POWER EFFICIENT DATA AGGREGATION BASED ON SWARM INTELLIGENCE AND GAME THEORETIC APPROACH IN WIRELESS SENSOR NETWORK

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ABSTRACT

While performing data aggregation in wireless sensor networks (WSN), significant energy is consumed not only during active communication but also during idle state. For this, an accurate estimate of energy cost and an intelligent routing technique having distributed heuristic capabilities are necessary. In this paper, we propose a power efficient data aggregation technique based on swarm intelligence and game theoretic approach for WSN. In this technique, swarm intelligence is used to perform route discovery and to select the nodes with maximum power level as controller nodes. These controller nodes always remain awake to carry out data aggregation and forwarding, while other nodes are either in sleep/awake state. In each round of data aggregation forwarding, the controller nodes are adaptively changed depending on their power levels. After the successful delivery of data to sink, game theory approach is applied to determine the energy consumed during data aggregation. By simulation results, it is observed that the proposed approach reduces the energy consumption and increase the packet delivery ratio when compared with the existing techniques.

Keywords: Wireless sensor networks, Data aggregation, Swarm intelligence, Game theory, Energy efficiency.

I.INTRODUCTION

A Wireless Sensor Network

The ad hoc network possessing huge number of small sensor nodes positioned in huge quantity in order to intuit the physical world is termed as wireless sensor networks (WSN). Its applications include both military and civilian environment services. Here the sensor nodes are characterized by limited resources and inhibited power and they experience limited computation, communication and power resources. [1].

A new field of computing known as Ubiquitous computing or ubicomp in which the user lifetime is completely pervaded by the computer. The ubiquitous computing acts as an
invisible force assisting the user in meeting his or her needs without getting in the way. For realizing ubiquitous computing, WSN plays a vital role. These devices called sensor nodes are usually deployed consists of sensors, transceivers, processing unit, storage resources and actuators. Those nodes are deployed in networks for achieving some process of sensing. Typically the sensor networks share a common communication channel. [2]

WSN constitutes three classes of sensor nodes. i.e. sensing node, aggregator and sink. **Sensing node** detects the data and forwards these detected data to the aggregator node. **Aggregator node** gathers the data from sensing nodes subset with the help of suitable aggregate function such as sum, avg, min, max etc and forwards it to superior aggregator or sent to sink directly. **Sink** processes these data and discovers a useful information [5]

**B Data Aggregation**

Usually in WSN, many quantities of sensor nodes gather particular information from the surrounding and transmit through aggregator and later to the sink node. In the sink node, the information are processed, investigated and utilized by the application. The wide-ranging approach in this network is together processing the data created by the sensor node during the time of forwarding it towards the base station. This method of processing the data together is termed as data aggregation that gathers the data which is appropriate to similar events. [4]

The ultimate goal of data aggregation is disposing redundancy in the transmitted data which reduces the quantity of data transmission thus saving substantial amount of energy and bandwidth. The data aggregation is categorized based on the network structure as tree based and cluster based data aggregation protocol. [5]

In **tree based data aggregation**, a tree structure is maintained. Here leaf node acts as sensing node, remaining non-leaf node acts as aggregator node and root acts as base station or sink. [5]

In **cluster based data aggregation**, nodes are divided into clusters. In each cluster, a cluster head is elected that executes the process of aggregation in localized manner aggregator node and further the aggregated data is sent to the next cluster head pathway to the sink. [5].

**C Limitation of Data Aggregation in WSN**

1] In case the process of data aggregation has some suspicions, the intermediate nodes compute the partial result and later they will be used in computing end results thus balancing the energy. The drawback of this process is that fundamental networking protocol to have a necessary support for synchronization. This synchronization enhances extra bandwidth with respect to bandwidth, and energy the retort duration of the queries. [6]

2] Usually the multi-sensing data elements are transmitted in single packet. But in aggregation, only limited number can be transmitted because of packet size constraints [10].

