A Survey on Wireless Sensor Network Clustering Protocols Optimized via Game Theory

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ABSTRACT

Wireless sensor network (WSN) consists of low size, power constrained nodes that sense the environment and communicate this information through wireless links. There are a number of research issues in WSN with energy efficiency being one of the prime issues for WSN applications. In clustering-based routing protocols, cluster head selection has significant effect on performance of the protocol, along with routing technique. Game theory as a mathematical notion, being able to analyze interactive decision situations, is applicable to a wide spectrum within WSN. It can assist in designing more efficient protocols. This article surveys the application of game theory in wireless sensor network protocols, specifically in the domain of communication protocols involving cluster formation i.e. clustering protocols in WSN and how it optimizes the functioning of these protocols.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design – *wireless communication*; **C.2.2** [**Computer-Communication Networks**]: Network Protocols.

General Terms

Design, Performance

Keywords

Clustering protocols, energy efficiency, game theory, wireless sensor network

1. INTRODUCTION

Embedded systems typically interact with the environment through sensing/actuation. Networking the devices (e.g. sensors) allows them to cooperate, which significantly enhances their capability to accomplish a certain task (e.g. region monitoring). The concept of networking the devices inevitably relates to wireless sensor network (WSN). A WSN can be defined as a network of (possibly small-size and low-complexity) devices referred to as *nodes* that can sense the environment and communicate the data collected from the monitored region through wireless links; the data is forwarded, possibly through multiple hops relaying, to a *sink* (sometimes called as *controller* or *monitor*) that can utilize it locally, or is connected to other networks, like the Internet, via a gateway [2, 5, 17]. The nodes can be stationary or mobile. The sensors can be location-aware or not. They can be homogeneous or non-homogeneous. One of the practical issues in WSNs is of energy management. Network lifetime must be as large as possible. Evidently, it is dependent on the fact that for how long a duration can the period of time be, starting with network set up and ending when the battery of sensor nodes is no longer able to supply the energy required for use in transmission/reception, processing or sensing tasks. The energy required for transmitting is usually assumed to be much larger than energy needed for processing a bit of information. For this reason, the communication protocols need to be designed according to energy-efficient pattern [18].

Game theory is a mathematical notion, which deals with the formulation of the right strategy that will enable a player (also referred to as an individual or an entity) when dealing with a complex challenge, to succeed in tackling the challenge. Game theory is somewhat not a novel notion, having been invented by John Von Nuemann and Oskar Morgenstern in 1944.Game Theory can be alternatively defined as the study of how the ultimate result of a competitive circumstance is decided by interactions among the players involved in the game (also called as 'agents'), based on the purposes and preferences of these players, and on the strategy that each player uses. Simply put, a strategy is a predetermined 'way of play' that guides a player regarding what actions to take in response to past and expected actions from other players. In any game, several crucial elements exist, some of which are: the agent, which represents an entity having its own aims and priorities, the second one is the utility (also referred to as agent payoff) which is a concept that relates to the amount of satisfaction that a player gets from an object or an event. Then there's the Game which is a formal description of a strategic situation, Nash equilibrium (also known as strategic equilibrium) which is a list of strategies, one for each player, which has the quality that no player can change its strategy and get a better payoff. Normally, any game has three components: a set of players, a set of possible actions for each player, and a set of utility functions plotting action profiles into the real numbers/values [13].

The paper provides an insight into the application of game theory in WSN clustering protocols. The paper is organized as follows: Section 2 reflects on the motivation behind this survey based on optimization of clustering protocols through game theoretic approach. Section 3 discusses the application of game theory in clustering based routing protocols of WSN. Section 4 reflects contemplation on other applications & future trends in WSN as far as the use of game theory is concerned.

2. MOTIVATION

With the quick development in wireless technology, WSN will surely find more and more application when the requirement for sensing the environment appears. There are many different techniques that can be applied to WSN, game theory being one of them. Game theory has been increasingly applied in the field of WSNs [16], and especially routing or clustering protocols, which require as much efficiency as possible. A node tries to obtain the maximum profit for taking series of actions. Whether a node gets a profit or not is dependent on the success of the action. Thus game theory can help in protocol optimization.

Often node's decisions at a specific layer are made with the idea of optimizing performance at some other layer; hence game theory can provide an insight into viewpoints for optimization. It allows scrutinizing the existence, distinctiveness and convergence to a steady state point when nodes in the network perform adaptations irrespective of others [3].

The above discussion, clearly justifies the use of game theory as a technique to realize enhancements in a WSN in one or another way, so as to bring about an optimal result in the specific fraction of field it is applied to.

In [16], the authors present a wide perspective of applications of game theory in the broad area of WSN, discussing game theoretic optimizations in many sub-areas including routing protocol design with some clustering protocols like [10],[11],[19] being included in it. However, there exists no paper providing an in-depth survey of all the existing clustering protocols optimized via game theory. This paper intends to realize a coherent and well-defined view of such optimized protocols. Thus, the scope of this paper is restricted to the exploration of the use of game theory in clustering protocols for WSNs.

3. WSN CLUSTERING PROTOCOLS OPTIMIZED VIA GAME THEORY

The following sub-sections discuss the WSN clustering protocols that have been optimized by game theory based techniques.

3.1 ACHGT (Adaptive Clustering Hierarchy based on Game-theoretic Techniques) [31]

ACHGT[31] models sensor nodes as players who make decisions regarding choosing to be a CH (Cluster Head) or not, using energy payoff functions. The assumptions include:

- Every node uses Global Positioning System (GPS) receiver.
- Base Station (BS) has unrestricted communication power & unlimited energy.
- Every node is static & isomorphic. It can stay in one of the three possible states (mentioned in Table 1).

Possible States: Table 1 summarizes the possible states.

