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PERFORMANCE ANALYSIS OF POWER MANAGEMENT IN WIRELESS SENSORS NETWORKS USING COOPERATIVE AND NON COOPERATIVE GAME THEORY

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ABSTRACT

Sensors are regarded as significant components of electronic devices. In most applications of wireless sensor networks (WSNs), important and critical information must be delivered to the sink in a multi-hop and energy-efficient manner. Inasmuch as the energy of sensor nodes is limited, prolonging network lifetime in WSNs is considered to be a critical issue. In order to extend the network lifetime, researchers should consider energy consumption in routing protocols of WSNs. A wide spectrum of issues can be efficiently addressed in recent efforts in applying Game theory in wireless communications and networking. It is envisioned that game theory will be a fundamental technique in the field of wireless communications and networks. Game theory was originally invented to explain complicated economic behavior. With its effectiveness in studying complex dynamics among players, game theory has been widely applied in politics, philosophy, military, Sociology, telecommunications and logistics. The game theoretic model is able to address efficiently resource allocation, congestion control, attack, routing, energy management, packet forwarding, and medium access control (MAC). This paper systematically introduces and explains the applications of game theory in wireless communications and networking. It provides a comprehensive technical guide covering introductory concepts, fundamental techniques, recent advances, and open issues.

Keywords: *Game theory, Non-Cooperative Game theory, Cooperative Game theory, Wireless communications, Wireless Networks.*

1. INTRODUCTION

Wireless communications and networking are always resource limited. In multi user wireless systems, all users compete for resources and can interface with each other. The conflicting objectives of users make it highly unlikely for any user to gain more profit without harming other users. This competition among the users should be analyzed and regulated to improve the overall performance of the whole multi user system.

The purpose of this paper is to discuss applications of game theory for designing multi user strategies in wireless communications and networking. A brief introduction to the need of game theory will be given first. Cooperation game theory and non-cooperation game theory power allocation, beam forming and pre coding problems will then be discussed. All these problems will be formulated as scalar, vector and matrix valued games respectively and analyzed from a game theoretic perspective. Performance metrics such as efficiency, fairness, uniqueness of the solution, and complexity will be compared and discussed.

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2. NEED FOR GAME THEORY

The flexibility, fault tolerance, high sensing fidelity, low-cost and rapid deployment characteristics of WSNs are desirable features in creating many new and exciting application areas for remote sensing, detecting, tracking, and monitoring. However, it is non-trivial and very involved to design an optimal WSN to satisfy performance objectives such as maximum sensing coverage and extended operation periods. In order to obtain a practical and feasible WSN and due to the operation nature of the network, game theory (GT) is regarded as an attractive and suitable basis to accomplish the design goal. Game theory is a branch of mathematics and can be used to analyze system operations in decentralized and self-organizing networks. GT describes the behavior of players in a game. Players may be either cooperate or non-cooperative while striving to maximize their outcomes from the game. In this regard, sensors manage their operations in terms of power resources devoted to sensing and communicating among themselves and with a global controller such that the assigned task could be completed effectively as desired.

Game Theory also classifies games according to other criteria, such that if games are **Static** or **Dynamic.** In **static games**, we assume that there exists only one time step, which means that players move their strategy simultaneously without any knowledge of what other players are going to play. In **dynamic games**, players move their strategy in predetermined order, meaning that the move of one player is conditioned by the move of the previous players (i.e.) the second mover knows the move of the first mover before making his decision.

The Strategic form of a game is defined by the three objects:

1. The set, $I = \{1, 2, 3.........n\}$, of players.
2. The sequence, $A_1, A_2, ...A_n$ of strategy sets of the players, and
3. The sequence, $f_1(a_1, a_2, ...a_n).............f_n(a_1, a_2, ...a_n)$ of real-valued payoffs to the players.

A game in strategic form is said to be Zero-Sum if the sum of the payoffs to the players is zero no matter what action are by the players. That is the game is zero-sum if $\sum_{i=1}^{n} f_i(a_1, a_2, ...a_n) = 0$ for all $a_1 \in A_1, ...a_n \in A_n$.

In **Zero-Sum** games each and every participant's gain or loss of utility is exactly balanced by the losses or gain of the utility of the other participants. So the strategic form is extended to two-person non-zero sum games. In general they have optimal strategies and the theory naturally breaks into two parts:
1. Non-cooperative Game Theory 2. Cooperative Game Theory.