**D Swarm Intelligence**

An artificial intelligence technique that represents the clever activities witnessed in swarms with the help of multi-agent systems is termed as swarm intelligence. A multi-agent system (MAS) is a system composed of multiple interacting intelligent agents. They can be used to solve problems that are difficult or impossible for an individual agent or a monolithic
system to solve. The similar activity of swarm is witnessed in other organisms such as birds, fish and insects. Swarm behavior results in unexpected and organized emergent behaviors that make the creature swarm stronger. [7]

In swarm intelligence, there is no presence of head or any universal scenario. However, intricate intelligence is resultant of interaction of collective effortless intelligence. As the agents communicate only with geographical neighbors and local surrounding, they can get information only from local environment and modifies the confined surrounding [8]. The independent and self-organizing agents are utilized to model swarm and it pursues set of low-level rules which presides over individual activities. An explicit weight factor is related to each rule which finds the extent of its power on agent’s behavior. Since every agent pursues the rule set, on the whole the activities of swarm organize to generate more complex evolving performances. [7]

The ant colony optimization (ACO) is related to one of the swarm intelligence technique which helps in performing route discovery [14]. The creation of new routes necessitates the use of a forward ant (FA) and a backward ant (BA). A pheromone track is established to the source node using FA and to the destination node using BA.

FAs are launched in order to search the destination. It travels in the network from node to node and gathers details about the node it has visited. When it arrives at the destination, it is transformed into backward ant. BAs backtracks the same path as forward ant follow. Its function is to update the routing tables along the path based on the energy level collected by the forward ant. Since BAs take additional data from the forward ants they can update both forward and backward paths at the same time. [17]

E Game Theoretic Approach

The field of applied mathematics that demonstrates and examines the decision making conditions is termed as game theory. The set model in the game theoretic approach utilizes the payoff tables and the strategies involved in it are organized. Here the set model is represented as “game” and those who make decision are represented as players. As a simple method to view the circumstance, the player selects a deed from pre-defined list of actions that enhances their profit. The utility function is used by players to examine the result of deed of neighbor players.

The game is described as follows. A game (G) in the normal form is viewed as:

\[ G = (D, S, \{u_i\}) \]

Where \( D = \{1, 2, 3, \ldots\} \) is the set of players (decision makers), \( S_i \) is the action set of player i, Here \( S = S_1 \times S_2 \times \ldots \ldots \times S_n \) is the Cartesian product of the action set existing to each player \( \{u_i\} = \{u_{i1}, \ldots, u_{in}\} \) is the utility function set that each player i wishes to maximize.

For every player i, the utility function \( \alpha_i \) depend on the earlier actions, \( \alpha_{-i} \) selected by the other players prior to player i. jointly \( \alpha_i \) and \( \alpha_{-i} \) build a unique action tuple \( \alpha \) which symbolizes the activities of each player. Mathematically \( \hat{\alpha} \) is the finest response by player i to \( \alpha_{-i} \) if
\[ \tilde{a} \in \{\arg \max u(a_1, a_2)\} \]

This model concludes that there may be existence of more stable model [9].

F. Problem Identification

It has been observed that energy is not only consumed by the active communication in wireless sensor networks, but also consumed in idle state. As a result, an important technique to reduce power consumption during data gathering in sensor networks is to place nodes in the low power sleep state whenever possible.

In order to overcome the problem of high energy consumption during data aggregation, we propose a proper efficient data aggregation based on design a power control technique using swarm intelligence and the game theoretic approaches.

II. RELATED WORK

Venkatesh Mahadevan et al [11] proposed a reliable, nature-inspired routing algorithm called iACO for sensor networks. The algorithm is partly based on the efficient max-min algorithm and it is suitable for flexible structure of wireless sensor networks and is not worse than other standard routing algorithms. This new routing scheme performs generally not worse than other standard routing algorithm, and in some occasions, it outperforms than min-hop algorithm.

Ayon Chakraborty et al [12] have proposed a novel data gathering protocol for enhancing the network lifetime by optimizing energy dissipation in the nodes. To achieve the design objective particle swarm optimization (PSO) with Simulated Annealing (SA) have been applied to form a sub-optimal data gathering chain and devised a method for selecting an efficient leader for communicating to the base station. In the scheme each node only communicates with a close neighbor and takes turns in being the leader depending on its residual energy and location. This helps to rule out the unequal energy dissipation by the individual nodes of the network and results in superior performance as compared to LEACH and PEGASIS.

