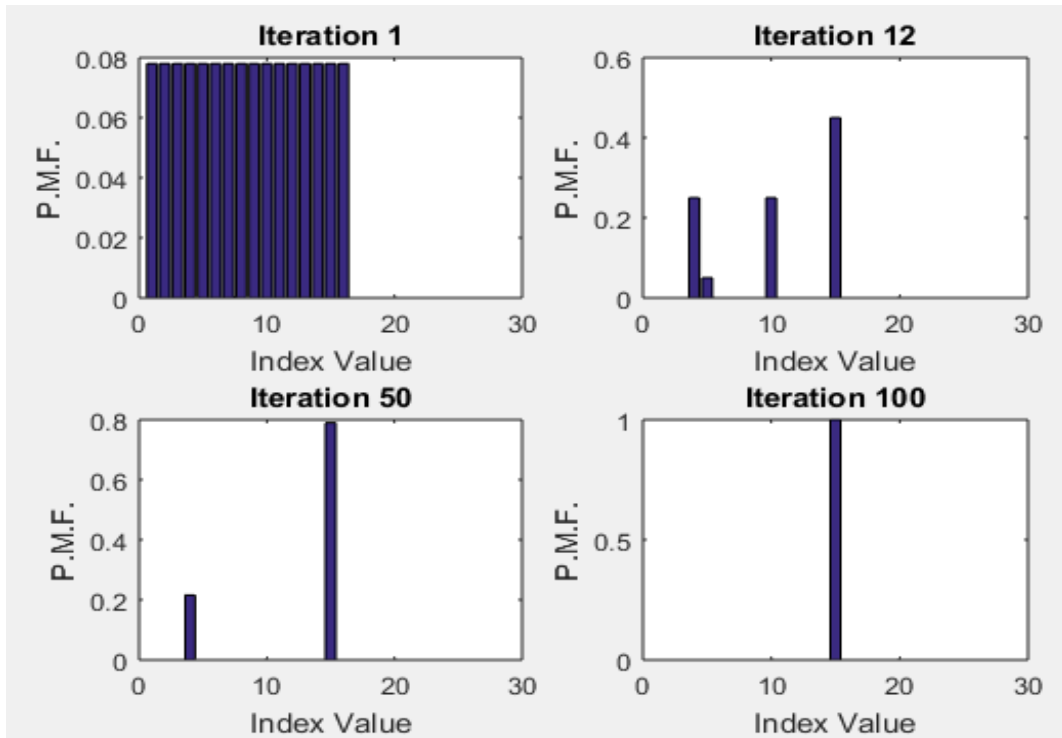


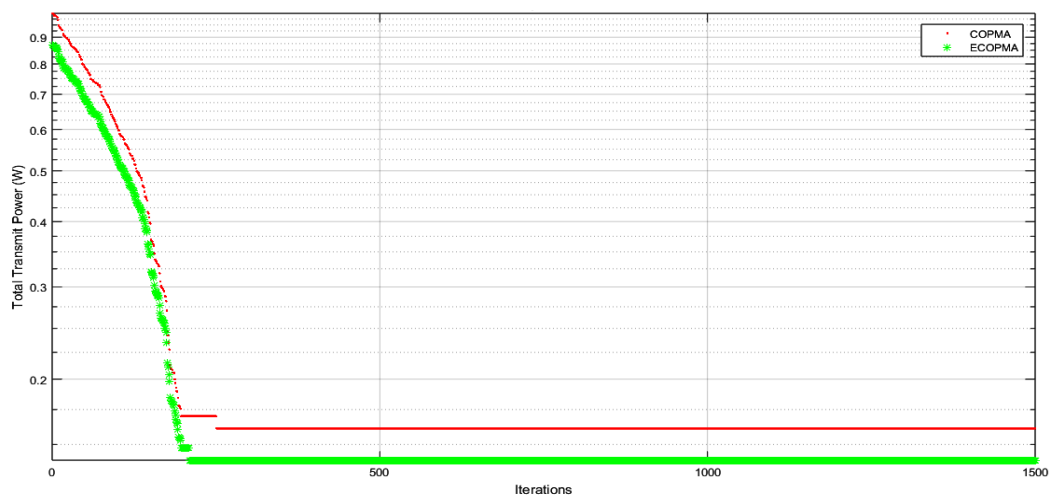
Figure 3.6 P.M.F. of RLPBA approach for single user (N=5)

3.3.2 Evaluations of 10-Pair Wireless Ad hoc system

Table 3.2 showing simulation parameters that are related to the large wireless ad hoc MIMO systems performances evaluation with the use of various approaches. As indicated in the table 3.2, smoothing factor, network area, in addition to the number of the clusters that are changed according to network's topology put to comparison with parameters of table 3.1. Comparable to the case of N=5, this study evaluated the performances related to non-cooperative, cooperative as well as all approaches in the figures 3.7-3.9 with regard to network's total transmission power.

Table 3.2 10-Pairs wireless ad hoc MIMO system Simulation parameters

Parameter	Value
Number of wireless ad hoc pairs	5
Size of network	100m x 100m
Constant Received SINR	10 dB
Grassmannian codebook	($\Upsilon = 16$, $A = 3$)
Binary codebook	($\Upsilon = 16$, $A = 4$)
E_max	100 mW
E_min	1 mW
Propagation channel	Radio propagation channel (path loss component is 4)
Predefined number of iterations (k)	1500
Smoothing factor (For COPMA and ECOPMA)	$200/k^2$
Clusters (ECOPMA)	4

**Figure 3.7** Evaluations of total transmission power vs. iterations (N=10)

Results are showing that utilizing suggested non-cooperative and cooperative approaches, overhead reduction as well as the total transmission power minimizations will be achieved in comparison to current non-cooperative and cooperative approaches. A suggested solution will be reducing the number of iterations for achieving NE and thus delivering maximum throughput in comparison to current methods. Also, centralized method isn't possible anymore in such case because of huge required strategy space [8], [42]. As can be seen in the figure 3.9, cooperative approaches showed decrease in the total transmission power

