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Game Theory Based Diligent Energy Utilization Algorithm for Routing in Wireless Sensor Network

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***Abstract*—**Many cluster based routing protocols have been proposed in the field of wireless sensor networks, in which a group of nodes are formed as clusters. A cluster head is selected from one among those nodes based on residual energy, coverage area, number of hops and that cluster-head will perform data gathering from various sensor nodes and forwards aggregated data to the base station or to a relay node (another cluster-head), which will forward the packet along with its own data packet to the base station. Here a Game Theory based Diligent Energy Utilization Algorithm (GTDEA) for routing is proposed. In GTDEA, the cluster head selection is done with the help of game theory, a decision making process, that selects a cluster-head based on three parameters such as residual energy (R_E), Received Signal Strength Index (RSSI) and Packet Reception Rate (PRR). Finding a feasible path to the destination with minimum utilization of available energy improves the network lifetime and is achieved by the proposed approach. In GTDEA, the packets are forwarded to the base station using inter-cluster routing technique, which will further forward it to the base station. Simulation results reveal that GTDEA improves the network performance in terms of throughput, lifetime, and power consumption.

***Keywords*—**Cluster head, Energy utilization, Game Theory, LEACH, Sensor network

I. Introduction

WIRELESS sensor networks are comprised of many sensor nodes linked together to gather information. It contains sensor nodes distributed to sense events like temperature, sound, pressure where it finds the application in the field of military, target tracking, indoor/outdoor environmental monitoring, health monitoring, power monitoring, forest fire detection etc. [1], [2].

Modern networks are bi-directional, also enable control of sensor activity. Each sensor node comprises of radio transceiver for transmission and reception, microcontroller for processing the sensed data as per requirements, electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting [3]. These sensor nodes are deployed and their position need not be engineered or predetermined. The nodes have a dynamic topology where the communication between the sensor nodes and to the base station consumes more power, and it is a challenge for researchers to deliver the data with minimum utilization energy [4].

The design of sensor networks is influenced by the factors including scalability, topology, power consumption, operating environment, media, and hardware constraints [5]. To consume the power effectively, transmission path has to be selected meticulously. Routing the packet in the right direction during dynamic topology is one of the primary issues in wireless sensor networks for energy management [6]. In routing, decision making plays a main role that decides where to handover the packet precisely. The sensor nodes deployed in an environment may be in layered architecture or in clustered. In layered architecture, a powerful base station broadcast signal around it. Based on this, several layers get formed and they have the same number of hop count to base station. In cluster architecture, several groups are formed and a head is elected in each group which is responsible for data dissemination and gathering.

Failures in sensor networks may happen in a number of ways. This may be due to the following reasons [7] like depletion of batteries due to unnecessary communication; changes in topology due to dynamic displacement of nodes, links may fail when blocked by an external object or environmental condition. Link failure can be identified using the parameters like residual energy, signal strength, PRR, RSSI, SNR [8].

This paper proposes an efficient routing approach GTDEA where the nodes are framed in clustered architecture and the cluster head gets elected using game theory, a mathematical / analytical tool of strategies for dealing with competitive situations where the outcome of a participant's choice of action depends critically on the actions of other participants. Game theory is strictly determined if it has at least one saddle point. Saddle point is a payoff (profit, utility), the point in a game where both players have made their decisions and an outcome is reached. In proposed algorithm players are the nodes in the cluster and the strategies are the parameters considered to improve network performance. The payoff is the desirable outcome expected, In GTDEA it is cluster head.

II. Related Work

Various researches supporting techniques for election of cluster head and routing have been studied and most of them relate to static sensor nodes.

Zhao Han et al. [9] propose a General Self-Organized Tree-Based Energy-Balance routing protocol (GSTEB), that builds

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a routing tree using a process where, for each iteration, BS assigns a root node and broadcasts this selection to all sensor nodes. Subsequently, each node selects its parent by considering only itself and its neighbour information, thus making GSTEB a dynamic protocol.