Swarup Kumar Mitra et al [13] proposed an Optimized Lifetime Enhancement (OLE) Scheme which shows enhanced performance over other schemes. OLE increases the network performance by ensuring a sub-optimal energy dissipation of the individual nodes despite their random deployment. It employs modern heuristics like particle swarm optimization instead of the greedy algorithm as in PEGASIS to construct energy efficient routing paths. Extensive simulations validate the improved performance of OLE.

Saeed Mehrjoo et al [20] proposed a Novel Hybrid GA-ABC based Energy Efficient Clustering in Wireless Sensor Network. As lifetime is directly dependent upon the energy supplies of the nodes, optimization of node energy consumption is a robust approach to contribute to the overall network lifetime. Network clustering is one of the potential approaches to perform the optimization. To overcome this problem, a hybrid algorithm based on Genetic Algorithm and Artificial Bee Colony is proposed in this paper. The algorithm resolves the issue through finding the optimal number of clusters, cluster heads and cluster members. Simulation results reveal that this algorithm outperforms LEACH and Genetic Algorithm based clustering scheme.
Enrique Campos-Nañez et al [15] proposed a Game Theoretic Approach to Efficient Power Management in Sensor Networks. In this paper, a distributed scheme for efficient power management in sensor networks that is guaranteed to identify suboptimal topologies in an on-line fashion is proposed. The scheme is based upon a general (game-theoretic) mathematical structure that induces a natural mapping between the informational layer and the physical layer. Sufficient conditions for the convergence of the algorithm to a pure Nash equilibrium and characterize the performance of the algorithm in terms of coverage is provided.

R.Valli et al [16] proposed a power control solution for wireless sensor network (WSN) considering ECC in the analytical setting of a game theoretic approach. The game is formulated as a utility maximizing distributed power control game while considering the cost function and the existence of Nash equilibrium is studied. With the help of this equilibrium a distributed power control algorithm is devised. From the analysis it is evident that the system is power stable only if the nodes comply with certain transmit power. The utility of nodes employing ECC and without ECC is compared; the results show that the algorithm employing ECC achieves the best response for the sensor nodes by consuming less power.

### III. PROPOSED SOLUTION

#### A Overview

We propose a power efficient data aggregation based on swarm intelligence and game theoretic approach for wireless sensor networks. In this approach, swarm intelligence based ant colony optimization is utilized to execute route discovery. In discovered route, nodes with maximum energy level are chosen as controller nodes and remaining nodes are chosen as non-controller nodes. This is done to carry out the process of data aggregation. The controller node gather the data packets received from the source nodes and forwards it to nearby controller nodes and this process proceeds till the packet reaches the sink and the controller nodes always remain awake since it makes all decisions related to routing and data aggregation. In every round of route discovery, the power level of the controller nodes is checked. When there is decline in the power level, then another node with higher power level is chosen as the controller node. This implies that the controller nodes keep changing adaptively in every round. After successful transmission of the data packet, the game theory is applied to determine the energy consumed during data aggregation. In this approach, the utility function is calculated based on the number of data packets transmitted, number of successful transmission and forwarding of the data performed by other nodes, in order to ensure reliability. Based on this function, the energy compensation value is then calculated for forwarding the data packets.

#### B Route Discovery based on Swarm intelligence

We consider a swarm intelligence technique based on ant colony optimization (ACO) for performing route discovery.

The procedure for route discovery is as follows.

1. When the source (S_o) has a necessity to transmit the data packet to the sink, FA is launched from S_o. FA chooses it movement to next neighbor node using probabilistic
decision rule (using equation 1). Using this rule, FA moves through the intermediate nodes and gathers the status of the nodes (i.e. node id, energy level, neighbor node status etc).

\[
P_k(N_i, S_o) = \begin{cases} 
\frac{[\mu(N_i, S_o)]^\psi [\lambda(N_i, S_o)]^\epsilon}{\sum_{N \in N_i} [\mu(N_i, S_o)]^\psi [\lambda(N_i, S_o)]^\epsilon}, & \text{if } k \notin L^N_i \\
0, & \text{otherwise}
\end{cases}
\]

Where \( N_i \) are the repeater nodes, \( S_o \) is the source node.
\( \mu(N_i, S_o) \) represent initial pheromone value
\( \lambda(N_i, S_o) \) represent the heuristic value related to energy level.
\( n_i \) represents the receiver node.
\( L^N_i \) represents the routing table for node \( N_i \).
\( \psi \) and \( \epsilon \) are the parameters that control the relative weight of the pheromone and heuristic value respectively.