Also according to the knowledge of players on all aspects of game, the non-cooperative / cooperative game further classified into two categories: **Complete information** and **incomplete information**. In the complete information game, each player has all the knowledge about other's characteristics, strategy spaces, payoffs and so forth, but all these information are not necessarily available in incomplete information**.** In games with incomplete information, the overhead resulting from information exchange is reduced, because each player predicts the strategies of other players.

In **Non-Cooperative Game Theory** if the players communicate, binding agreements may not be formed. The main concept, replacing values and optimal strategy in the notion of a strategic equilibrium, also called Nash equilibrium. This Nash equilibrium is a building block of game theory since it both inspires new solution concepts and corresponds to the solution of many interactive situations.

In **Cooperative Game Theory** the players are allowed to form binding agreements, and so there is strong incentive to work together to receive the largest total payoff. The problem then is how to split the total payoff between or among the players. This cooperative theory also splits into two parts. If the players measure utility of the payoff in the same units and there is a means of exchange of utility such as **side payments**, we say the game has **transferable utility;** otherwise **non-transferable utility**. When the number of players grows large, even the strategic form of a game, though less detailed than the extensive form, becomes too complex for analysis.

3. GAME THEORY FOR WIRELESS NETWORK POWER MANAGEMENT IN WSN

The design of a wireless network and optimization of its performance is a non-trivial and complicated process. The WSN has to fulfill straight requirements imposed from a set of operation goals. Game theory thus plays a supportive and critical role in designing and operating a WSN. Figure 1 illustrates the relationship between various WSN elements and the way that game theory is employed. Representative requirements in a WSN include network management which is responsible for making the most economical use of power resources such that WSN can be put into operation for an extended period of time. A fundamental need for the WSN is to communicate with centralized or base station that sensed data is fused and analyzed. In order to derive an effective WSN, one needs to consider the quality of service (QoS) specified, the topology used in the network architecture and how data is dispatched according to some preferred routing protocol. When the WSN is put into operation, it is always susceptible that the network may be attacked by hackers where data could be intercepted and retrieved illegally. To this end, the WSN has to be designed for deny of service (DoS) prevention and the incorporation of intrusion detection capability. With the desire to enlarge the application domain of WSN, attentions are also directed toward target tracking and data collection in the WSN design.

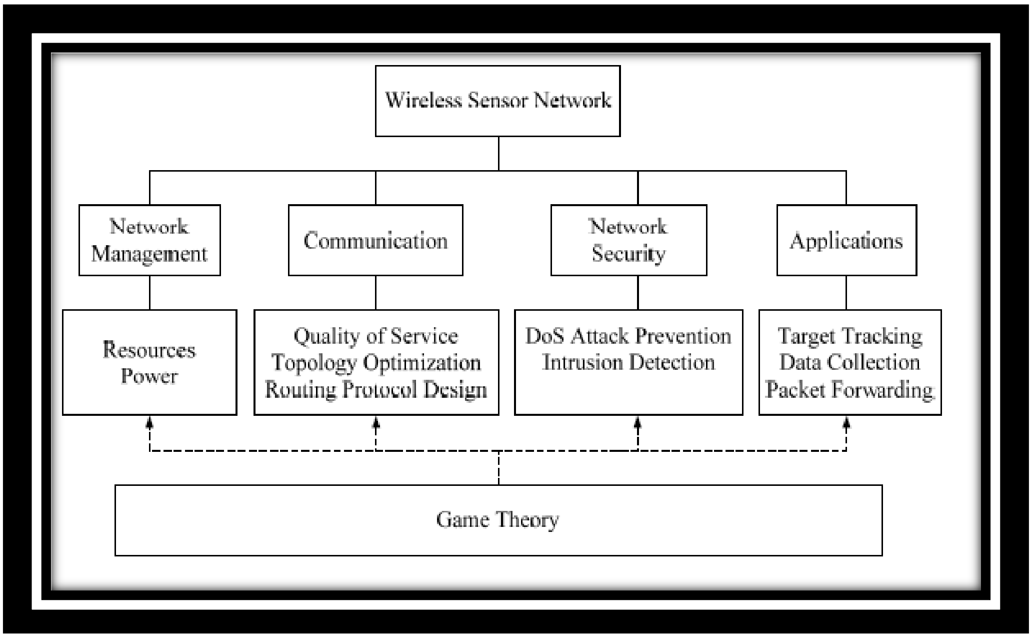

Figure-1: An illustration of the relation between WSN and game theory.