Jianwei Niu et al. [10] propose the Reliable Reactive Routing Enhancement (R3E) to increase the resilience to link the dynamics for WSNs/IWSNs. R3E is designed to enhance existing reactive routing protocols to provide reliable and energy- efficient packet delivery against the unreliable wireless links by utilizing the local path diversity. R3E remarkably improves the packet delivery ratio, while maintaining high energy efficiency and low delivery latency.

Xiao Chen et al. [11] propose a framework protocol called reverse path (RP) to deal with asymmetric links and then present two efficient routing algorithms LayHet and EgyHet built on RP to satisfy performance requirements. LayHet is a performance guaranteed layer-based routing protocol that embeds the shortest path information and saves energy by minimizing the number of broadcasts and the probability of forwarding. EgyHet is its energy-upgraded version that considers nodes' remaining energy.

Degan Zhang et al. [12] propose an energy-balanced routing method based on forward-aware factor (FAF-EBRM). Here next-hop node is elected based on awareness of link weight and forward energy density. Furthermore, a spontaneous reconstruction mechanism for local topology is designed additionally.

Chen et al. [13] propose ProHet: a distributed probabilistic routing protocol that utilizes asymmetric links to reach assured delivery rate with low overhead. For every link ProHet protocol produces a bidirectional routing by finding a reverse path. Then, based on historical statistics, forwarding nodes are chosen.

ZhanyangXu et al. [14] propose a Density-based Energy-efficient Game-theoretic Routing Algorithm (DEGRA) that uses game theory and utility function is framed based on density of nodes, residual energy and average energy consumption of its neighboring nodes. Selection of cluster head is taken iteratively.

It is observed that various decision making techniques are proposed for efficient management of power in sensor network. Each node in the network must self configure in case of mobility. It is noted that such kind of topology changes with respect to movement of nodes and it is not quantified because of its instantaneous changes. Hence it is necessary to consider the decision making process to reduce the instability of the entire network.

III. Problem Definition

In wireless sensor network most of the energy is consumed during communication or improper routing. Proper routing can be done if the energy is managed properly in a network, thereby increasing the lifetime. A cluster head election can be based on the criteria such as energy level, the position of the node, coverage area, speed, direction [15]. The first influenced cluster head election protocol is LEACH which elects each node as cluster head with a certain probability of energy levels in several iterations [16]. When a node moves from its coverage area, concerns how the data sensed is routed to the cluster head and, if a cluster head is elected based on several criteria, then is it about sufficient for a node to act as a cluster head [17]. The objective of this work is to elect the cluster head effectively based on the parameters' residual energy (R_E), Received Signal Strength Index (R_{SSI}) and Packet Reception Rate (P_{RR}) using game theory, a decision making process. This approach guarantees a considerable amount of reduction in power consumption during node mobility due to improper routing.

IV. Proposed Work

In the proposed algorithm, cluster-based routing method is followed and more attention is given to the selection of cluster head, which plays a major role in packet forwarding and data gathering. Cluster head is elected based on Game theory, a mathematical method that describes the phenomenon of conflict and cooperation between intelligent rational decision-makers [14]. In particular, the theory has been proven very useful in the design of wireless sensor networks. There are many methods available in game theory [21], in which the method of finding a saddle point or equilibrium point is chosen and Residual energy(R_E), Received Signal Strength Index (RSSI) and Packet Reception Rate(PRR) are considered for choosing the cluster head.

A. Cluster Formation

Consider a sensor network having 'n' sensor nodes such that $S_i = \{s_1, s_2, s_3, s_4, ..., s_n\}$. After deployment of 'n' sensor nodes entire square region of length 'L' is divided into *l* clusters [14], by considering the transmission radius as 'R_i' for exchanging messages during the formation of clusters which is given by

$$L^2 = \sum_{i=1}^{l} \pi R_i^2 + \sum_{j=1}^{m} \Delta d_j - \sum_{k=1}^{n} \Delta O_k \quad (1)$$

where Δd- minimal separation between clusters, m - number of minimal gaps between clusters, ΔO - least overlapping area among clusters, n- number of possible overlapping among clusters.