Table 1. Possible states [31]

State	*Processor*	*Memory*	*Sensor, ADC*	*Transcei-ver*	*GPS*
S_0	Active	Active	On	T,R	On
S_1	Active	Active	On	T,R	Off
S_2	Active	Active	On	R	Off

(T= transmit, R= receive)

Network Model: Figure 1 depicts the network model.

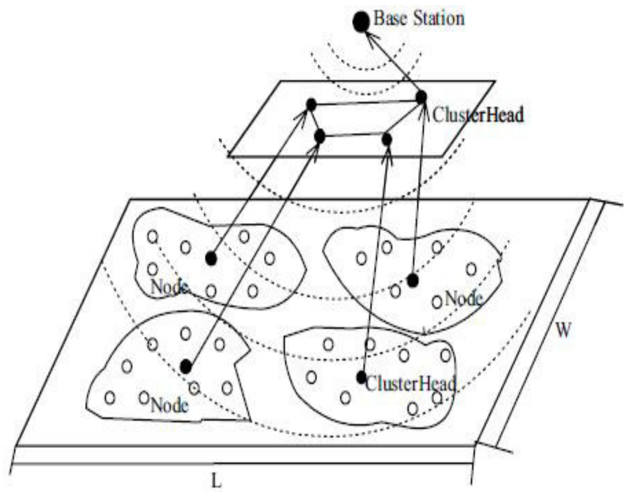

Figure 1. Sensor network model of hierarchical clustering based routing algorithm [31]

3.1.1 Steps in ACHGT:

- *Initialization*: With GPS of every node turned on, BS broadcasts control packet. Every node in state S_0, saves in its CACHE its position values after receiving the control packet & routes DATA packet, containing position value & remainder energy E_r, to BS by multi-hop routing. Nodes move to state S_1.BS computes average remainder energy E_a.
- *CH Node Referencing Position Computing:* BS decides total cluster number *n* based on:

$$n > \frac{L*W}{\pi * R_{max}{}^2} \qquad (1)$$

R_{max} is nodes' maximum transmission range, *L* is network area's length & *W* is its width. BS broadcasts CH reference position values (computed in set C= $\{C_1, C_2,.., C_n\}$) & E_a.

- *CH Node Selection*: WSN is considered as an undirected graph G=(V,E) with set of nodes $V=\{u_1,u_2,...u_m\}$, $M=\{1,2,..,m\}$ & set of edges, $E=\{(u_i,u_j)|u_i,u_j\ \ V,d(u_i,u_j)^o R,i,j \in M, i \neq j\}$, where $d(u_i,u_j)$ is distance between nodes u_i and u_j.

  CH node election function:

$$P(u_i) = \begin{cases} 1\,, E_r(u_i) \geq E_a \\ 0\,, Otherwise \end{cases}, u_i \in V\,, i \in M \qquad (2)$$

  Using node energy payoff function, all nodes satisfying (2) are chosen to be CH. In *n* network regions, the i-th region's CH node should satisfy:

$$y=f(d(u_j,c_i)^{\alpha},E_a,E_r(u_j))|_{min(d(uj,ci))}, u_j \in V, c_i \in C \qquad (3)$$

  (if $d(u_j,c_i)$ > distance threshold $d_{threshold}$, then α=4, else α=2)

  If many nodes satisfy (3) in same area, a node is chosen as *i-th* CH which satisfies:

$$y=f(d(u_{j'},c_i)^{\alpha},E_a,E_r(u_{j'}))\ |_{max(Er(uj'))}, u_{j'} \in U \qquad (4)$$

  where set of nodes, $U=\{u_{j1},u_{j2},..,u_{jk}\} \subset V$, $j \in M$, $k<m$. If many nodes satisfy (4) in same area, random selection is done.

- *Implementation Procedure:*
  - *Clustering Phase:* In i-th region, each node uses (2). If p=0 it switches to state S_2.As per (3) & (4), all nodes with p=1 can be chosen to be that region's CH. Once CHs are selected, rest of the nodes are informed about it through broadcast. Each non-CH node decides which cluster to join based on least communication energy. It first moves to state S_1, if in S_2.
  - *Steady Phase:* The CHs set up & transmit TDMA schedule to cluster members. Before the beginning of next round, BS computes new cluster number.

3.1.2 Performance

Compared with randomized rotation election method, ACHGT provides lower dissipation value of energy, improved evenness of dissipated network energy & improved ability of postponing network partitions. Network average remainder energy (average remainder energy per node), node energy quadratic mean deviation (indicator of evenness of network energy usage), first network partitions occurred (indicator of protocol postponing the network partitions) are the main metrics. Average remainder energy and energy quadratic mean deviation have been plotted against number of rounds. ACHGT achieves higher remainder energy and better evenness of dissipated network energy as compared to random method. The ability to postpone network partitions has been depicted through the plot of number of rounds v/s number of clusters, which illustrates ACHGT's enhanced performance, with higher values observed in case of ACHGT[31].

3.2 CGC (Cooperative Game theoretic Clustering algorithm) [10]

The authors in [10] propose a cooperative game theoretic model of clustering algorithms. The assumptions are:

- Self configuring cluster formation
- Nodes determine their cluster on the basis of advertisement message's received signal strength

It considers a cost sharing game *(A,c)* consisting of set of *n* agents(A) and a cost function *c*. Shapely value φ is a solution that allots one cost allocation to cost sharing games. $S \subseteq A \backslash \{i\}$,denotes set of all coalitions *S* of *A* not containing agent *i*. s=|S| is cardinality of *S*. Shapely value:

$$\varphi_i(c)=\sum_{s\subseteq A\backslash\{i\}} \frac{s!(n-1-s)!}{n!}\left(c(S\cup\{i\})-c(S)\right) \qquad (5)$$