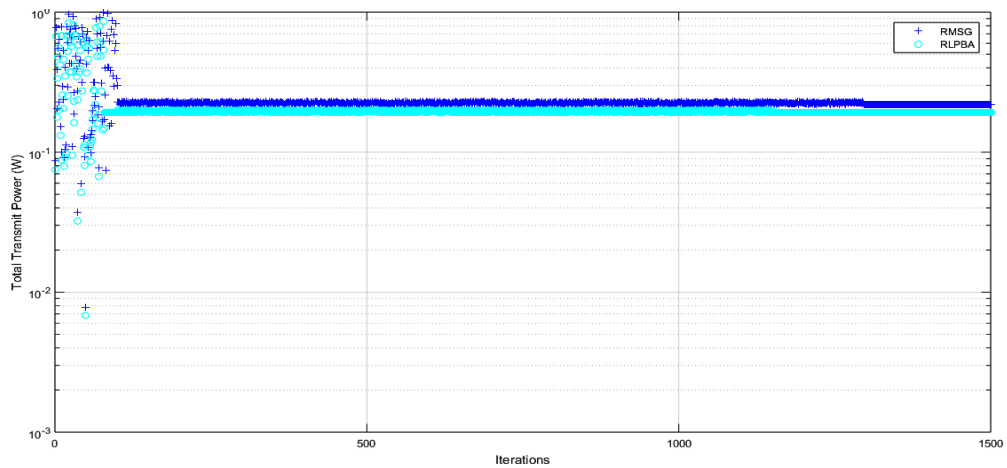


Figure 3.8 Evaluation of the total transmission power vs. iterations (N=10)

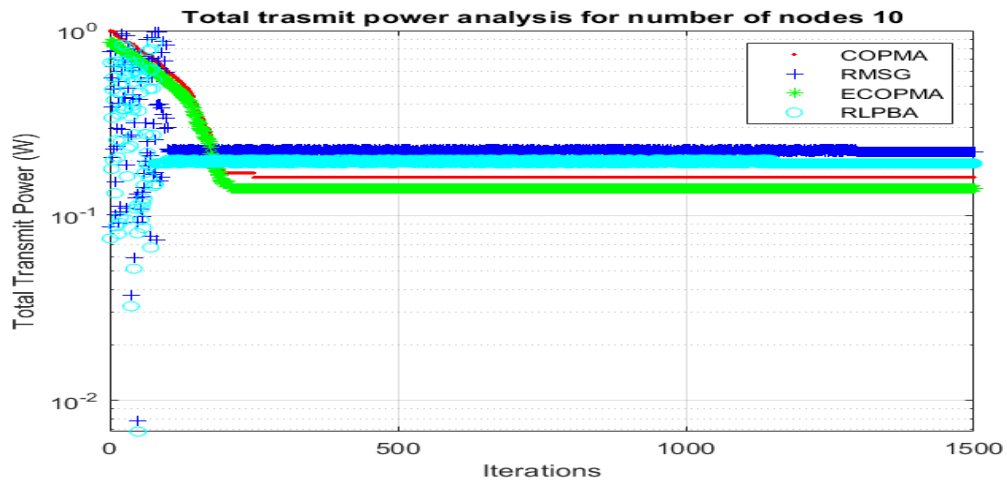


Figure 3.9 Total transmission power vs. iterations (N=10).

in comparison to the non-cooperative approaches as they were converged early. Furthermore, non-cooperative approaches are taking a lot of iterations for achieving NE step, therefore unsuccessful in reducing transmit power, yet requiring minimum

overhead in comparison to the co-cooperative solutions. With regard to $N=10$, the suggested solutions will be optimizing cooperative approaches. RLPBA decreased the number of iterations with regard to the convergence and therefore the total transmits power reductions in comparison to RMSG. Figure 3.10 showing variations in the P.M.F. related to RLPBA approach estimated via Eq 3.13 following iterations 1, 500, 1000, as well as 1500 related to single user in such case.

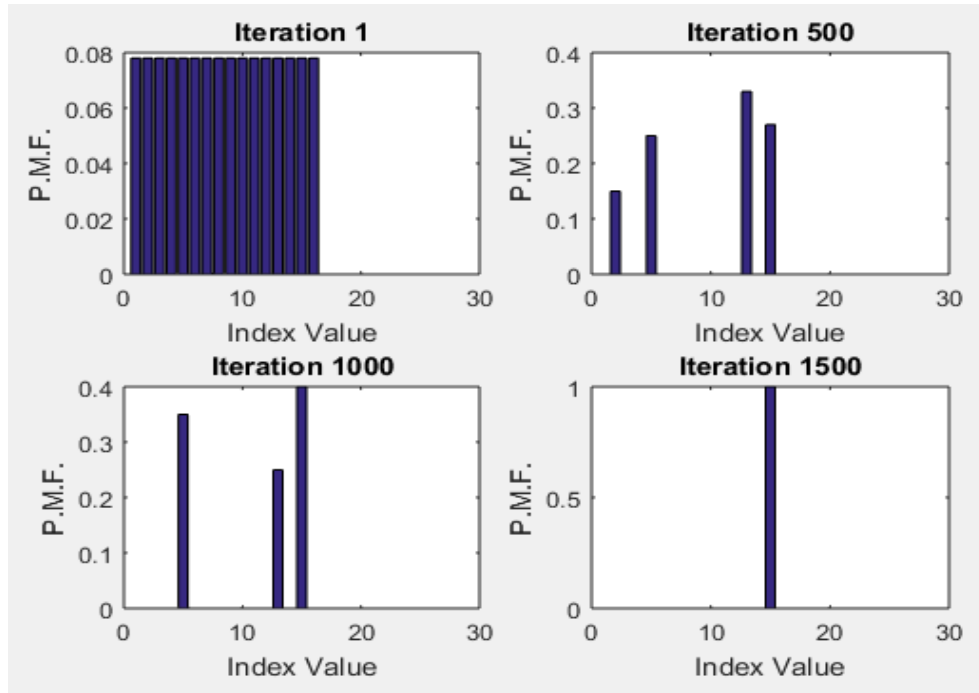


Figure 3.10 P.M.F. of RLPBA for single user ($N=10$)

The suggested solutions showed decrease in communications overheads in comparison to earlier approaches. Also, clustering with the binary code-book related to cooperative approaches helping in reducing communication overheads in comparison to COPMA as well as reinforcement learning helping in reducing communication overheads in comparison to RMSG methods.