4. GAME THEORY FOR WSN SECURITY

Due to the limited capabilities of sensor nodes in terms of computation, communication, and energy, providing security to WSN has increasingly become one of the most interesting areas of research in recent years. WSN security is a primarily important and critical issue before WSN can be widely used. There usually exist two mechanisms of intrusion prevention and detection in WSN security. GT provides a mathematical method for analyzing and modeling WSN security problems for it considers scenarios where multiple players with contradictory objectives compete with each other. Shen had proposed a taxonomy which divides current existing typical game theory approaches for WSN security into four categories: preventing DoS attacks, intrusion detection, strengthening security, and coexistence with malicious sensor nodes. They pointed out some future research areas for ensuring WSN security based on game theory, including Base Station credibility, IDS efficiency, WSN mobility, WSN QoS, real-world applicability, energy consumption, sensor nodes learning, expanding game theory applications, and different games.

5.1. POWER CONTROL

In the power control problem, each user's utility is increasing in his signal-to-inference-and-noise ratio and decreasing in his power level. If all other user's power level were fixed, then increasing one's power would increase one's SINR. However, when a user raises her transmission power, this action increases the interference seen by other users, driving their SINRs down, inducting them to increase their own power levels**.**

5.2. Game Theoretical Formulation of Transmission Power

A wireless network can be modeled as a game according to Fig. 3. The decision making nodes in the network form the player set of the game, each node's available power levels form the action sets of the players, and the algorithms used by the nodes to modify their behavior form the utility functions and learning processes within the game.

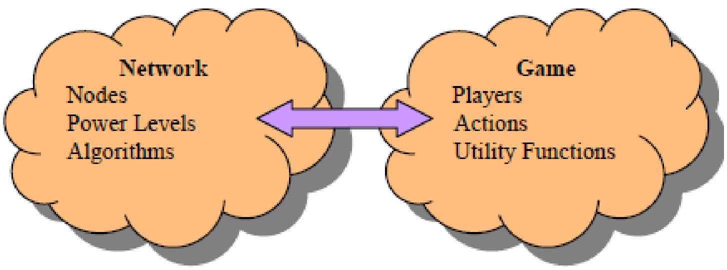

Figure-3: Network model as a game

Here, we now introduce a more specific game model for distributed transmission power for cognitive radio based wireless ad-hoc networks. The model is based on the following key assumptions:

- Fundamentally, the choice of a power levels are the adaptations that may be adopted at the physical layer by a node of the network.
- From a physical layer perspective, performance is generally a function of the effective signal-to-interference-plus-noise ratio (SINR) at the node(s) of interest.
- Effective SINR is a function of the choice by a node: the transmit power level. The exact structure of this function is also impacted by a variety of factors not directly controllable at the physical layer; the most notable of these factors are environmental path losses and the processing capabilities of the node(s) of interest.
- When the nodes in a network respond to changes in perceived SINR by adapting their signal to SINR changes, a physical layer interactive decision making process occurs.

Based on these assumptions, a game theoretic model for transmission power level of a cognitive radio wireless ad hoc network can be formed using the parameters listed in Table 1.

Power control Notation

S.No	Symbol	Meaning
	N	The set of decision making (Cognitive) radios or nodes in the system
2	i,j	Two different cognitive radios or nodes *i, j*∈ *N*
3	p_j	The set of power level available to radio or node *j*
4	p_i	A power level chosen by *j*
5	P	The power space formed by Cartesian product of all P_{j*} P = $P_1 \times P_2 \times P_3 \times \ldots\ldots \times P_n$
6	p	A power vector from P formed as P = {$P_1, P_2, P_3, \ldots\ldots P_n$
7	u_j(p)	The utility that *j* receives from *p*. This is the specific function that *j* is looking to maximize.

Thus the general notation of power game is, $G = (N, P, \{ u_i \})$

5.3. Power Game Model of Network

In this subsection we describe the power game model of a cognitive radio wireless network.