3.2.1 Cooperative Game Theoretic Model

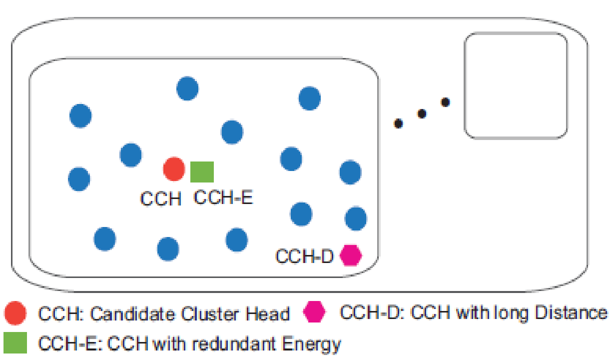

Figure 2. Cluster architecture for cooperation [10]

Figure 2 illustrates the cooperative game theoretic model. A cost sharing game *(A,c)* with 3 agents is considered. As depicted in Figure 2, the CCH is the candidate CH. The CCH_E and CCH_D are considered with redundant energy and the distance from CCH respectively.

Set A={CCH,CCH_E,CCH_D}.For the coalition set S, the cost function is the "total energy usage of all sensor nodes(SNs) for data gathering in single round including β frames while each agent in S is as a CH".CCH_E with redundant energy(E_{red}) is near to CCH while CCH_D is farthest.

Cost Function:

$$c(S)=\beta c_{CH}(S) + \beta c_{non\text{-}CH}(S) + c_{red}(S) \qquad (6)$$

c_{CH}=energy consumption of all CHs in S.
$c_{non\text{-}CH}$=energy consumption of non-CHs when agents in S are as CHs.
$c_{red}(S)$ =redundant energy of CCH_E when CCH_E ∈ S.

$$c_{red}(S)=\begin{cases}-E_{red} & : CCH\_E \in S,\\ 0 & : otherwise.\end{cases} \qquad (7)$$

Shapley value provides the solution for this game.

3.2.2 Conditions for Cooperation

Following are the conditions of coalition:

- Cooperate with a SN with redundant energy:
  $\varphi_{CCH} + \varphi_{CCH\_E} < c(\{CCH\})$
- Cooperate with a SN with long distance:
  $\varphi_{CCH} + \varphi_{CCH\_D} < c(\{CCH\})$.

3.2.3 CGC Algorithm

- It is assumed that there are *N* nodes and *k* clusters. At the start of round *r*, each SN chooses itself to be a CCH with probability P_i (similar to DCHS[8])*:*

$$P_i = \frac{k}{N-k*(r \bmod (N/k))} \frac{E_{residual}}{E_{initial}} \qquad (8)$$

- Each CCH broadcasts advertisement message. After reception of advertisement message other SNs can select optimum cluster on the basis of received signal strength.
- Each non-CCH sends join message containing SN's ID, residual energy, distance from CCH dealing with CH selection. A CCH decides final coalition (conforming to conditions of cooperation mentioned in sub-section 3.2.2) after receiving all such join messages, where for *i*-th node S_{Ni}: $E_{red\_i}=E_{residual\_i} - E_{residual\_CCH}$. CCH then does broadcasting of the set ID of CHs as other nodes wait for CH coalition message from CCH.
- If after reception of coalition message a node is elected as CH, it notifies other nodes of this decision. However, if a node is not elected as CH, this non-CH node waits for CH announcements & selects appropriate cluster (each non-CH node sends join message to the CH it selects on the basis of received signal strength).
- Having received all the join messages in cluster, CH sets up TDMA schedule & transmits it to members. The data collected after each SN transmits data in its slot, is aggregated & sent to BS.

3.2.4 Performance

CGC achieves better results than other algorithms like LEACH, in terms of network lifetime, reducing data transmission latency & energy efficiency with concern of position distributions. Data transmission capacity has been represented through number of SNs transmission times, which is the sum of transmission times for each node. Higher values of data transmission capacity are observed for CGC when plotted against time and also when plotted against energy consumption. This indicates higher amount of transmission to base station, thus reducing transmission latency. The network lifetime is prolonged in case CGC [10].

3.3 GTC (Game Theoretic Clustering) [29]

GTC [29] is a clustering algorithm which decides appropriate cluster size as per their hop distances to sink. It uses game theory in cluster formation. The assumptions are*:*

- Sensors & sink, all are stationary.
- Each sensor transmits data sensed to sink through multi-hop route periodically and can adjust its transmission power as per the distance needed.
- Links are symmetric.
- Sensor can estimate its distance to another sensor and sink as well (hence knows the hop distance to sink after initial phase).

Figure 3 depicts the concept of hop distances to sink & rectangular regions (each including nodes deployed at certain hop distance).

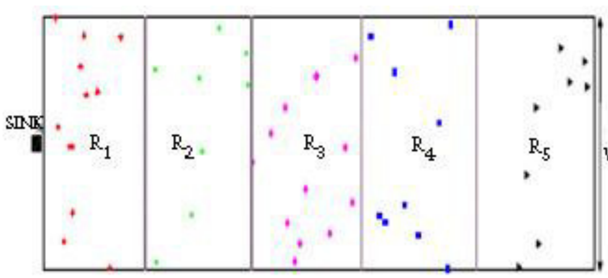

Figure 3. Hop distances to sink & rectangular region[29]

3.3.1 GTC Procedure

It consists of two parts: LBA (Load Balancing Algorithm) and Cluster formation using WSLS (Win-Stay, Loose-Shift).

3.3.1.1 LBA

It determines appropriate widths of all regions to ensure equalized energy consumption of CHs. The nodes in regions with less hop distance to sink tend to run out of energy sooner (as a result of relay load), so LBA aims to mitigate this problem.

On the basis of analysis, it is concluded that a CH in region $i+1$ can achieve approximately same energy consumption level as a CH in region i by attaching more member nodes.