If the transmission range of clusters are same, R_i=R

$$L^2 = l\pi R^2 + \sum_{j=1}^{m} \Delta d_j - \sum_{k=1}^{n} O_k \quad (2)$$

$$R \approx \frac{L}{\sqrt{l\pi}} \quad (3)$$

It gives the standard transmission radius chosen to form '*l*' clusters. Cluster Heads are selected by using game theory (game with saddle points) with some values obtained from the parameters such as Residual Energy, Received Signal Strength Index (R_{SSI}) and Packet Reception Ratio (P_{RR}).

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B. Residual Energy

Energy dissipation during communication is considered as E_{elec} and the power dissipation of the transmitter amplifier is taken as $\mathcal{E}_{amp}$ and assume d^2 as path loss [18].

The power consumed by the transmitter for k-bit packet transmission to a distance 'd' and packet reception is given by

$$E_{Tx}(k,d) = E_{elec} * k + \mathcal{E}_{amp} * k * d^2 \quad (4)$$

$$E_{Rx}(k) = E_{elec} * k \quad (5)$$

The energy consumption and the residual energy are calculated by

$$E_{consumption} = E_{Tx}(k,d) + E_{Rx}(k) \quad (6)$$

$$E_{Residual} = E_{total} - E_{consumption} \quad (7)$$

C. Received Signal Strength Index

The received radio signal strength measurement is RSSI [19] and the received signal power is given by

$$P_r = P_t \times G_t \times G_r \times (h_r \times h_t)^2 \times d^{-2} \times L^{-1} \quad (8)$$

P_r is the received power of wireless signals, P_t is the transmitted power of wireless signal, d is the distance between the sending nodes and receiving nodes, G_t, G_r are the antenna gain of Transmitter and Receiver respectively. h_r, h_t are the antenna height of Transmitter and Receiver respectively, L is system loss factor.

Suppose the transmission power of the wireless signal is P_t, the power of received signals of nodes located in the distance of d can be determined by:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \quad (9)$$

$$PL(dB) = 10\log\frac{P_t}{P_r} = 10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] \quad (10)$$

where P_L is the signal attenuation in dB.

D. Packet Reception Rate

The Packet Reception Rate is a measure of successful reception of data between two successive nodes [20]. If the PRR is high quality of link is excellent and possibility of error is less and vice versa. The PRR is given by

$$PRR = \left[1-\left(\frac{8}{15}\right)\left(\frac{1}{16}\right)\sum_{j-2}^{16} -1^j \binom{16}{j} exp\left[20\gamma(d)\left(\frac{1}{j}-1\right)\right]\right]^{176} \quad (11)$$

where $\gamma(d)$ is Signal to Noise Ratio (SNR).

V. Game Theory Based Diligent Energy Utilization Algorithm

Game Theory is the process of strategic decision making based on the situation containing a number of rules, strategies and outcomes [21], [22].

There are many techniques in game theory, in which the method of finding a saddle point or equilibrium point is chosen and considered parameters are residual energy, Received Signal Strength Index (RSSI) and Packet Reception Rate (PRR) for choosing a cluster head.

Two or more decision makers called players set circumstances so that a game is set to attain an optimal solution with the following assumptions

- Participants of the game are finite.
- Individual decisions can be made by the players based on the situation without communicating to others.
- The rules framed during process are specified and known to all participants in a game.
- Payout a player receives during outcome of a game is fixed and known in advance.

The overall structural arrangement of game theory approach for the proposed algorithm is depicted in Fig. 1.

