PROLONGING NETWORK LIFETIME OF WIRELESS SENSOR NETWORKS USING INFINITE ZERO-SUM GAME THEORY APPROACH

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Abstract: Game theory is a collection of mathematical tools developed to model interactions between agents with conflicting interests. It is a field of applied mathematics that defines and evaluates interactive decision situations. It has been recently introduced in wireless sensor networks (WSN) design as a powerful modeling and analyzing tool for competitive and completely distributed environments. Wireless sensor network is a large collection of sensor nodes with limited power supply, constrained memory capacity, processing capability and available band width. This will creates a great popularity regarding their potential use in a wide variety of applications like monitoring, environmental attributes, intrusion detection, and various military and civilian applications. The main performance criteria for these sensor networks is prolonging network life time while satisfying coverage and connectivity in the deployment region. In this paper we look at the problem of lifetime maximization, reliable routing and multi-hop in wireless sensor network within a infinite two-person zero-sum game theoretic formulation. In particular, the theory has been proven very useful in the design of wireless sensor networks. Simulation results are provided to show the effectiveness of the proposed games is able to maintain the energy level which will improves the network lifetime.

Keywords: Wireless Sensor Networks, Game Theory, Zero-sum Game Theory, Routing, Lifetime.

Introduction: Wireless Sensor Networks is a new technology which is used in a huge majority of applications. This networking plays an important role in today's worldwide communication. Internet is reflecting the profound network technology that has changed the way how people communicate. Wireless sensor network is one of the most interesting research areas. The flexibility, fault tolerance, high sensing fidelity, low-cost and rapid deployment characteristics of wireless sensor networks 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 wireless sensor network 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 is regarded as an attractive and suitable basis to accomplish the design goal.

Game theory is a field of applied mathematics and can be used to analyze system operations in decentralized and self-organizing networks. Game theory 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. Generally game theory focuses only the strategic behavior of rational agents.

Strategic behavior, occurs when the utility of each agent not only affected by his own choice of strategy but also depends on the strategy chosen by other players. The potential use of game theory monetization to introduce a method for finding optimal path which enables lifetime maximization is also within the main issues of this paper. In this approach, sensor nodes and routing are assumed to be the game and the players.

II. Wireless Sensor Networks: Wireless sensor networks have features like low cost, flexibility, fault tolerance, high sensing fidelity, creating many new and exciting application areas for remote sensing. So, WSN has emerged as a promising tool for monitoring the physical world with wireless sensor that can sense, process and communicate. Main objectives of sensor networks include reliability, accuracy, flexibility, cost effectiveness and case of deployment. Each node has one or more sensing unit. All nodes in the sensor network act as information sources, sensing and collecting data samples from their environment. The main components of sensors are consisting of a sensing unit, a processing unit, a transceiver, and a power unit. As with the popularity of wireless networks, importance of sensor networks has grown.

A sensor network is composed of a large number of sensor nodes, which are densely deployed either inside the phenomenon or very close to it. The position of sensor nodes need not be engineered or pre-determined. This allows random deployment in inaccessible terrains or disaster relief operations. On the other hand, this also means that sensor network protocols and algorithms must possess self-organizing capabilities. Another unique feature of sensor network is the cooperative effort of sensor nodes. Sensor nodes are fitted with an on-board processor.

The flexibility, fault tolerance, high sensing fidelity, low-cost and rapid deployment characteristics of wireless sensor networks 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 wireless sensor network 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 is regarded as an attractive and suitable basis to accomplish the design goal.

III. Infinite Zero-Sum Game Theory Model: A game generally consists of a set of players, a set of strategies for each player, and a set of corresponding utility functions.

A strategy for a player is a complete plan of actions in all possible situations throughout the game. In any games, the players try to act selfishly to maximize their consequences according to their preferences. These preferences are expressed by a utility function, which maps every consequence to a real number. Nash equilibrium is a solution concept that describes a steady state condition of the game; no player would like to change his strategy unless there is a better strategy that can result in more utility that is favorable for the player current.