The width of region i is computed by:

$$(L/k+\alpha(i-(k+1)/2)/W\sigma \quad (9)$$

where L & W correspond to the network area length & width respectively. k is the number of regions and σ is node density. α is a factor that makes energy consumption by receiving & processing data packet(E_g) equal to energy consumption caused by packet relay(E_r).i.e. $\alpha E_g=E_r$.

3.3.1.2 Cluster Formation Using WSLS

An iterated normal form game for k nodes elected as CHs in a Data Collection Round (DCR) in k-region network is defined in this phase, which further includes:

Win-Stay, Loose-Shift strategy: The principle followed is,' if the most recent payoff was high, the same choice will be repeated, otherwise the choice would be changed' [21].

Clustering process: This includes CH election & cluster formation. As there's only one CH in region i, the strategy for CH selection is highest-residual-energy-first. At the start of DCR, each node sets a competition timer with expiration time inversely proportional to its remaining energy. The first node whose timer expires, broadcasts a "CH-announcement" packet. Other nodes in transmission range turn off their timer on hearing this announcement. After the CH election, cluster formation starts. Initially, each CH j transmits a "cluster-formation-announcement" within a region of radius r_j (initialized to $\sqrt{W^2+{d_i}^2}$) determined by:

$$r_j = \begin{cases} \min\left(\frac{N_{exp}(j)d_{max}(j)}{N_{act}(j)}, \sqrt{W^2+d_i^2}\right), \; if\ m>2 & (a) \\ r_{last}(j), \quad if\ m\le 2 & (b) \end{cases} \quad (10)$$

where $m=|N_{act}(j) - N_{exp}(j)|$

N_{act} is the actual number of nodes associated with node j when last time it was the CH. N_{exp} is the expected number of nodes that should associate with CH j. $d_{max}(j)$ is the maximum distance between member nodes & node j when it was CH. Width of the region i is denoted by d_i and the transmission range by $r_{last}(j)$ when it was the CH. Minimum payoff a CH can accept is 0.5.(a) means the node lost and (b) means it won last time when it was the CH.

Thus CHs adapt their cluster-formation-announcement transmission ranges.

Each non-CH node may hear these announcements from many CHs, but sends "CH-association" request to CH that has announcement message with maximum RSSI. CH replies with "CH-confirmation" packet. At the phase's end, a node with no-CH association transmits "CH-association" request with a range$\sqrt{W^2+\ {d_i}^2}$ and nearest CH replies.

3.3.2 Performance

The authors mention that, as per the results of simulation, on comparing the performance of GTC with EC based on same condition in [20], GTC achieves greater energy efficiency than EC (which includes random selection of CHs). The parameter of stable operation period (worst-case time until a node depletes its energy), referred to as network's lifetime also, is used for evaluation. The SOP (Stable Operation Period) values are higher in case of WSLS being used than in case devoid of WSLS. For GTC's comparison with EC, SOP is observed with respect to node density, network width and total number of regions. Improved SOP values are observed in case of GTC [29].

3.4 DEGRA (Density based Energy efficient Game theoretic Routing Algorithm) [24]

DEGRA[24] assuages the energy hole problem(sensors near the sink or on critical paths drain out much faster in terms of energy consumption than other nodes). It's a hierarchical routing algorithm which involves clustering and uses game theory in CH selection. The assumptions are as follows*:*

- Homogeneous & stationary nodes which can adjust their power level as per the distance to receiver.
- Symmetric links.

The *utility function* for CH determination is:

$$U_i = \frac{E_{residual}(s_i)}{E_{total\_cost}\ (s_i)/Den(s_i)} \tag{11}$$

$E_{residual}$ denotes residual energy of one node and E_{total_cost} denotes total energy consumption of its *Den* neighboring nodes. *Den* is density i.e. count of nodes located within a circle transmission region of neighboring nodes. Thus, node with greater remaining energy, relatively lesser average energy consumption among its neighbors has better possibility of becoming CH.

3.4.1 CH Selection Procedure

The CH selection is nodes' decision making procedure. All nodes calculate their utility value & broadcast it. Any receiving node that has greater value becomes new CH candidate & broadcasts a new message with its own information. The receiving nodes with lesser utility value broadcast original message. Nodes with equal utility value compare ID to resolve conflict with the rule of smaller ID winning. Node with largest utility becomes CH.

DEGRA aims to finds *k*-cluster head, the process is done in k-rounds periodically. The focus is on nodes beyond the transmission range of determined CHs, recalculating nodes' density & corresponding utility, so that CHs are distributed more evenly. The rest CHs are still decided for the greatest utility value per round, following the method mentioned above.

CH deduction can be considered as k-stage dynamic game. With highest utility value selected, the finite game of complete & perfect information has pure-strategic *nash equilibrium* for each stage.

3.4.2 Performance

As per the simulation results mentioned in [24], CH distribution is more even in case of DEGRA than LEACH [9]. The locations of CHs in DEGRA and LEACH are observed, with more evenness evident in DEGRA. The energy consumption metric is observed against the advancement of rounds and it is observed that DEGRA consumes less energy than LEACH and DEER [28]. The network lifetime, as a metric, is depicted through the plot of alive nodes v/s rounds. The values are much larger in DEGRA, than LEACH and DEER.

3.5 CROSS (Clustered Routing Of Selfish Sensors) [11]

CROSS [11], considers selecting a number of cluster heads as a clustering game played by nodes. The assumption is*:*

- Every sensor may hear transmissions from other sensors.

Payoffs description:

- If a node decides not to be a CH, then if no other node chooses to be a CH, payoff=0.
- If at least one other neighbor node chooses to be a CH, payoff=v; i.e. the gain in successfully delivering data to sink.
- If a node chooses to be CH itself, payoff=v-c; i.e. payoff for successfully delivering data to sink minus the cost of becoming CH.