3.4 Conclusions and Future Work

This study focused on designing beamformer selection in addition to its significant function in the adaptive wireless communication systems. Also, this work suggested 2 game theory-based algorithms for optimizing the performance that is related to the ad hoc wireless MIMO systems with regard to joint transmit powers in addition to transmit beamforming with the least power consumptions as well as overhead,

providing cooperative (ECOPMA) solutions with the use of clustering as well as binary codebook, also non-cooperative (RLPBA) solutions with the use of distributed reinforce learning. Furthermore, simulation results showing that the convergence properties related to the suggested approaches as well as their performances with respect to overall power minimizations, the rate of convergence, as well as network's communication overhead. The suggested solutions showed considerable performance in comparison to current approaches. With regard to future works, this study suggested examining the performance within various propagation channels as well as SINR constraints.

DISTRIBUTED COOPERATIVE AND NON-COOPERATIVE JOINT POWER AND BEAMFORMING ADAPTATION FOR MIMO SENSOR NETWORK

4.1 Introduction

The emergence of massive MIMO has fueled new research into the design of future generation wireless communications. Multi User-MIMO (MU-MIMO) supports the implementation and expansion of Massive MIMO (MIMO extension technique) system technologies [7]. Ad hoc networks are formed by nodes of limited battery power, under limited bandwidth channels across which nodes form unstable capacity links due to random changes in topology [31]. Beamforming algorithms in such networks need to be fast converging, low overhead and computationally simple while conserving battery life by reducing transmission power. Quantized transmit beamforming (codebook) is used to reduce the overhead incurred from multi-user beamforming in a MIMO wireless network, this limits the messaging overhead of the protocol to the transmission of the beamforming index [13]. MIMO communication technology efficiency largely depends on the intelligent adaptation of transmitting and receiving parameters of the wireless node like the selection of beamformer strategies, transmit node power criteria, total transmission average, modulation mode types, etc. The suitable and efficient design of the beamformer selection can function as a significant step in the adaptive wireless communication systems. MIMO beamforming in wireless communication systems has been designed for several wireless networks such as point-to-point systems, mobile cellular networks, and MIMO ad hoc technology [9].

The competition between wireless nodes is often modelled using game theory [32]. The game theory-based approach has raised the efficiency and convergence

proofs of the algorithms for distributed power control, beamforming, and other algorithms [42]. The cooperative and non-cooperative distributed game methods for iterative joint channel allocation and power control, which are selected from the “discrete” strategy space profiles, are presented under wireless mesh networks scenario [30]. The distributed cooperative and a non-cooperative based learning schemes for joint power control, and transmit beamforming selection in multiple antenna wireless multiuser interference environment is presented in [8]. Directly below the total network power reduction standard, a joint iterative method is studied to minimize mutual interference present at each sensor node with a constant received SINR at each receiver node.

In this paper, the performance of ECOPMA in the cooperative game and the RLPBA for the non-cooperative one are further investigated, by considering the network performance under different SINR constraints with minimum system overhead, convergence computation and interference burden, as compared to state-of-art algorithms. The novel contributions of this paper are the analysis of the ECOPMA and RLPBA algorithms [42] and their comparison to COPMA and RMSG in [8] for various SINR constraints. Both the total transmission power and the communication overhead incurred by the algorithms are compared. In simulations ECOPMA and RLPBA algorithms are found to exhibit lower total power transmission while meeting the SINR requirements with lower communication overhead.

The remaining issues of this work are arranged as follows: In section II the system model and parameters are presented. The optimization and game approach solution description (the cooperative and non-cooperative game theory) with overhead rates have been studied in Section III. The system performance evaluation has been presented in Section IV. The Final conclusion of the obtained results has been presented in section V.

4.2 Model of Framework and Parameters

The network is comprised of N sensor node pairs. Each sensor $q \in \{1, 2, \dots, N\}$ has a single transmitter/receiver unit, each is equipped with A antennas. The complex symbol stream $b_q \in \mathbb{C}$ has constant average power of 1, $E\{|b_q|^2\} = 1$. Each sensor has a unit-

norm (receive and transmit) beamformer pair $(w_q, t_q) \in C^A$. At any point in time, each node is assumed to function as either a transmitter or a receiver, each pair of communicating nodes is assigned a link number. At the q -th receiving node, the received signal vector $r_q \in C^A$ is given by:

$$r_q = \sqrt{E_q} H_{q,q} t_q b_q + \sum_{\substack{j=1 \\ j \neq q}}^N \sqrt{E_j} H_{q,j} t_j b_j + n_q \quad (4.1)$$

where $H_{q,j}$ represents the $A \times A$ MIMO channel between the transmitter of the j -th link and the receiver of the link in the ad hoc network. E_j is the transmit power of the j -th sensor node, and $n_q \in C^A$ is the additive white Gaussian noise covariance matrix $\sigma^2 I_{A \times A}$. The quasi-static MIMO channel is assumed in this work, and each receiver has an identical noise variance σ^2 . t_q is the selected transmit beamformer for the q -th link. Since the first term in Equation (1) contains the desired signal, the second and third expressions contain interference and noise for the signal of interest respectively, the SINR at receiver q is given by:

$$\tau_q = \frac{E_q |w_q^H H_{q,q} t_q|^2}{\sum_{j \neq q} E_j |w_q^H H_{q,j} t_j|^2 + \sigma^2} \quad (4.2)$$

In this scenario (limited feedback beamforming communication system), the main contribution of the receiving node that, it selects a suitable transmit beamformer from the predefined codebook, known for both sensor node pairs and feeds back the label of the chosen one to the transmitter. The set of available codebook beamformers for the q -th transmitting and receiving sensor node pair is denoted by $S_q = \{t_q^1, t_q^2, \dots, t_q^\Upsilon\}$ with cardinality Υ . It is assumed that such a sensor node can easily choose from Υ transmit beamforming codebook (vectors). Let $t_q \in S_q$ be the selected transmit beamformer for the q -th transmitting/receiving sensor node pair. The beamformer codebook which is assumed to be initialized prior to the beginning of the algorithm. The optimization problem has been defined in [8]:

$$\min_{\substack{(w_q, t_q) \in C^A \\ E_{min} < E_q \leq E_{max}}} \sum_{q=1}^N E_q(t_q, w_q, E_{-q}) \quad (4.3)$$

$$\text{Subject to} \quad \tau_q \geq \gamma_0 \quad (4.4)$$

$$\|w_q\|^2 = \|t_q\|^2 = 1, \quad (4.5)$$

$$E_{min} < E_q \leq E_{max} \quad (4.6)$$

where γ_0 is the threshold SINR requirement and E_{min} and E_{max} are the maximum and minimum transmit powers achievable by nodes in the system. Let $T = [t_1, t_2, \dots, t_N]^A$ and $E = [E_1, E_2, \dots, E_N]^A$ where T is the selected transmit beamformer and E is the transmit power vectors for N sensor nodes. For $A \times A$ matrix channels, the interference plus noise covariance at the q -th receiving sensor node can be expressed as:

$$R_q(T_{-q}, E_{-q}) = \sum_{j \neq q} E_j H_{q,j} t_j t_j^H H_{q,j}^H + \sigma^2 I \quad (4.7)$$

where T_{-q} and E_{-q} are the transmit beamform and powers of nodes other than q . The optimal normalized receiver beamformer, given the known channel between the target receiver q and all transmitting nodes is [8]:

$$w_q = \frac{\hat{w}_q}{\|\hat{w}_q\|} \quad (4.8)$$

where

$$\hat{w}_q = R_q^{-1} H_{q,q} \quad (4.9)$$

The proposed distributed algorithms achieved the given SINR threshold by regulating each individual transmit power of the nodes after selecting the beamformer which is closest to the optimal beamformer above it.

4.3 Optimization Method and Game Theory Analysis

The optimization problem has been formulated as a game with normal form style, such a game can be practically realized by the triplet $G = [N, C, \{U_q\}_{q=1}^N]$ where G is a game, $N = \{1, 2, \dots, N\}$ is the finite number set of players in such a game, $C = C_1 \times C_2 \times \dots \times C_N$ represents the available actions group for all the Nodes (players), and $\{U_q\}_{q=1}^N: C \rightarrow \mathbb{R}$ is the set of pay off (utility function) by which the sensor nodes can be linked with

their actions (strategies) in the game. Actions $c_q \in C_q$ for a node q are the transmit powers $E_q \in [E_{min}, E_{max}]$ and the transmit beamformer selections $t_q \in S_q$.

The players usually select their acceptable performance (actions) to maximize their achieved payoff functions (for decreasing system power consumption and overhead incurred by cooperative and non-cooperative manners). Any game formulation which is shown to have a Nash Equilibrium (NE) is guaranteed to converge to a stable state.

4.3.1 Centralized Method

The centralized procedure helps minimizing the total network transmit power of all system transmitting antennas A as shown in the following equation:

$$(\Theta^*, E^*) = \arg \min_{\Theta, E} \sum_{q=1}^N E_q(\Theta, E_{-q}) \quad (4.10)$$

where $\Theta^* = (t_1^*, t_2^*, \dots, t_N^*)$ and $E^* = (E_1^*, E_2^*, \dots, E_N^*)$ are defined as the best (optimal) node transmit beamformer and its power vectors respectively. The transmit node power E_q of q -th sensor node pair can be defined as:

$$E_q(\Theta, P_{-q}) = \frac{y_0}{t_q^H H_{q,q}^H R_q^{-1} H_{q,q} t_q} \quad (4.11)$$

Here R_q depends on the values of (Θ_{-q}, E_{-q}) as presented in Equation (4.11), to determine the transmit node power E_q , the centralized operator can estimate the whole sensor network power for γ^N available transmit beamforming index collections ponderous in small-scale network topology (in our case, the wireless MIMO network). For that, we will introduce decentralized algorithms.

4.3.2 Enhanced Cooperative Power Minimization Algorithm:

According to the clustering analysis [39], let $E_i^{M,m}$ and $t_i^{M,m}$ represent the node transmission adjustment power and transmit beamformer selected parameters (vectors) for m^{th} sensors pair, in the M^{th} cluster, respectively. Thus, the main payoff for each node pair in ECOPMA is:

$$U_i(t, E) = - \sum_{m=1, i=1}^{M, -M} E_i^{M,m}(t, E_{-i}^{M,m}) \quad (4.12)$$

which is also equal to the global (utility) function [8] i.e.

$$U_i(t, E) = U_{\text{net}}(t, E) = - \sum_{m=1, i=1}^{M, -M} E_i^{M, m}(t, E_{-i}^{M, m}) \quad (4.13)$$

As shown by Zeng *et. al.* [102], power based non-orthogonal multiple access systems, where users share the same frequency, time and code and user separation is accomplished through beamforming at the receiver achieve higher throughput with better fairness than orthogonal multiple access with minimum overhead rate and equal power consumption. Similarly in ECOPMA the m^{th} sensor node pair in each of the M clusters can share common transmit beamforming index, similarly to the scheme described by Zeng *et. al.* [102]. Let $E_q^{M, m}$ and $t_q^{M, m}$ be transmission power vectors and transmit beamformer selection vectors for m^{th} node pair in cluster M . The strongest and special potential games modeled (special case) in this dissertation is called an identical interest game [8], [42]. Given this, it will also be a special type of game known as a potential game. There is at least one pure Nash equilibrium (NE) strategy profile produced by all the identical interest games, and this profile is achieved when all players play an action (decision) profile that enhances their own utility payoff $U_i(T, E)$ [103]-[104].

4.3.3 Reinforcement Learning based Power allocation and Beamformer

In [1], the second proposed technique is based on non-cooperative game theory-based approach for beamforming and adaptive power allocation in multi-user ad hoc MIMO networks, along with using the reinforcement-learning algorithm. For non-cooperative nodes, the utility function has been employed in this scenario. In contrast to the cooperative solution, the q^{th} node pair focuses on their own power minimizations instead of the entire power of the network. For every node, the utility function is based on the selections of transmit beamformers and its power, and other node's decisions for beamformers and transmit power during recognize incurred interference.