A normal form of a game is given by a tuple $\Gamma = \langle I, X, P \rangle$ where Γ is a particular game, I is a finite set of players, $X = \{X_i\}_{i \in I}$ where X_i is the set of strategies for each player $i \in I$, and $P = \{P_i\}$ is the set of utility functions that the players wish to maximize.

Definition1:A zero-sum game is a mathematical representation of situation in which a participant's gain or loss of utility is exactly balanced by the losses or gains of the utility of the other participants. If the total gains of the participants are added up, and the total losses are subtracted, they will sum to zero.

The zero-sum two-person game in normal form is formally defined as a triple $\Gamma = \langle X, Y, P \rangle$ in which X and Y are arbitrary infinite sets representing the sets of strategies of Players I and II respectively and P is a real function defined on the set $X \times Y$ of all situations and is called the payoff function or kernel of the game. (If $P : X \times Y \to R$ is the payoff function of Player I. Player II's payoff in the situation (x, y) is $[-P(x, y)]$, where $x \in X$, $y \in Y$ the game being zero-sum)

The existence of optimal ($\in -$ optimal) strategies for the opponents in a zero-sum two-person game is equivalent to satisfaction of the following equations:

$$\max_{x\in X} \inf_{y\in Y} P(x, y) = \min_{y\in Y} \sup_{x\in X} P(x, y) = \upsilon \quad \text{---(1)}$$

$$\sup_{x\in X} \inf_{y\in Y} P(x, y) = \inf_{y\in Y} \sup_{x\in X} P(x, y) = \upsilon \quad \text{---(2)}$$

The quantity υ is called the value of the game. Even in the simplest cases, however, equations (1) and (2) fall short of being satisfied. Their proof requires the imposition of rather stringent algebraic constraints on the strategy sets X, Y and the function P (such as concavity in x and convexity in y) as well as topological constraints (the sets X and Y are topological spaces, and the function P has properties of the continuity type).

It is reasonable, therefore, to extend the strategy sets of the players in such a way that the payoff function, now defined on a new extended set of situations, will satisfy the required constraints .The extended strategy sets must be convex and include the usual strategies.

Let χ be a certain $\sigma -$ algebra of subsets of X containing all one-element subsets, let γ be a $\sigma -$ algebra of subsets of Y, and let the function P be bounded and measurable under the $\sigma -$ algebra χ x γ. A probabilistic measure defined on χ (γ) is called a mixed strategy of Player I (II). If μ is a mixed strategy of Player I and ν is a mixed strategy of Player II, then the payoff function $P(\mu,\nu)$ under the conditions of the mixed situation (μ,ν) is defined by the integral $P(\mu,\nu) = \int_X \int_Y P(x, y) d\mu(x) d\nu(y)$.

If the set of pure strategies of a player is infinite (and especially if it is denumerable), then in the choice of his set of mixed strategies there is a certain arbitrariness, which rests on the particular choice of $\sigma -$ algebra of subsets of the pure strategy set on which the probabilistic measure is defined . Theorems establishing the validity of equations (1) and (2) for an infinite game or its mixed extension are called existence theorems (or minimax theorems). The proof of existence theorem, (i.e.) the identification of classes of games for which a value of the game exists (or does not exist), is one the fundamental problems of the theory of infinite zero-sum two-person games.

A pair of optimal strategies of each player in a zero-sum two-person game (or the set of $\in -$ optimal strategies for each player) in conjunction with the process of finding those strategies is known as a solution of the game.

In the infinite game, as in any zero-sum two-person game $\Gamma\langle X, Y, P \rangle$ the principle of player's optimal behavior is the saddle point (equilibrium) principle.

Definition 2: The point $(x*, y*)$ for which the inequality

$P(x, y^*) \le P(x^*, y^*) \le P(x^*, y)$ ------------(3) holds for all $x \in X$, $y \in Y$ is called saddle point.