2) \( \lambda(N_i, S_o) \) in equation (1) helps in selection of controller nodes along the traversed path based on the energy level of the node. This means that the node with lower energy has less probability to get selected. The heuristic value of the node \( N_i \) is expressed as follows.

\[
\lambda(N_i, S_o) = \frac{(E_i - e_{N_i})^{-1}}{\sum_{n \in n_i} (E_i - e_{N_i})^{-1}}
\]

where \( E_i \) is the initial energy
\( e_{N_i} \) is the current energy level of receiver node \( N_i \).

3) Each FA deposits a quantity of pheromone \( \Delta \mu^g(k) \) in the visiting node according to following equation.

\[
\Delta \mu^g(k) = 1/V^g(k)
\]

Where \( V^g(k) \) represents the total number of nodes visited by FA during its tour represented as \( s \) at iteration \( k \) and each ant is represented by \( g = 1, 2, \ldots, n \).

4) The amount of pheromone at each link \( c(N_i, S_o) \) of the nodes is described as follows.

\[
\mu(N_i, S_o)(k) = \mu(N_i, S_o)(k) + \Delta \mu(N_i, S_o)(k), \forall c(N_i, S_o) \in s^g(k), g = 1, \ldots, n
\]

5) Increasing pheromone amounts on the paths according to lengths of tours, \( V^g(k) \), would continuously cause an increasing positive feedback. In order to control the operation, a negative feedback, the operation of pheromone evaporation after the tour is accomplished which is described as follows

\[
\mu^g(k) \leftarrow (1-\xi)\mu^g(k)
\]

Where \( \xi \) represents the control co-efficient which determines the weight of evaporation for each tour. In simulations, ACO parameter settings are set to values \( \psi = 1, \epsilon = 5, \text{and } \xi = 0.5 \) which were experimentally found to be good by Dorigo [18].

6) After FA reaches the sink, the sink generates BA and transfers all the information of FA into BA. The BA takes the same path as that of its corresponding forward ant, but in the opposite direction. The BA updates the routing table \( (LN_i) \) at \( N_i \) for all the entries related to the FAs destination node.
7) The BA upon reaching the source delivers the status of all nodes in the network. The source then selects the controller node which is described in section III.C and transmits the data packet to the sink through the chosen controller nodes.

C Selection of nodes based on power level

Based on the status of the nodes power level deposited by the BA to the source, the controller nodes are chosen. The nodes with maximum power level are selected as controller nodes (CN) and remaining nodes are selected as non-controller nodes (NCN). This is done in order to perform data aggregation [3]. The controller nodes gather all received data packet from the source nodes and forwards it to next controller node or to the sink (using section III.C.1 and III.C.2) as it makes all decisions related to routing and always remains awake. NCN are within the transmission range of CN node and will be in wake-up mode in periodical manner.

The steps involved in the selection of CN are:

- The forward ant agent (FA) is launched in $S_0$ and it travels in the direction of the sink through the intermediate nodes in the network. The ants upon reaching every node updates its list with the node details such as node’s id, flag (informs the status whether node is CN or NCN), power level, node activating counter, and information about the neighbors (id, status and CN node).
- The information of every node is collected and finally FA delivers the details into sink ($S_i$). The sink provides all details to the BA.
- The backward ant agent (BA) sends the information about the CN nodes along the path as a feedback to the source.

Let $R_1$ represent the first round where the path is established and source transmits the packets through the selected controller nodes at time $T_1$.

Let $R_2$ represent next round where another is established and source proceed its transmission of packets through the selected controller nodes at time $T_2$ and this investigation cycle continues with remaining range of time period to minimize power consumption.