According to the selection of the node transmit beamformer $t_q(k)$, the current (new) node transmit power E_q is determined by applying Equation (4.11) on the selected $t_q(k)$, until:

$$E_{q(k+1)}^{updated} = E_{q(k)}^{current} \times \left(\frac{\gamma_0}{\tau_q} \right) \quad (4.14)$$

or a predefined number of iterations is reached. The utility functions of a greedy user for choosing the specific beamformer and the expected power consumption at the time can be expressed as:

$$U_i(t_i, t_{-i}(k)) = \log (t_i^H H_{i,i}^H R_i^{-1} H_{i,i} t_i) \quad (4.15)$$

In Regret Matching (RM), the players minimize the regret $R_m^{\bar{t}_m}$ of not playing a certain action:

$$R_q^{\bar{t}_q}(k) = \frac{1}{k-1} \sum_{i=1}^{k-1} (U_q(\bar{t}_q, t_{-q}(i)) - U_q(t_q(i))) \quad (4.16)$$

The player is assumed to be able to evaluate the utility under different actions at time k . The action is chosen according to the probability distribution found by normalizing a regret vector.

$$t_q^{\bar{t}_q}(k) = \Pr(t_q(k) = \bar{t}_q) = \frac{[R_q^{\bar{t}_q}(k)]^+}{\sum_{\bar{t}_q \in \partial} [R_q^{\bar{t}_q}(k)]^+} \quad (4.17)$$

In Reinforcement Learning (RL), the player pursues a certain behavioral rule if an action enhances payoff function in point k is guaranteed with higher probabilities in the game phase $k+1$, which leads to more utility enhancement.

$$R_i = r_{i+1} + \sum_{k=1}^i \beta^k r_{i+k+1} \quad (4.18)$$

where R_i represents the reinforcements that have been received over 200 iterations, r_{i+1} is the current reinforcement signal with a discount factor denoted by symbol β . The achieved utility is bounded and each player can periodically supervise their own payoff. In RM, the players must be able to observe all actions of other players that lead to large overhead, this is where RL has an important advantage, it only needs an observation of the utility by applying algebraic computations (for more details see [70]).

4.3.4 OVERHEAD RATE

The communication overhead required by the algorithms depends on the time required for the beamforming and power adaptation, by using different methods. The communication overhead rate is computed from the Matlab simulation code as:

$$R = (T^c - S^c), \quad (4.19)$$

where R is the communication overhead for the current method, T^c is the time at which the solution is generated, and S^c is the time at which the solution generation starts to solve the problem. Accordingly, we have measured the R for each iteration and for each method.

4.4 SIMULATION RESULTS

In this section, we present the total network performance results of the centralized (optimum) solution, COPMA, and RMSG, ECOPMA and RLPBA. The target SINR has been represented by three different values, $\gamma_0 = 8, 10$ [42] and, 12 dB for all the node pairs. The total iterations number is $\kappa = 200$ for a small-scale networks to search for all possible profile spaces. Table 4.1 in reference [42] illustrates the simulation parameters for small-scale (5-Node Pairs) wireless ad hoc MIMO topology.

The performance of the total power consumption is shown in Figures 4.1, 4.2 and 4.3 for target signal to noise ratios of 10dB, 12dB and 8dB respectively. It has been observed that ECOPMA's performance settles to an optimum search result as indicated by the COPMA algorithm for the cooperative solution.

Fast convergence speed over 200 iterations can significantly decrease the system overhead rate, as well as the whole transmit power exhaustion of the ad hoc wireless system. ECOPMA performance is enhanced because of the clustering and the simple binary codebook [101]. Likewise, we have predestined herewith, the non-cooperative distributed game with learning-based algorithm again, for the same SINR constraints. The implementation of RLPBA technique shows a significant reduction in terms of power exhausting, convergence time, and overhead rate for optimum and efficient allocation solutions for sensor node pairs, over the regret-based learning approach in RMSG as shown in Table 4.1. Figure 4.1 compares the overhead required for the algorithms, measured through runtime. The proposed model RLPBA shows a reduction in the overhead rate over the iterations to be 200, which is significant when compared to the existing methods, this reduction in communication overhead compared to the previous RMSG technique is a result of the reinforcement learning approach [25], [70] and [105].

The proposed algorithms in this paper, (ECOPMA and RLPBA) have achieved a better total transmit power reduction performance compared to the previous algorithms (COMPA and RMSG), with a fast convergence rate to NE.

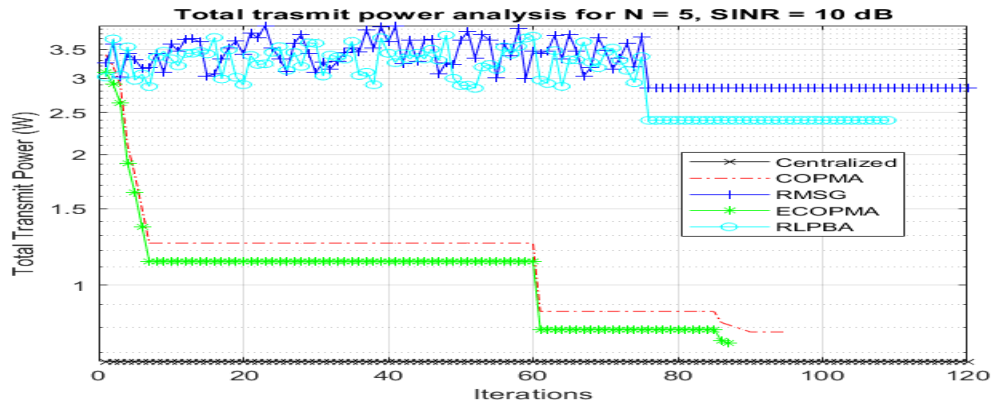


Figure 4.1 Total transmit powers with $N = 5$ users [42]