Thus *utility function* (for player *i*) is:

$$U_i(s) = \begin{cases} 0\ ,\ if\ s_j = ND, \forall j\ \in N \\ v - c\ , if\ s_i = D \\ v, if\ s_i = ND \text{ and } \exists j \in N\ s.t.\ s_j = D \end{cases} \tag{12}$$

Strategy set, S={D,ND} i.e. declare itself CH, not declare itself as CH. The probability that a node declares itself as CH in clustering game with *N* nodes:

$$p = 1 - \omega^{1/(N-1)} \tag{13}$$

The CH consumes energy in aggregating packets and communicating it to sink. A cluster member consumes energy in sending data to CH, i.e. $E_{i,CHi}$ which is denoted by δ. The benefit node gets playing ND (while at least another node plays D) is v- δ; ω represents c/v. However with incorporation of δ, as mentioned above, it becomes (c- δ)/(v- δ).

3.5.1 CH Selection Procedure

A node calculates the probability of becoming CH in first round. Because of random method, some nodes will choose to be CH and send beacons, so every other node can choose the nearest CH. The CH will then gather data from members, aggregate it & send to sink. To distribute energy usage evenly of CH role, *p* is set to zero (as per zero probability rule) for nodes who have been CH in earlier round. Thus, in round *j+1*, number of players playing clustering game is total nodes sans number of nodes who have been CH in previous *j* rounds. When all nodes have served as CH, a "reset" occurs & number of players is set to *N*. However if a node's whole energy is consumed, total number of players is reduced accordingly.

Nash equilibrium: The strategy where a single player plays D and all other play ND is a nash equilibrium. Symmetrical equilibrium exists for mixed strategy cases.

3.5.2 Performance

The authors mention the use of network lifetime as the most important metric for performance evaluation and describe it as 'lifetime of the node which first runs out of energy'. CROSS performs better in terms of network lifetime (plotted against parameter ω) than LEACH. But for the other metric, maximum node lifetime (plotted against parameter ω), the performance is inverted. Maximum node lifetime has been described as the lifetime of last node which runs out of energy. This is because as more nodes deplete their energy, the rest of the nodes have their probability of being CH increased which causes higher energy usage [11].

3.6 CROSS2

CROSS2 is a slight modification of CROSS protocol mentioned in [11].CROSS2 uses the probability p' that maximizes the expected payoff of a node (as opposed to CROSS1 using equilibrium probability).

$$p' = 1 - (\frac{c}{Nv})^{1/(N-1)} \tag{14}$$

3.6.1 Performance

CROSS2 achieves higher network lifetime (plotted against number of nodes) values than CROSS1. The authors mention that ω value used is 0.5 as CROSS achieves near optimal performance at this value. Although LEACH outperforms CROSS1, yet it is not able to outperform CROSS2 for higher number of nodes [11].

3.7 LGCA (Localized Game theoretical Clustering Algorithm) [22]

LGCA [22], involves localized clustering game. Following are the observations on CROSS that LGCA aims to improve:

- CROSS assumes global view as every node can hear transmission from every other node, which isn't realistic. LGCA does clustering in localized manner by introducing parameter Rc (maximum communication distance reachable by a sensor node serving as a normal node).
- The equilibrium probability in CROSS indicates that the node has very little probability to become CH as all nodes play clustering game. In LGCA clustering game is played locally.

Assumption in LGCA is as follows:

- Each node can hear transmission from its neighbors which are in its communication radius.

3.7.1 Clustering Procedure

Following are the phases involved in clustering procedure.

3.7.1.1 Initial Phase

When deployed each of the sensors broadcasts "Hello" message to its neighbors. It also gets to know number of neighbors (notation: Nn(i),for node *i*) on receiving "Hello" messages.

3.7.1.2 Setup Phase

It further includes:

- *Potential CH electing:* A node *i* believes that Nn(i)+1 players are participating. Thus probability that node *i* declares to be CH is:

$$p(i) = 1 - \omega^{1/Nn(i)} \quad (15)$$

  ω is *c/v*, where *v* is the payoff a node gains when its packet is delivered to base station via at least one other CH and *c* is cost of being CH. If a node chooses to be a CH, it temporarily resides in the potential CH state. A potential CH has to further contend for a real CH, otherwise returns to normal state. If a node becomes an actual CH, localized zero probability rule is used. Thus, node *i* updates its number of qualified neighbors to play next round as: N_{cur}=Nn(i) - N_{CH}(i) & hence updates potential CH election probability ($N_{CH(i)}$ is number of served neighbors for i^{th} node). By using N_{cur}(i) in potential CH electing probability calculation instead of Nn(i), the probability is updated.
- *Real CH contention:* A potential CH who is the earliest to strive for physical media(using CSM/CA) will instantly announce itself as real CH. On hearing the announcement, potential CHs return to normal state. Each real CH is at least Rc meters away from other.
- *Cluster formation:* The real CHs, broadcast their selection as CH. Rest of the nodes choose their closest CH.

3.7.1.3 Steady-State Phase

Every node sends data to CH which aggregates data & sends it to base station. After predefined time, round ends & next round starts.

3.7.2 Nash Equilibrium

Nash Equilibrium remains similar to CROSS as the protocol is similar to CROSS except that it uses concept of localized game.

3.7.3 Left Behind Node Problem

Restricting the communication radius of every node, a node cannot be covered by another if distance is more than Rc.

LGCA1 eliminates this problem by allowing all left behind nodes to become potential CH & bid for real CH through MAC contention.

