International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-6 Issue-3, February 2017

A Study on Game Theory Approaches for Wireless Sensor Networks

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Abstract*: *Game Theory approaches and their application in improving the performance of Wireless sensor networks (WSNs) are discussed in this paper. The mathematical modeling and analysis of WSNs may have low success rate due to the complexity of topology, modeling, link quality and etc, however Game Theory is a field, which can efficiently used to analyze the WSNs. Game theory is related to applied mathematics that describes and analyzes interactive decision situations. Game theory has the ability to model independent, individual decision makers whose actions affect the surrounding decision makers. The outcome of Complex interactions among rational entities can be predicted by a set of analytical tools, however the rationality demands a stringent observance to a strategy based on measured of perceived results. Researchers are adopting game theory approaches to model and analyze leading wireless communication networking issues, which includes QoS, power control, resource sharing and etc.

Index Terms*: *Wireless sensor network; Game Theory; Cooperative game theory; Non-cooperative game theory; Wireless communications.

I. INTRODUCTION

The roots of Game theory are very old and the thoughts behind game theory have appeared in history [5], apparently in the holy books, the writings of Charles Darwin and etc [7]. However, there are some arguments on Daniel Bernoulli, that the first study of game theory was done by him i.e., the "Bernoulli's Principles"[8] and other argument is that the first mathematical analysis tool was presented by Thomas Bayes, known as "Bayes 'Theorem". The basis of modern game theory is development of a three determining works; a nash equilibrium, a competitive equilibrium and a mixed strategy [9]. Now, we can say that "Game Theory" is not a new concept. However, the concept has not yet been fully established and it limits the application to special conditions only [1].

II. GAME THEORY

Game theory is defined as a collection of mathematical models formulated to study situations of conflict and cooperation. It results into finding the best measures for individual decision makers in these situations and recognizing stable outcomes. The object of study in game theory is the game, defined to be any situation in which:

- There are at least two players: A player may be a wireless node, individual, a nation, a company or even a biological species.
- Each player has a number of courses of strategies and possible actions, he/ she may choose to follow.
- The outcome of game is decided by the strategies chosen by each player.

John Nash (1950) demonstrated that finite games always have a strategic equilibrium (also called a nash equilibrium). Nash equilibrium is a list of actions one for each player. To get a better payoff, no player can unilaterally change his/her strategy. This concept is referred as non-cooperative game theory

III. ASSUMPTIONS AND TERMINOLOGIES

The different terminologies of the game theory are now defined.

1. Players: Decision making in the game is done by the players. If there are two players in a game and if the players are two organizations (for e.g. organization R and organization S) competing for tenders, trade gain in a country by two other countries, two persons bidding in a game, etc.

2. Strategy: It is action taken by a player in a game, for e.g., giving furniture free of cost, giving additional discount on additional hardware, special prize, etc. In strategic form of game, a strategy is one of the given possible actions of a player. In an extensive game, a strategy is a complete map of choices, one for each of the player. Further, the strategy can be classified into mixed strategy and pure strategy.

Let m be the strategies of player R and n be strategies of player S, P_i be the probability of selection of the alternative i of player R, i = 1,2,3,….m. Let Q_j be the probability of selection of the alternative j of player S, for j = 1, 2, 3…..n. The sum of the probabilities of range of various alternatives of each of the players is equal to equation as shown below

$$\sum_{i=1}^{m} Pi = 1 \ \& \ \sum_{j=1}^{n} Qj = 1$$

(i)**Pure strategy**: If a player uses a particular strategy with a probability of 1, then that is a pure strategy. This means if player R follows a pure strategy, then only one of the P_i values will be equal to 1 and the remaining P_i values will be equal to 0. A set of probabilities of selection of the alternatives for player R is shown below: $P_1= 0$, $P_2=1$, $P_3= 0$. The sum of these probabilities is equal to 1.That is $p_1 + p_2 + p_3 =0+1+0=1$.

Manuscript published on 28 February 2017.
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(ii)**Mixed strategy**: In this, a player follows more than one strategy. But the probability of selection of the individual strategies will be less than one and their sum will be equal to one. $Q_1= 0.65$, $Q_2=1$, $Q_3= 0.35$

The sum of these probabilities is equal to 1.That is $p_1 + p_2 + p_3 =0.65+1+0.35=1$.

3. Nash equilibrium: It consists of list of strategies, one for each player, which has a property that no player can unilaterally change his strategy.

4. Perfect information: At any point of time if a player makes a move and holds the information about actions made until then, is referred as perfect information

5. Payoff matrix: A payoff is a utility that reflects the appeal of an outcome to a player, for whatever reason. For a random outcome, payoffs are usually weighted and the players attitude towards risk is expected by payoff.

6. Rationality: If a player wants to play in a manner which maximizes his own payoff then it is Rationality. Common knowledge about the game is rationality of all players.

7. Dominating strategy: If a strategy is dominating another strategy of a player, if it always gives a better payoff to that player then it is dominating strategy.

8. Zero-sum game: In a game, if the sum of the payoffs to all players is zero then it is zero-sum game.

9. Strategic form: If the players are simultaneously choosing their strategies then it is called as normal or strategic form. The resulting payoff's will be presented in a table.

10. Maximum Principle: This principle maximizes the minimum guaranteed gains of player R. The minimum gains with respect to different alternatives of R, irrespective of S's alternatives are obtained first.

11. Minimax Principle: This principal minimizes the maximum losses. The maximum losses with respect to different alternatives of player S, irrespective of player R's alternatives, are obtained first.