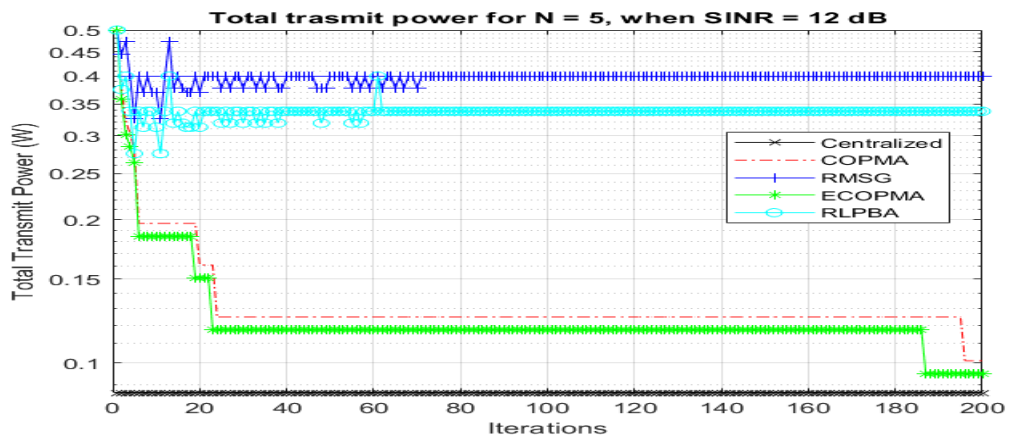


Figure 4.2 Total transmit consumption powers versus iteration

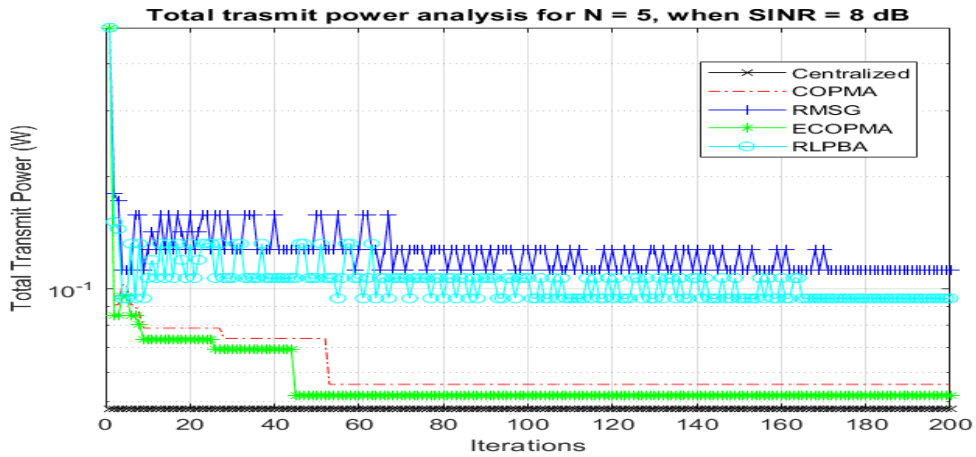


Figure 4.3 Total transmit consumption powers versus iteration number

Cooperative game techniques have introduced significant overhead in comparison with the non-cooperative game procedures since the beamformer updates require less overhead in non-cooperative game techniques. The presented cooperative and

non-cooperative solutions achieved much better computational performance compared to the previous methods.

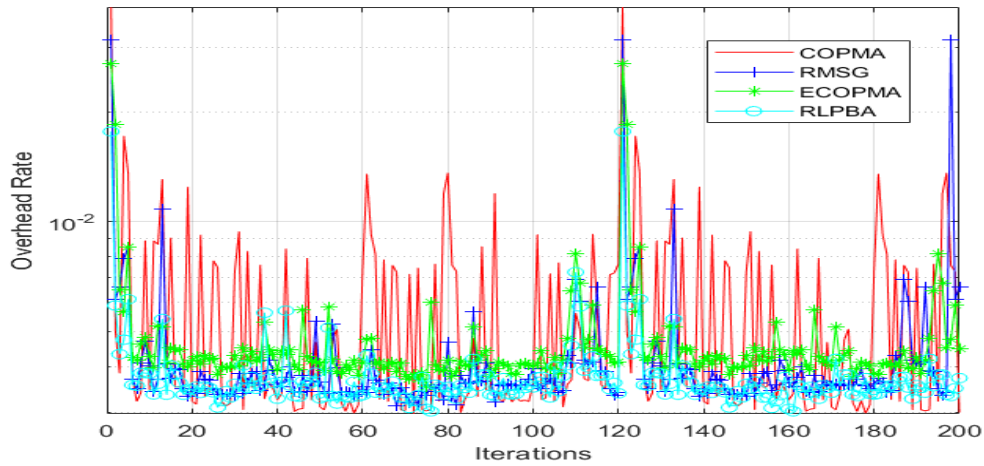


Figure 4.4 Communication overhead analysis for N=5

Table 4.1 Simulation result values

Algorithm Types	Total no. iteration	Convergence Total Power (mW) / NE		
		<i>SINR</i> 8 dB	<i>SINR</i> 10 dB	<i>SINR</i> 12 dB
Centralized	200	48/1-200	67/1-120	87/1-200
COPMA	200	55/53	78/95	125/198
ECOPMA	200	52/45	74/87	117/191
RMSG	200	112/171	200/120	399/71
RLBPA	200	95/166	170/110	338/62

The global optimum solution obtained by enumerating all feasible strategies 16^N profiles in this case, in the performance, the maximum number of iterations is $k = 200$.

The presented methods (ECOPMA and RLPBA) have achieved a much better performance in terms of nodes power reduction, compared to the previous algorithms (COMPA and RMSG), with higher speed of convergence (NE).

The simulation results of the proposed algorithms and pervious work have shown to achieve the appropriate solution based on the power consumption, convergence rate and, overhead reduction (see Table 4.1 and Figure 4.4 for overhead rate, respectively).

4.5 Conclusion

This chapter has investigated the performance of two algorithms based on game-theory to enhance the performance of wireless sensor networks, for joint transmit power and transmit beamforming, with minimum total power and overhead incurred under different SINR constraints. Results have indicated that combining cooperative (ECOPMA) according to cluster-based approach, binary codebook, and non-cooperative (RLPBA) solution, the reinforcement learning-based algorithm, can achieve good performance even with the SINR value changes. The simulation outputs reflect the fast convergence rate of our algorithms and their achievement based on the whole power reduction, convergence, and overhead rate in the system. The proposed techniques can significantly improve the performance as compared to the previous methods. Future work includes investigating the network performance for different propagation channels and for large network topologies.

Resource sharing problems have been interdisciplinary as well as requiring regulatory in addition to certain political bodies, market and business specialists. Also, network and communication engineers are providing technical input. Current discussion related to spectrum commons resulting majorly from market as well as regulatory perspective. Yet, development in the communication systems (interference cancellation, adaptive receivers, multi-antenna systems, software-defined-radio, as well as multi-carrier systems) have been specified for having solid effect due to the fact that they are enabling effective as well as concurrent use regarding the spectrum. Share infrastructure or spectrum end up in developing interferences on physical layer. Thus, MAC and physical layer optimization with regard to the resource sharing is studied extensively.

Ad Hoc MIMO communication systems are considered to be the foundation of next generation of the wireless communication systems Massive MIMO. Furthermore, the Multiuser-MIMO (MU-MIMO) boosting development and design regarding the Massive MIMO technology. Also, the efficiency of MIMO communication systems depending on adaptability regarding the transmit parameters like the modulation methods, transmit power, beamformer selection, transmission rate, and so on. Beamformer selection's design is of high importance in adaptive wireless communication systems. With regard to MIMO, the approaches of beamforming have been developed for various network types like ad hoc, cellular, as well as point-to-point. An analytical model is presented to examine the performance.