3.7.4 Performance

LGCA outperforms LEACH & CROSS to some extent in terms of average network lifetime. The authors use network lifetime as a performance metric and depict it as the round of first node dead (similar to CROSS). LEACH has no influence of parameter ω, but for CROSS and LGCA as ω increases, network lifetime decreases because the probability of a node choosing to be CH decreases. However, the decline observed in network lifetime with increase in ω is less in case of LGCA than CROSS. It is also observed that the maximum node lifetime (depicted through round of last node dead) is highest for LEACH, yet its energy usage is uneven. LGCA achieves the most uniform rate of energy expenditure [22].

3.8 LGCA2

LGCA2 has been mentioned in [22] itself. It is similar to LGCA1, but differs in the mechanism to handle left behind node.

3.8.1 Mechanism to Handle Left Behind Node

All left behind nodes increase their power level to communicate with the closest CH and join that cluster.

3.8.2 Performance

Average no. of CHs is less in LGCA2 than LGCA1 when Rc is less than 20 m, LGCA2 performs better than LGCA1 on the maximum node lifetime. As mentioned in sub-section 3.7.4, LGCA family has the most uniform rate of energy usage [22].

3.9 A Game-Theory Based Clustering Approach for Wireless Sensor Networks [25]

In 'A Game-theory Based Clustering Approach for Wireless Sensor Networks' [25], the authors propose a game theory based clustering approach. The assumption is:

- Similar to general clustering algorithms, it assumes one CH per cluster and CHs sending their respective cluster data to sink.

3.9.1 Clustering Procedure

A CH is chosen based on maximum residual energy. But some nodes may lie about it, to refuse becoming CH. A game theoretic model is adopted to promote co-operation of such selfish nodes.

Strategy Set, S: {Declare, Refuse to Declare}={D,RD};

Utility function:

$$U_i(S)=\begin{cases} v - c_D \ \ if\ S_i = D \\ v - c_{RD}\ \ if\ S_i = RD \text{ and } \exists j \in N, s.t. S_j \in D \\ 0 \ \ if\ S_j = RD, \forall j \in N \end{cases} \quad (16)$$

c_D and c_{RD} represent the cost of node when it declares itself as CH and the refusing state respectively. *N* is the set of nodes. Payoff *v* is given to node ready to become CH.

Probability of a node declaring itself CH:

$$p = 1 - \left(\frac{c_D - c_{RD}}{v - c_{RD}}\right)^{\frac{1}{N-1}} \quad (17)$$

Based on the calculated probability each node decides to be a CH or not.

3.9.2 Concept of Candidate CHs

A candidate node does replication of CH's data so that in case of disconnection of link between CH & sink, the data is not lost.

Selecting Candidate CH: All the member nodes(except CH) are players for they aim to become candidate CH to win possible payoff. Nodes offer bid(represented by B^i_k for node *i*). The one with maximum value wins.

$$B^i_k = \frac{E^i{}_{residual}}{R^i_k \cdot c^i_{sink}} \quad (18)$$

$E^i{}_{residual}$ is residual energy of node *i*. $R^i{}_k$ is the cost for *i* to replicate data in its CH. $c^i{}_{sink}$ is node *i*'s cost of communicating with the sink.

3.9.3 Nash Equilibrium

A mixed strategy nash equilibrium exists if it is assumed that each player can select its strategy in random manner using probability distribution.

3.9.4 Performance

In performance evaluation, throughput of sink is the metric considered. With this protocol the throughput of sink is barely changed when connection between CH and sink get cuts off, as opposed to dropping to zero in case devoid of this protocol [25].

3.10 A Game-Theoretic Approach for Efficient Clustering in Wireless Sensor Networks [4]

In [4], the authors propose a 'game-theoretic approach for efficient clustering in wireless sensor networks' which uses game theory to solve the selfish nodes problem in clustering. The assumptions are:

- Homogeneous & stationary nodes
- Multiple sink nodes
- Nodes can adjust their transmission power as per relative distance from receiver
- Symmetric Links

3.10.1 Game Theoretic Model for CH Selection

Need of Game Theoretic Model: Each cluster has one CH, which aggregates data received from member nodes and sends to sink. Residual energy is the metric used for CH selection. Since a node may lie about its residual energy to avoid being chosen as CH, game theoretic model is used to model CH selection as a game, similar to [25]. Thus, to optimize selection procedure and to make selfish nodes cooperate game theoretic model has been devised, which is explained below.

- N is the set players i.e. number of nodes
- Strategy set S={declare, refuse to declare}
- c_D and c_{RD} are the costs of node declaring itself as CH & refusing to declare itself as CH.
- A payoff *v* is provided to nodes willing to be CH.
- Utility for node i, $U_i(S)$:
  v-C_D , if *i* declares to be CH
  v-C_{RD} ,if *i* refuses to be CH & some other node chooses to be CH.
  0,if all nodes refuse to be CH
- Probability of a node declaring itself to be a CH is denoted by *p*. At equilibrium,
  $$p = 1 - \left(\frac{c_D - c_{RD}}{v - c_{RD}}\right)^{\frac{1}{N-1}} \quad (19)$$
- With probability *p* set, a mixed strategy nash equilibrium is there. With *p* calculated for every node, each node has a natural incentive to cooperate & declare itself as CH.
- Average utility at equilibrium,
  $$\overline{U}_{NE} = v - c_D \quad (20)$$

3.10.2 Performance

The two metrics considered are: transmission delay and loss rate. With respect to performance evaluation, the authors explain that if two nodes, say A and B, want to send data to sink through their CH and if A used to be a CH then it'll get chance to send data, causing selfish node B to wait. Thus, a decrease in the delay and loss rate is observed if a node chooses to be a CH, which rationally causes a selfish node to cooperate. Simulation results depict the same, leading to the conclusion that this game theory based mechanism provides good performance [4].

3.11 A Novel Game Theoretic Approach for Cluster Head Selection in WSN [6]

In [6], the authors propose a novel game theoretic approach for CH selection using game theory. The assumption is:

- Single hop cluster based network with sensors dispersed in field is the scenario assumed. The field has several clusters with each cluster having one CH.