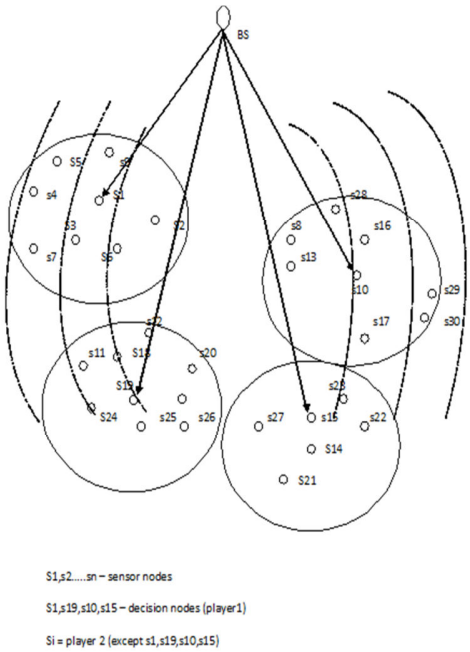


Fig. 1 Structure of Game Theory Approach for GTDEA

A. Cluster Head Selection Algorithm

Cluster head can be elected based on game theory, a decision making process in which the method of finding a saddle point or equilibrium point is chosen by taking the metrics Residual energy R_E, Received Signal Strength Index (R_{SSI}) and Packet Reception Rate (P_{RR})

1. ***Setup phase***: The network contains 'N' sensor nodes at M x M square region. In that, the base station will choose a cluster head in each cluster at initial stage based on RSSI.
2. ***Dispersal Phase***: Based on the cluster head chosen, clusters act independently and they gather required data and send it to cluster head. The collected data are handed over to base station based on

i). Timing: For each time duration 'T' collected data in queue is forwarded to base station

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ii). Unstable condition: whenever cluster head observes a critical situation requiring immediate action, then the data has to be forwarded immediately to base station.

iii). Based on the requisition: On demand, if base station requires the status from clusters, then the data is to be forwarded to the base station immediately.

iv). Based on queue (buffer) delay: When the data packets experiences maximum queue delay then the packets get forwarded to the base station

3. ***Re-election Phase***: Another cluster head is elected whenever

i) Energy dissipation is below the specified level in the present CH.

ii) Cluster head crosses its coverage area due to dynamic movement.

In Re-election phase, *k* clusters, each having *n* no. of sensor nodes, the obtained values are formed in a matrix in a way that the nodes are represented in "rows" and the parameters are represented in "columns".

From the obtained values, an optimal point has to be selected to elect a cluster head. Algorithm to find the optimal point or saddle point is shown in Fig. 2.

I. Find *min* value of each row that represents each sensor node's R_{SS}, P_{RR} and Residual Energy R_E values.

$$min\,value(S_i) = min_i\{R_i, P_i, E_i\}\ of\ k^{th}\ cluster\quad i \to 1\ to\ n$$

II. Find *max* value of each column that represents the parameters of n sensor nodes.

$$[max_value(R) = \max\{s_i(R)\}$$

$$max_value(P) = \max\{s_i(P)\}$$

$$max_value(E) = \max\{s_i(E)\}\ ]\ of\ k^{th}\quad i \to 1\ to\ n$$

III. Find the optimal point,

$$[\max\{min\,value(s_i)\} \cap \min\{max_value(R), max_value(P), max_value(E)\}]$$

Fig. 2 Saddle Point detection algorithm

The optimal point is chosen as a Cluster Head. Similarly, the process for finding an optimal point is followed by each cluster to elect a Cluster Head and its algorithm is shown in Fig. 3.

Fig. 4 shows the formation of clusters in Game Theory based Diligent Energy Utilization Algorithm (GTDEA) for routing.

B. Cluster Head Election with Saddle Point

Consider the parameters observed in each sensor node present in the cluster, and its optimal point is calculated. In Table I, the saddle point observed is 7. So the node S1are selected as cluster head.