Lately, game theory has been gradually utilized in the computer sciences, also in AI, networks, as well as cybernetics. Utilizing game theory, one can model the cases where there have been no centralized entities with the partial/full information network conditions. Therefore, significant interests indicated to solve network as well as communication problems. The major interests for research with the use of game theory

in such problems: adaptive interference avoidance, power control, flow control, routing, as well as congestion control. Co-operation between wireless network's devices was specified as a major technology enabler needed for facilitating the next-generation systems of wireless communications. In the last 10 years, a lot of studies assumed point-to-point communications between centralized and terminal access points or the point-to-multipoint communications between terminals and central entity. The wireless users might be engaging in co-operative behavior, leading to enhanced performance of the network. Also, the co-operation between devices might be coexisting with the centralized infrastructures, for instance, cellular networks, yet it is of high importance as well in ad-hoc autonomous networks. Coalitional game theory is majorly dealing with cooperative group's formation, for instance, coalitions, which enable cooperating players in strengthening their position in certain game. The current interests in wireless network's cooperative paradigms, indicated that using coalitional games-based techniques is somewhat natural. In such regard, the coalitional games are tools of high importance to design effective, robust, fair, and practical cooperation plans in the communication networks. Yet, the majority of researches in wireless communities is focused on either the games which are non-cooperative or utilizing methods and models of standard coalitional game theory for examining the extremely limited factors related to network cooperation, including the stability within fairness or ideal cooperation. This has been majorly because of the sparse literature which is tackling the coalitional games as the major pioneer game theoretical reference like focusing on the non-cooperative games.

With regard to non-cooperative networks, there are agents which have been concerned with non-cooperative games. The major element related to non-cooperative game theory has been Nash Equilibrium (NE), that has been considered as strategy profile like that no one of agents could reduce their individual costs through unilaterally change the strategies. With regard to distinctive case strategic game in the case when NE exists, also in the case when strategic game can be specified as pure strategy, as well as when specified as mixed strategy. There might be incomplete or complete information in the game. Furthermore, a game might be static that indicates that players might not be having over a single move. Yet the game might be dynamic, and that indicates that players might be observing the former moves or the data, also following making new decisions for moving. Thus, dynamic games have been specified as general game models. This study will be

provided certain cases which might be ensuring the equilibrium's uniqueness. Also, a game might be having more than single equilibrium, after that there have been certain conditions for the purpose of selecting such equilibrium.

Mathematically, potential games might have many types. In all such game's types, the general thread is the presence of related to function (potential function) which is mapping the strategy space S of a game to real number R space. The classifications are on the basis of certain relation between the utility function and potential function of players.

Before, the presence of minimum single pure-strategy Nash equilibrium was established. The presented section is presenting how a player will be achieving Nash equilibrium in the potential games. The major concept is through sequential decision dynamics where the players are taking turns for acting in sequence or in round-robin way. Each one of the players will be selecting (in turn) novel approach on the basis of some decision rule, therefore create unilateral strategy deviations as well as inducing corresponding changes in potential function. In the case when the changes are representing improvements in the function's value, one is expecting series of improvements which is driving the game towards one of its equilibria.

Regret matching must be introduced, from, where players are choosing their actions on the basis of their regret for not selecting specific actions in past steps.

In Reinforcement Learning, player follow a certain behavioral rule. Action set is assumed to be finite, achieved utility has been bounded. Each one of the players might be periodically observing their achieved utility. The concept of RL is that the action which lead to high utility observation in the stage n is granted with high probabilities in game stage $n + 1$, and conversely. JUSTE-RL: utility as well as actions are estimated based on Observations. BRD, FP, and RM, the players must be able to observe. ALL actions of other players => large overhead, particularly in a wireless network. This is where RL and JUSTE-RL have an advantage: they only need an observation /estimate /measurement of the utility and they do only algebraic computations. BRD, FP, and RM need to solve an optimization problem, so they are computationally more demanding.

The competitions between the operators and service providers has been modelled with the use of game theory. For ad hoc networks the reduction of power using the distributed algorithms and transmit beamformer selection is a difficult tasks and hence its challenging

to formulate the beamforming games for multi-user wireless communications. In [8], the first attempt over joint discrete transmits beamforming and power adaptation introduced using the cooperative and non-cooperative game theory based solutions. The decentralized approach designed for optimizing the transmit beamformer and power adaptation exploits only local information with the acceptable computational burden under constraint of constant received target SINR. However, designing the optimized game theory based approach for the power adaptation and beamforming in ad hoc MIMO systems is still a complex research problem as the both solutions failed to achieve the trade-off between power minimization and overhead. The first solution cooperative power minimization algorithm (COPMA) achieved the power minimization but introduced the overhead and second non-cooperative solution Regret-matching-based joint transmit beamformer and power selection game (RMSG) minimizes the communication overhead but takes more power and iterations to converge. In this thesis, we further optimize COPMA and RMSG techniques to minimize the overhead and power consumption respectively. The key contributions of this dissertation summarized as:

- (1) Enhanced Co-Operative Power Minimization Algorithm (**ECOPMA**) for MIMO Ad hoc networks proposed to overcome the challenges of COPMA. We proposed cooperative method using the potential game approach in which first compute the allocated power and beamformer for each user until the convergence to the steady state according to Nash equilibrium technique, then divide users in clusters and enable them to converge at same time in order to minimize the overhead. In short, in this case the users cooperate each other to reduce the power and interference using the potential game theory and Nash equilibrium.
- (2) To reduce the communication overhead in ECOPMA, the binary weight books designed rather than using the complex Grassmannian Weight books. The binary weight book reduces the overhead incurred by cooperative solution.
- (3) Proposed Reinforcement Learning based Power allocation and Beamformer Algorithm (**RLPBA**) for multi-user ad hoc MIMO systems. In RLPBA, optimized non-cooperative solution designed using the Reinforcement learning game based approach in which the local information used for the beamforming and power adaptation decisions. The Reinforcement approach propose to reduce the number of iterations and hence the transmit power for convergence.

- (4) Extensive experimental results and comparative evaluations presented for ECOPMA and RLPBA with centralized and state-of-art co-operative and non-cooperative algorithms.
- (5) For proving approach efficiency of the wireless system, BER and overhead rate computed for all methods under different SINR values.