12. Saddle Point: The game is said to have a saddle point, if the minimax value is equal to the maximum value. Each player will have a pure strategy if the game has a saddle point.

Value of the game: The value of the cell at the saddle point is called the value of the game.

IV. WIRELESS SENSOR NETWORKS (WSNS)

A network consisting of distributed autonomous sensors to cooperatively monitor physical or environmental conditions such as sound, temperature, pressure, pollutants and etc. is called as a wireless sensor network (WSN) [6]. Wireless Sensor Networks (WSNs) consists of distributed sensor nodes and they usually transform data into electric signals. The unique nature of the WSN is the cooperative effort of sensor nodes. Wireless sensor network can support rescue operations by identifying dangerous areas, locating survivors and etc.

The sensor nodes are typically scattered in a sensor field, each of these scattered sensor nodes has the capabilities to collect and route data to the sink (gateway) by a multihop communication less architecture as shown in Fig. 1.

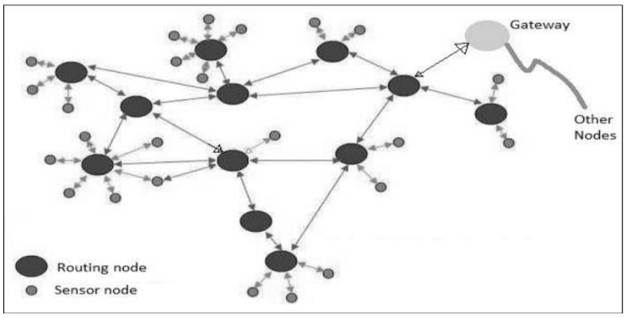

Fig. 1 Nodes of wireless sensor networks (WSNs)

V. GAME THEORY APPROACHES FOR WSNs

The basic components of a game are a set of strategies, set of players and set of payoffs. Different strategies are available for nodes and nodes are decision makers. At the end, payoffs decide the outcomes of each player. Table-1 shows the components of WSN game.

Table I. Components of A WSN Game

Components of game	Elements of WSN
Set of strategies	Modulation, Coding, power level and etc
Set of players	Nodes of WSN
Set of payoffs	Performance measures

There are several game theory approaches, which can be classified on the basis of parameters like the sum of gains or losses, the number of nodes involved in the game and the number of strategies employed in the game. Games can be designed as a 1-player game, 2-player game or n- player's game [12]. The commonly used Game theory approaches for solving WSNs issues and several terminologies are listed in Table-2.

Table II. Typical Game Theory Approaches and Terminologies Used in WSNS

Game Theory Approaches	Elements of WSN
(i) Cooperative game	(i) Nash Equilibrium
(ii) Non cooperative game	(ii) Pareto Optimal
(iii) Repeated game theory	(iii) Nash Bargaining Solution
(iv) Coalitional game	(iv) Shapley Value
(v) Evolutionary game	(v) Core
(vi) Guar game	(vi) Mechanism Design
(vii) Bargaining game	(vii) Incentive compatible
(viii) Dynamic game	(viii) Strategy proof Mechanism
(ix) Transferable Utility game	(vii)Auction
(x) Non Transferable Utility game	(viii)Viceroy-Clarke-Groves(VCG)Mechanism
(xi) Ping-pong game	(ix) Utility Function
(xii) Zero-sum and Non Zero-sum game	(x)Bayesian Nash Equilibrium(BNE)
(xiii) Jamming game	

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VI. COOPERATIVE AND NON-COOPERATIVE GAME THEORY

A cooperative game is a coalitional game, in which the players can make binding commitments [4]. The analysis of cooperative game theory includes distribution of wealth gained through cooperation, coalition formation and finding outcome procedures for various situations. Cooperative game theory is most obviously useful to international relationship or political science.

Non-cooperative game theory is related to the analysis of strategic choice and explicitly models the process of player's making choices out of their own interests [11]. Non-cooperative games can be divided into two categories: static and dynamic games. In static game, players make their choices of strategies simultaneously, without knowledge of what the other players are choosing. i.e., a game is also simultaneous when players choose their actions in isolation, with no information about what other players have done or will do, even if the choices are made at different points in time.

VII. APPLICATION OF GAME THEORY IN WSNs

Conventional control architectures and centralized information fusion will be challenged by autonomous sensors [2], owned by different stakeholders with individual goals, to interact and share information. Computational mechanism design (CMD), a field at the junction of non-cooperative game theory and computer science [3], to address the challenges of WSNs. Game theory has many applications in WSNs. The most important roles of game theory in the design of WSNs are listed in Table-3

Table III. Important Role of Game Theory in WSNS

Components of Game
(i) Routing protocol design
(ii) Target tracking
(iii) Power control
(iv) Energy saving
(v) Data collection
(vi) Topology control
(vii) Spectrum allocation
(viii) Bandwidth allocation
(ix) Quality of Service (QoS) control
(x) Task scheduling

VIII. CONCLUSION

Game theory approaches shows how players should rationally play games, and it is a powerful analysis tool in many areas, such as politics, war, economics, sociology, psychology, biology, and communications, networking and so on where the cooperation and conflict exist. In this paper, it is proposed that a game model to interpret the working mechanism and also point out the some directions that deserve study. The game theory is an appropriate tool to analyze and research the performance of WSNs. However, most networks are enormously complex, it is usually not possible to describe all possible strategies and to say what outcomes they lead to, and it is not easy to assign payoffs to any given outcome.

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