1. Begin:
2. Initialization of parameters.
3. For(iteration=1; do clustering 'k'; i++)

{

compute (P_{RR}, R_{ssi}, E_R)

broadcast "HELLO" message to BS

if $(P_{RRi} > P_{RR(i=1,2\ldots k)})$ except for S_i then

elect CH = $S_i \forall$ k

endif

4. process: collect messages from nodes $S_k; k = 1,2 \ldots n; \neq i;$
5. if $(E_{si} < E_{th} \parallel Cov_{area} \neq R_i)$

re-elect CH(P_{RR}, R_{SSI}, E_R)

cal(opt_value)

elect CH = S_i

else

CH = $S_i \forall$ k

Endif

6. Goto process

Fig. 3 Cluster Head election algorithm

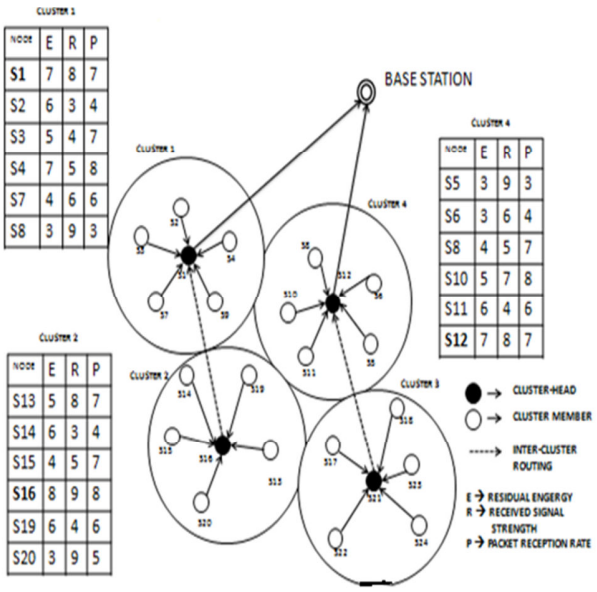


Fig. 4 Clustering in GTDEA

TABLE I
CLUSTER-HEAD SELECTION WITH SADDLE POINT

Node	R	P	E	Min value (s_i)
S1	8	**7**	9	**7**
S2	7	6	7	6
S5	8	3	8	3
S9	6	4	9	4
S10	5	5	5	5
S11	6	7	6	6
S14	4	5	7	4
Max value	8	**7**	9	

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C. Cluster Head Election without Saddle Point

In this case, no saddle point is reached. The intersection of *max(min)* and *min(max)* values is found and the corresponding node is selected as a cluster-head and it is shown in Table II.

TABLE II
CLUSTER-HEAD SELECTION WITHOUT SADDLE POINT

Node	R	P	E	Min value (s_i)
S1	6	**7**	9	6
S2	7	6	7	6
S5	8	3	8	3
S9	6	4	9	4
S10	5	5	5	5
S11	6	7	6	6
S14	4	5	7	4
Max value	8	**7**	9	

VI. PERFORMANCE ANALYSIS

Repeated experiments were conducted using GTDEA algorithm and the result are compared with existing protocol LEACH using MATLAB simulator. The comparison is done using the number of packets sent to the base station, the number of the dead nodes and the total sum of the energy of nodes versus the number of rounds the cluster head is selected. The result obtained is shown in Figs. 6-8, which shows the proposed algorithm has outperformed the LEACH protocol in all scenarios. The simulation environment is set up with the parameters listed in Table III and the network model is shown in Fig. 5.

TABLE III
SIMULATION ENVIRONMENT

Parameter Name	Value
Deployed sensor nodes	100
Packet length	4000 bit
Sensor nodes initial energy(E_{init})	0.25J
Energy consumption (E_{elec})	50nJ/bit

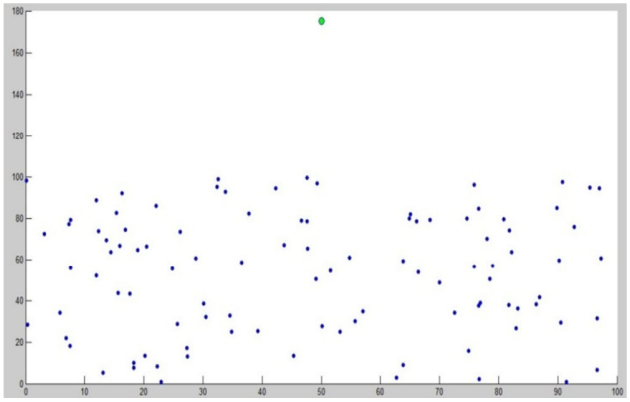


Fig. 5 Network Model

To evaluate the performance, the algorithms are subjected to evaluation under various performance metrics. Fig. 6 shows the number of packets sent to the base station in LEACH and GTDEA algorithm and it is observed that it is increased compared to LEACH.