This principle may be realized in the game Γ if and only if $\upsilon = \bar{\upsilon} = \underline{\upsilon} = P(x^*, y^*)$ where $\underline{\upsilon} = \max_{x\in X} \inf_{y\in Y} P(x, y)$ ----------(4)

$$\bar{\upsilon} = \min_{y\in Y} \sup_{x\in X} P(x, y)$$

(i.e.) the external extreme of maximin and minimax are achieved and the lower value of the game $\underline{\upsilon}$ is equal to upper value of the game $\bar{\upsilon}$. The game Γ for which the (4) holds is called strictly determined and the number υ is the value of the game.

Definition 3: The point $(x_\in, y_\in)$ in the zero-sum two-person game $\Gamma\langle X, Y, P \rangle$ is called the $\in -$ equilibrium point if the following inequality holds for any strategies $x \in X$ and $y \in Y$ of the Players I and II, respectively:

$P(x, y_\in) - \in \le P(x_\in, y_\in) \le P(x_\in, y) + \in$ ----(5).

The point $(x_\in, y_\in)$ for which equation (5) holds, is called the $\in -$ Saddle point and the strategies $x_\in$ & $y_\in$ are called $\in -$ optimal strategies for the players I and II, respectively.

Compare the definitions of the saddle point equation (3) and the $\in -$ Saddle point equation (5), A deviation from the optimal strategy reduce the player's payoff where as a deviation from the $\in -$ optimal strategies may increase the payoff by no more than $\in$.

The following theorem yields the main property of $\in -$ optimal strategies.

Theorem1: For the finite value υ of the zero-sum two-person game $\Gamma = \langle X, Y, P \rangle$ to exist, it is necessary and sufficient that, for any $\in >0$, there be $\in -$ optimal strategies $x_\in, y_\in$ for the players I and II, respectively, in which case $\lim_{\in \to 0} P(x_\in, y_\in) = \upsilon$ ----------(6)

Consider zero-sum two-person game $\Gamma = \langle X, Y, P \rangle$. If it has no value, then $\bar{V} \ne \underline{V}$. In this case in order to increase his payoff for the player it is important to know the opponent's intention. The only rational course of action here is to choose a strategy by using some chance device (i.e.) it is necessary to use mixed strategies. Now we shall see a formal definition of the mixed strategy for the infinite game.

Definition: 4. If χ is some $\sigma -$ algebra of subsets of the set X where $x \in X$ and if γ is $\sigma -$ algebra of subsets of Y where $y \in Y$. Let $\bar{X}$ and $\bar{Y}$ be the sets of all probability measures on the $\sigma -$ algebras χ and γ, respectively, and let the function P be measurable with respect to $\sigma -$ algebra of χ x γ.

IV.Related Works: Game theory in general and mechanism design in particular have been used with great success in analyzing routing algorithms. Some routing algorithms adopt game theory on the hierarchical topology. The various hierarchical routing protocols for sensor networks are based on energy, the location and quality of services (QoS). Of data-centric protocols such as SPIN, broadcast live, consolidate redundant data when routing from source to destination. On the other hand, QoS protocols such as SPEED meets the diverse needs such as energy efficiency and reliability as well as real-time requirements. Finally LEACH, APTEEN Pegasus form clusters (Cluster Head) CH minimizes the energy consumption for both processing and data transmission.

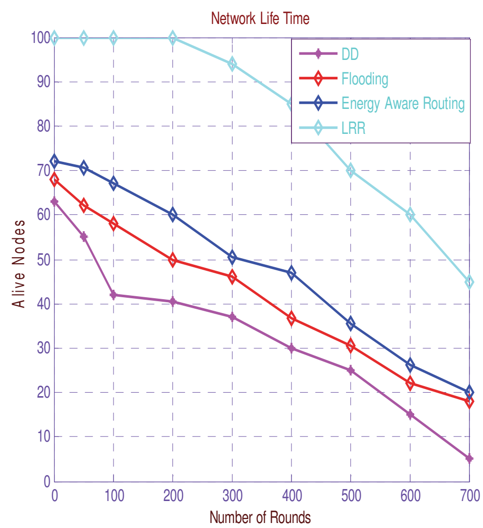
REER adopts a game-theoretic model with both remained energy and average energy loss on among neighboring nodes under consideration while evaluating the utility function for determining cluster heads.