As we mainly focused on multi-user MIMO ad hoc networks. There is only single study reported regarding to the joint power adaptation and beamforming using the cooperative and non-cooperative games. This paper proposed the efficient cooperative and non-cooperative games based beamforming and power adaptation techniques for multi-user MIMO ad hoc systems with goal of solving below set of problems:

- For MIMO Ad hoc networks (such as MANET and VANET), the power minimization using the distributed methods is challenging research problem.
- For MIMO Ad hoc networks, the beamforming decisions on each user lead to the higher interference due to the dynamic behaviour of nodes in network area, thus interference mitigation is required.
- The transmit power minimization, interference minimization using distributed methods leads to the increased overhead.
- Lack of sufficient and optimized joint methods to address the problem of transmit beamforming and power adaptation for multi user-MIMO ad hoc systems.

This thesis proposed two solutions ECOPMA and RLPBA to address the challenges of power minimization with minimum interference and communication overhead with guaranteed QoS for multi-user MIMO ad hoc systems with constant SINR constrain. The ECOPMA is based on potential cooperative games and NE using clustering and binary weight rather than complex Grassmannian Weight book to reduce the communication overhead. The ECOPMA is similar to the COPMA [8] with the inclusion of cluster nodes. The RLPBA is non-cooperative games based power allocation and beamforming technique similar to RMSG [8] with use of reinforced learning to reduce the power consumption and number of iterations to converge.

This thesis presents the performance investigation of proposed ECOPMA and RLPBA methods with state-of-art solutions such as centralized optimization, RMSG, and COPMA. While evaluating such methods we designed ad hoc networks with assumption of 5 (small) and 10 (large) homogenous pairs with each having one transmitter and

receiver node, note here we added one node pairs to the previous work to make a fair comparison with our proposed algorithm. The complete sets of parameters are described for 5 pairs and 10 node pairs. For COPMA the Grassmannian codebook of size $\Upsilon = 16$ with $A = 3$ antennas for all users, however as the Grassmannian codebook complex, for ECOPMA we used binary codebook of size $\Upsilon = 8$ with $A = 4$ antennas for all users in this work.

The purpose of ECOPMA is to reduce the overhead by reducing the number of iterations compared to COPMA method which is achieved in results. We observe that ECOPMA's performance settles at the global optimum combination after 87 iterations as compared to COPMA (93 iterations). The reduction in iterations reduces the communication overhead as well as total power consumption of network. The performance of ECOPMA is improved due to the clustering and simple binary codebook. Similarly, we evaluated the non-cooperative distributed learning based techniques in figure 2. The RLPBA designed to reduce the power consumption with the reduction of iterations for optimum allocation solutions for network pairs. We exploited the advantages of reinforcement learning technique over the regret based learning approach in RLPBA. The outcomes of RLPBA show that it reduced the total transmission power for small wireless ad hoc MIMO networks compared to RMSG technique. It takes 110 iterations to converge total network transmission power compared to RMSG (120 iterations).

We demonstrated the comparative study of all the methods. It shows that total power in network varies using the non-cooperative methods over the 120 iterations. The cooperative methods (COPMA and ECOPMA) achieved the better total transmit power reduction performance compared to non-cooperative methods (RMSG and RLPBA). But the cooperative methods introduced the significant overhead compared to non-cooperative methods. The updating task needs less overhead for non-cooperative methods. The proposed cooperative and non-cooperative achieved the optimum performances compared to existing solutions in this thesis.

We demonstrated the power tracks in ECOPMA for every user pair in network, every user starts with maximum power levels initially (i.e. 100 mW), and then power is updated iteratively as per the behaviour of ECOPMA algorithm till the NE achieved.

It demonstrates the variations in probability mass function (P.M.F.) of RLPBA method was computed after iterations 1, 12, 50, and 120 for single user. At the start, the user selects the transmit beamformers with equal probability, further it changes according to working reinforcement learning.

Finally, we demonstrated the overhead of all the methods, the proposed models RLPBA and ECOPMA shows the significant reduction in overhead rate over the iterations 120 compared to existing methods. The RLPBA techniques shows less overhead compared to ECOPMA technique as the cooperative computation tasks are complex compared to RLPBA. The same scenario was applied for large network topology.

Later paper has investigated the performance of two algorithms based on game-theory to enhance the performance of wireless sensor networks, for joint transmit power and transmit beamforming, with minimum total power and overhead incurred under different SINR constraints. Results have indicated that combining cooperative (ECOPMA) according to cluster-based approach, binary codebook, and non-cooperative (RLPBA) solution, the reinforcement learning-based algorithm, can achieve good performance even with the SINR value changes. The simulation outputs reflect the fast convergence rate of our algorithms and their achievement based on the whole power reduction, convergence, and overhead rate in the system. The proposed techniques can significantly improve the performance as compared to the previous methods. Future work includes investigating the network performance for different propagation channels and for large network topologies. Future work will investigate a more relax potential game algorithm for a cooperative approach with freezing the adaptive beamforming for some wireless node.

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PUBLICATIONS FROM THE THESIS

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Papers

1. A. K. Khiarullah, U. Tureli, and D. Kivanc. "OPTIMIZED INTELLIGENT DESIGN FOR SMART SYSTEMS HYBRID BEAMFORMING AND POWER ADAPTATION ALGORITHMS FOR SENSOR NETWORKS DECISION-MAKING APPROACH" *International Journal of Computational Intelligence Systems*, vol. 12, no. 2, pp. 1436 – 1445, 2019. (DOI: 10.1049/iet-its.2018.5267).
2. A. K. Khiarullah, U. Tureli, and D. Kivanc. "Low Complexity Power Reduction and Beamforming Selection: An Intelligent System for Cooperative Game Approach in MU-MIMO Wireless Sensor Networks," to be submit.

Conference Papers

1. A. K. Khiarullah, U. Tureli, and D. Kivanc, "LOW COMPLEXITY DISTRIBUTED GAME FOR JOINT POWER AND BEAMFORMING SELECTION IN MIMO AD HOC NETWORK" 6th Annual international engineering conference, (IEC), Erbil, Iraq, February, 2020, pp.48-53. (DOI: 10.1109/IEC49899.2020.9122936).
2. A. K. Khiarullah, U. Tureli, and D. Kivanc, "Distributed Cooperative and Non-cooperative Joint Power and Beamforming Adaptation for MIMO Sensor Network," submitted to IEEE IT-ELA2020 (accepted).