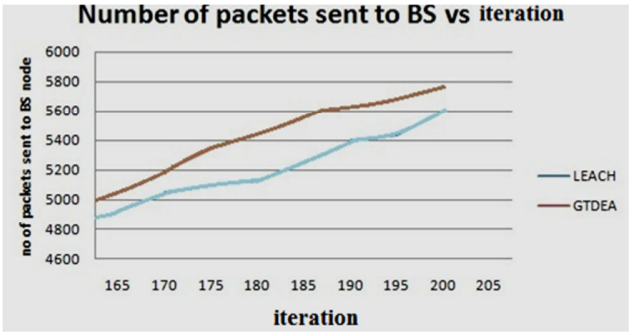


Fig. 6 Comparison of throughput using LEACH and GTDEA

Fig. 7 shows the lifetime of the network and it is observed that it is increased in case of GTDEA compared to LEACH. It is noted that in LEACH first node dies at the 138th round, in case of our proposed GTDEA the first node dies at the 177th round.

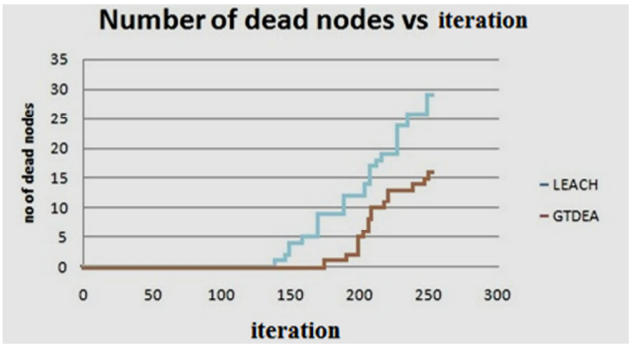


Fig. 7 Comparison of network life time in LEACH and GTDEA

In Fig. 8, the power consumed during each round is comparable and is analyzed using LEACH and GTDEA. It is observed that power consumption is reduced in GTDEA compared to LEACH.

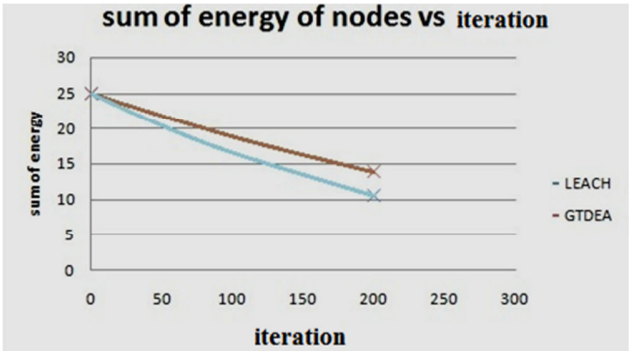


Fig. 8 Comparison of energy consumption in LEACH and GTDEA

VII. CONCLUSION

In cluster based wireless sensor networks, cluster head is elected based on several criteria and each node transmit sensed information directly to the base station without communicating with other nodes. However, it shows the inefficiency of the entire network to manage the energy

consumed by an individual. In this paper, a Game Theory based Diligent Energy utilization Algorithm (GTDEA) for WSNs is used where Residual Energy, Received Signal Strength Index (RSSI) and Packet Reception Rate (PRR) is used for electing its cluster-head iteratively. The routing of packets from Cluster-Heads to the base station are done using Inter-Cluster Routing Technique. Simulations show that both the energy consumption, throughput and network lifetime get improved comparing with LEACH algorithm.

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