The parameters for CH selection are:

- *Distance factor*: Distance between a node to rest of the nodes in cluster.
- *Internal energy*: Remnant energy of node.

$$Payoff = (\alpha+\beta)*ET_x(q,d) - E_D \quad (21)$$

α,β are the rate of depreciation of packet forwarding and rate of packet receiving respectively. $ET_x(q,d)$ is the energy used to transmit *q* bit of data at a distance *d* for each sensor. The first term becomes the reward based on network usage. E_D is decline in energy of a node due to packet transmission.

3.11.1 CH Selection Procedure

The authors in [6] follow the below mentioned procedure:

- Initialize remaining energy of nodes & deploy nodes over simulation region. Fuzzy-c means clustering technique is used to initially find clusters & their members.
- Each member in each cluster computes its euclidean distance from BS and also the energy usage for transmission & reception.
- Packet transmissions are allowed and payoff of each node of each cluster is computed. A table containing payoff & residual energy of every node of each cluster is maintained with a certain regular interval.
- Total payoff for each cluster is computed .i.e. payoff(C_i).
- For each interval of time the cumulative payoff is calculated i.e.$\sum$ payoff(C_i) & it can be justified that its

within threshold value and hence it is concluded that the system shall stabilize with the chosen CHs. Threshold is expressed as a certain percentage of initial energy.

- Repeat the procedure by going to first step when total payoff of a cluster reaches a value that's less than the threshold value.

3.11.2 *Performance*

As per the simulation results mentioned in [6] the proposed algorithm performs better than LEACH and HEED [30] in terms of number of nodes alive over time. Thus, the performance metric of network lifetime witnesses an improvement.

3.12 The Inter-cluster Routing Algorithm in Wireless Sensor Network Based on the Game Theory [23]

The inter-cluster routing algorithm in [23] considers the cluster routing problem as a game problem & analyses the game equilibrium which decreases energy consumption & optimizes Quality of Service (QoS).The algorithm is a compromise between the network QoS & node's energy consumption. The assumptions are:

- The system architecture consists of hexagonal cluster topology
- CH node is fixed, located in hexagon's center.
- The sink relays the information further to remote monitoring centre.

Network structure: Figure 4 depicts scenario of data forwarding. Each CH has certain relay nodes, e.g. in Figure 4, node C can relay data to sink via common node 4 or 6. So when nodes decide whether to be a relay node or not, they may refuse so as to save energy consumption and this affects network performance.

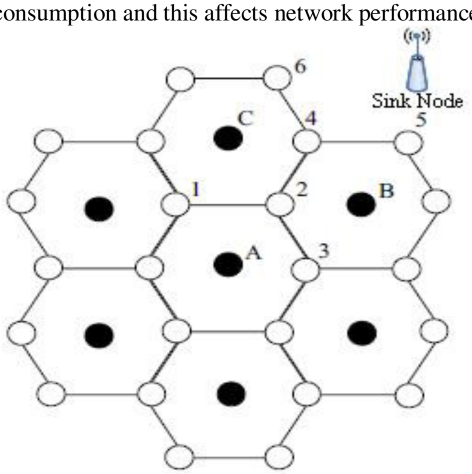

Figure 4. Scenario of CH nodes data forwarding [23]

3.12.1 *Game Model*

Utility function description:

M is the network QoS:

$$M = \frac{C_1}{1+\exp\left(-S\sum_{i=1}^{K} w_i (T_i - V_i)\right)} \qquad (22)$$

In the above expression,C_1,S are constant, k is the no. of network attributes, w_i refers to the sensitivity factor of chosen parameters *i*, T_i is tolerate offset degrees of the networks, V_i is the offset degree of the selected parameters(to quantify QoS, parameters are divided into two categories: beneficial attributes like bandwidth, throughput etc. and cost attributes like delay, jitter etc.).These attributes are normalized & then denoted by V_i. In U(M), $M=(M_1,M_2,\ldots,M_k)$ is QoS of k nodes, e_i is the efficiency factor of M_i. ρ is the competitive factor between different QoS, E_i being the node *i*'s residual energy.

Table 2 gives the detail of game model.

Table 2. Game model

Element	*Detail*
Players	CH nodes & public nodes(between the clusters)
Information	Main information consists of the participants needing to transmit the data volume, node's residual energy, QoS
Strategies	Strategy includes whether to be a relay node or not
Utility function U(M)	: $\sum_{i=1}^{k} M_i e_i - \frac{1}{2}\left(\sum_{i=1}^{k} M_i^2 + 2\rho\sum_{i\neq j} M_i M_j\right) - \sum_{i=1}^{k} E_i M_i$

3.12.2 *Routing Procedure*

The routing scheme is simple. Ordinary nodes periodically collect data & send to their CH, which after processing it transmits to sink node with multi-hop routing. The main decision required is selection of relay node.

Assume that node *j* selects node *i* as next hop node .Decision function to select node *i*:

$$u_i=\pi_i/C_i \qquad (23)$$

π_i is the revenue function:

$$\pi_i=M_{ij}\rho + (E_i(1-\rho))/E \qquad (24)$$

M_{ij} is the QoS between node *i* & *j*. *E* is node's initial energy.

Cost of node *i* when its selected as relay node:

$$C_i=((E_i^r.n)/ E_i \qquad (25)$$

E_i^r refers to the energy consumed in receiving unit bits of data. Forwarding data volume to node *j* is represented by *n*. Replacing π_i, C_i (from (24), (25)) in (23) gives the decision function on QoS & node's remaining energy.