Besides LEACH, PEGASIS is a chain based protocol. Each node communicates only with a close neighbor and takes turns to transmit data to the sink [4]. Cluster heads are decided based on the average minimum reach ability power. Unequal clustering algorithms like [5] aim to solute the energy hole problem. For the clusters, the closer they are to the sink, the smaller size they are formed. It saves energy for the inter-cluster communications. However, too many clusters around the sink will produce a large number of summary packets that leads to heavy traffic load.

Usually the traffic load in wireless sensor networks is unbalance. For example, sensors which are nearer to the source have more data load. Therefore, optimization of load distribution, called Load Balancing, is one of the most important factors for improving the efficiency of the networks. Optimization of load traffic distribution in WSN could increase the lifetime of the network. Since, there is more power consumption in nodes with more traffic load then the data transaction in the network could be optimized.

The authors in [1], [2], [3] proposed game theory which has been used in sensor networks, with incentives for forwarding nodes and punishing misbehaving nodes [1]. In the autonomous sensor network using zero-sum two-person game theory technique, $\in$ - equilibrium mixed strategies is used to get optimal solutions of energy conservation.

V. Simulation Results And Discussion: The proposed algorithm has been simulated and validated through simulation. The sensor nodes are deployed randomly in a 100x100 meters square and sink node deploy at the point of (50, 50), the maximum transmitting radius of each node is 80m. In this section, we evaluate the algorithm of LRR protocol and compare it with other existing protocol.



Network Lifetime: The network lifetime for each simulation is showed in Figure 3. These curves are showing that in direct diffusion (DD) protocol, after 400 rounds, about 80% of nodes in the network are died, but in proposed link reliability routing (LRR) protocol, after a rounds the network is arrived to this point. So the network lifetime is increasing about 37% with using of our model and proposed routing algorithm.

The average delivery delay means the averaged time delay between the instant the source sends a packet and moment the destination receives this packet. When the transmission rate is 1 packet per second, we can see that the average delivery delay of LRR is higher than the proposed protocol.

Conclusion: In this paper we presented a zero-sum game theoretic model for clustering algorithms in wireless sensor networks, which is provided for balancing energy consumption of sensor nodes and increasing network lifetime and stability. Furthermore, we presented performance evaluation and comparison of the existing clustering algorithms with our approach quantitatively with respect to network lifetime, data transmission capacity and energy efficiency. Comparing with other approaches through simulations, our protocol can surely guarantee to prolong network lifetime and improve the data transmission capacity up to 37% respectively.

References:

1. F. Akyldiz, W. Su, Y. Subramanian, Sankaras and E. Cayirci, "Wireless sensor works: a survey", Computer Networks, vol. 38,, 2002, pp. 393-422.
2. Chang, C.Y.; Shih, K.P.; Lee, S.C.; Chang, S.W. RGP: Active route guiding protocol for wireless sensor networks with obstacles. In Proceedings of IEEE MASS, Vancouver, Canada, October 2006; pp. 367-376.
3. K. Sangria, B. Dahill, B.N. L E.M. Royer, "A Secure Rohoc Networks", In Proc. of on Network Protocols (IC2002, pp. 78-87. Levine, C. Shields, and Routing Protocol for Ad 10th IEEE Int'l. Conf.CNP'02), IEEE Press.
4. O.Younis and S.Fahmy, Editors, "HEED: Hybrid Energy-efficient distributed clustering approach for adhoc sensor networks" mobile computer, vol.3,(2004), pp-366
5. B.S.Lee, H.W.Lin and W.Tarng, "A cluster allocation and routing algorithm based on node density for extending the lifetime of WSN" proceedings of the 26th international conference on advanced information networking and application workshops (2012) march 26-29.
6. TarekEl-fouly, Abderrazak, Abdaoui, Ryan Denver rile "A survey of Game-theoretic methodology in WSN Routing" procedia computer science (2012).

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