- ***Players***: A set of all decision making nodes in the participating networks. For an example here the set is $N = \{1,2,\ldots\ldots\ldots,n\}$ nodes in the networks.
- ***Actions***: The set of available power for each node $i \in N$, i.e. p_i={p;p∈[$p_{i,min}, p_{i,max}$]}.
- ***Utility Functions***: We consider p_i the transmission power of node *i* and *i* $g_i$the link gain of *i* . Then $y_i = p_i g_i$, *i* = 1, 2,......,*m* is the received power of each node *i* . The quality of service QoS of each node *i* is measured in terms of the signal to interference plus noise radio (*SINR*) of *i* .Thus the *SINR* for each node *i* is given by,

$$\text{SIN}R_i = \frac{Y_i}{\sum_{j\to i} y_i + e} \quad (1)$$

where e designates external noise power. It is presumed that self-interference is negligible or nonexistent. Each node of interest relays its *SINR* information back to the nodes transmitting to it. Each transmitting node then adapts its transmission parameters as a function of *SINR* at its node of interest constrained by a cost function that models the internal costs for a particular energy / waveform pair (battery life, complexity, distortion) and / or a cost function imposed by a network for a particular energy / waveform pair. Thus the objective functionu_i can be described in terms of *SINR* as follows,

$$u_i = \sqrt{(\text{i} \times \text{SIN}R_i)} - c_i(p_i) \quad (2)$$

$$u_i = \sqrt{i \times \frac{y_i}{\sum_{j\to i}^{M} y_{i+e}}} \quad (3)$$

Here $c_i(p_i)$ is the cost function of each node *i* which can be described in unit price of power p' , i.e. $c_i(p_i) = p' * p$ .In this power control game each node will try to increase its utility by choosing a power from available power vector rationally and finally reach a steady state condition i.e. *Nash Equilibria*.

5.3. SPECTRUM ALLOCATION

The spectrum sharing problem addresses the issue of how to allocate the limited available spectrum among multiple wireless devices. The allocation of spectrum should utilize as much of the resource as possible: however, when utilization is maximized, fairness can be compromised. A cooperative game for distributed spectrum sharing is discussed in and spectrum sharing game is formulated**. Figure 5.1** represents the applications of communication networks.

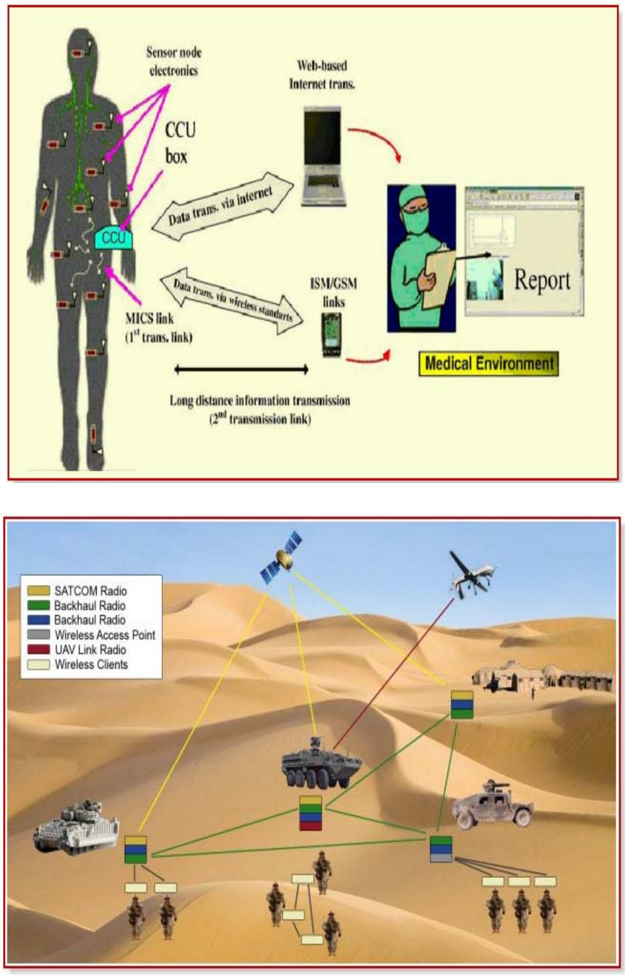

Figure-5.1: Applications of communication networks medical and military

5.3. Energy consumption without losing accuracy:

Sensor nodes can use up their limited supply of energy performing computations and transmitting information in a wireless environment. As such, energy conserving forms of communication and computation are essential. Sensor node lifetime shows a strong dependence on the battery lifetime. In a multihop WSN, each node plays a dual role as data sender and data router. The malfunctioning of some sensor nodes due to power failure can cause significant topological changes and might require rerouting of packets and reorganization of the network.

6. CONCLUSIONS

Game theory is a fascinating field of study. In this work, we have barely scratched the surface. We hope that the reader will now have an understanding of the fundamental concepts in game theory that will enable him or her to pursue a more in-depth study of the available literature. The purpose of this survey was to guide the interested readers familiar with computer science through the basics of both non-cooperative and cooperative game theory and to help them integrate this fascination tool into their own studies.

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