3.12.3 *Nash Equilibrium*

It corresponds to stable game result.

$$E_i^* = \frac{1+\rho(N-2)}{2(1-\rho)} \cdot \frac{E}{\sum(e_j - E_j)} \qquad (26)$$

E_i^* is calculated as the best energy utilization strategy function of node *i*, similarly for rest of the nodes best energy consumption strategy function joint the node's best energy consumption strategy function, nash equilibrium is obtained.

$$E^*=(E^*_1, E^*_2,\ldots, E^*_k)$$

3.12.4 *Performance*

The decision function takes into account both network QoS and node's remaining energy. With a CH having the option of selecting one path out of the two possible, it is observed that with increased energy usage of a path, the decision quantity of other path increases leading to inclination towards choosing the other path. Solving the nash equilibrium solution, to find best strategy, can result in steady usage of node's energy & prolong network lifetime [23].

3.13 TEER (Trustworthy Energy Efficient Routing) [19]

TEER[19] algorithm models CH selection using game theoretic model. It also provides even energy usage distribution amongst sensors & more path security. The assumptions are:

- SensorNet Architecture consists of two-level hierarchy. The lower level has standard WSN. The higher level, corresponds to CHs, which aggregate data received from member nodes & send data to sink.
- Sensors are considered to be fixed. Sink is the only rechargeable node connected to internet.
- All nodes have broadcast range to either communicate with neighbors or sink.

3.13.1 Trust Model

Need: This evaluates node's trust level & finds evil nodes with malicious behavior. Table 3 gives its description.

Table 3. Trust model

Trust Model Feature	*Description/use*
Trust level range	0-1
Initial trust level	Value:1
Threshold T	If trust level<T,node is considered evil node
Data secrecy, integrity & undeniability	Each node has a pair of public & private key to encrypt & sign data packet
Encryption procedure at source node	Source node signs packet with private key, encrypts with sink's public key.
Encryption procedure at CH	CH fuses packets & signs with its private key
Dynamic updation of trust values	Sink detects misreporting sources & CHs doing packet modification and dynamically updates their values

3.13.2 Analytical Model

Table 4 gives the description of the analytical model.

Table 4. Analytical model

Election Game Features	*Description*
Set of n players	Set of sensors $S=\{s_1,s_2,..,s_n\}$
Strategies	Set of strategies, $L=\{l_1,l_2,\ldots,l_n\}$ If *i* chooses to CH, $l_i=1$ else 0.
Payoffs	Each node's payoff is equal to CH's π value

- The expression for π value of node *i* is as follows:

$$\pi_i=\alpha E_i/E_{init}+\beta R_i - \gamma\sum P_{pathloss}/(n_i.P_{max}) \quad (27)$$

α, β, γ are the weight parameters of node's residual energy, trust level, average path loss within neighbors respectively. E_{init} is node's initial energy level, E_i is node's current residual energy level, R_i is node's trust level. $-\sum P_{pathloss}/(n_i.P_{max})$ is node's average path loss to its neighbors.

- Each node tends to choose neighbor node with highest π value as CH to cause maximization of its payoff.

3.13.3 CH Election Algorithm

- Initial information of each node includes remaining energy level, trust level, initial energy level, average path loss to neighbors. Sink maintains cluster information and does all nodes' trust evaluation.
- Each node sets up possible head set P(initialized to empty).Each node broadcasts its π value to neighbors. Each node compares received values with its own & adds those whose π value is greater.
- If node's possible head set is vacant, it declares itself as CH & broadcasts declaration message. Normal node on receiving this, adds it to candidate CH head set C_i. If normal node gets multiple messages, it selects node with greatest π value to be its CH. After selection, it sends a member report message to its CH.
- If node *i* sees member report message from node *j* which is in its possible head set but it hasn't received any CH declaration message, node *i* will omit node *j* from its possible head set.
- When all sensors select their CH, CHs report to sink.

3.13.4 Nash equilibrium

The election game's nash equilibrium relates to optimal healthier CH with more energy & trust level [19].

3.13.5 Performance

Through game theoretic approach, the performance metrics of network lifetime and variance of energy level (variation in energy level of all remaining nodes in WSN) have been targeted for improvement. Simulation results in [19] show that TEER's better than LEACH in terms of network lifetime (the first node in case of LEACH dies in lesser number of rounds than in the case of TEER), even distribution of energy consumption (LEACH has higher variation of remaining energy distribution than TEER). In addition, TEER has increased path security(for *n-th* round, it is measured by ratio of number of secure packets received by sink in round *n* to total number of packets reported by source in round *n*) as well because of the trust model used.

4. OTHER APPLICATIONS OF GAME THEORY IN WSN AND FUTURE TRENDS

A variety of clustering protocols exist in WSN. Game theory has emerged as a new approach to analyze problems in WSN. With the application of game theory to clustering protocols, a more proficient approach has risen. Game theory, as observed in all of the above protocols mentioned in this survey, has resulted in optimization. It is of immense use, especially in the case of selfish nodes, e.g. game theoretic model for selfish node avoidance routing [7].Thus, applicable in scenario of network, whose security has been compromised by making the nodes behave selfishly which can lead to perilous consequences, e.g. the importantly needed data may not be accessible because of DoS (Denial of Service) attack. In [1] authors devise the prevention of DoS attacks in WSN as a repeated game between an intrusion detector and nodes of a WSN, where some of these nodes are malicious.

Game theory is not just applicable to domain of clustering protocols but to a variety of domains within WSN. For example, improving routing protocols using game theory [12, 32], energy saving and power control [15], detection of malicious behavior by nodes [14] (hence the application in field of WSN security).It can also be used in applications of WSN, e.g. target tracking. A technique for target tracking utilizing multi-agent and game theory has been proposed in [26, 27].When a target emerges in the sensing region, sensor nodes start formation of coalition dynamically and then they begin to negotiate using game theory. Coalition is made to track it with the target moving [16].

These are a few fields mentioned for using game theory, though a whole many realms still exist within WSN, to which game theory can be appropriately applied.

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