1 First round ($R_1$)

During $R_1$, $S_0$ transmits the data packets to the sink $S_i$ through the chosen path (as per section III.B). Let nodes 4, 7 and 9 be the CN at time $t_1$. (Ref figure 1)

![Fig. 1 Controller nodes during first round $R_1$](image)

When the packet reaches node 1,
If node 1 is awake,
Then the packets are transmitted to node 1.
Node 1 checks its neighbor nodes 2 and 3.
If a node 2 or 3 is awake,
Then the data is transmitted to node 2 or 3.
End if
Else
The source checks the neighbor list of node 1 which is nodes 2 and 3.
It then checks for the nearest CN of nodes 2 and 3.
Then, the packets are transmitted to the nearest neighbor CN (node 4), directly from $S_0$.
End if
Node 4 checks for the nearest awake node
If a node 5 or 6 is awake
Then the data is transmitted to that node.
End if
Else
The packets are transmitted to the nearest neighbor CN (7) directly from node 4.
Node 7 checks for the nearest awake node and packets are transmitted to node 9 directly.
End if
Node 9 checks for the nearest awake node
If node 10 or 11 is awake
Then the data is transmitted to that node
End if
Else
The packets are transmitted to the destination directly from node 9

2 Second round $R_2$
After completion of $R_1$, Source $S_0$ transmits the data packets to the destination $S_i$ through the path containing another set of selected controller nodes. Let nodes 1, 4, 8 and 10 be the CN at time $t_2$. (ref. figure 2)

When the packet reaches node 1, the data is transmitted to that node since it is CN.
Node 1 checks the neighbor list node 2 and 3
If a node 2 or 3 is awake,
Then the data is transmitted to node 2 or 3.

Fig. 2 Controller nodes during second round $R_2$
End if
Else
Node 1 checks the nearest CN of node 2 and 3
Then, the packets are transmitted to the nearest neighbor CN (node 4), directly from node 1.
End if
Similarly the process proceeds as per first round at time $T_1$.

**D Game model of data packet forwarding**

After the route discovery process, the game theory approach is applied which determines the energy consumed during data aggregation. A player consists of a set of nodes including the source and its corresponding nodes involved in transmission of the data to the sink. For each node in the network, we consider the following assumption

Let $P_i(t)$ be the total number of data packets transmitted by the controller node to other nodes
Let $S_i(t)$ be the number of data packets transmitted successfully
Let $F(es)$ be the available energy compensation for providing approval to forward data packets
Let $h$ be the average number of hops crossed by the exchange of data between the source and sink nodes
Let $k$ be the number of controller nodes involved in the aggregation and forwarding of data between the source and sink nodes.

The energy compensation value is then calculated for forwarding the data packets using the utility function (using equation 6). The mathematical expression for a utility function in the model of DR-G (Data Relaying base on Game Theory) is as follows:

$$U(P_i(t), S_i(t)) = k \times h \times S_i(t) - P_i(t) + F(es)$$

Equation (6)

The following assumptions are made from the viewpoint of each node.

1) The node obtains interest from the network, when the network forwards the data packet successfully.
2) The node pays costs for the network, when the node accepts the forwarding request to forward data packets for the network.

As the average number of hops ($h$) crossed by the exchange of data between the source and sink nodes are not less than 1, the benefits received after every successful transmission of data packet is $h$ times than the loss for forwarding a data packet for the network. If a node agrees to forward the data packet, then it will get awards from the network, which is energy compensation, to encourage the node forwarding data. If the node refuses to forward data packets, then it will not get the energy compensation, as a punishment to nodes from the network.

Using equation (6), a decision function of node forwarding is introduced as follow, which is used to determine whether to forward data for the other nodes.

$$\Delta(P_i(t), S_i(t)) = \begin{cases} 1, & k \times h \times S_i(t) - P_i(t) + F(es) \geq 0 \\ 0, & k \times h \times S_i(t) - P_i(t) + F(es) < 0 \end{cases}$$

Equation (7)

where
h is the average number of hops crossed by transmitting a data packet to the sink node
k is number of controller nodes involved in the aggregation and forwarding of data to the sink node.
F (es) is the available energy compensation for agreeing to forward data packets.
If \( \Delta(S_i(t), P_i(t)) = 1 \),
Then
   \( N_i \) agrees to forward;
End if
If \( \Delta(S_i(t), P_i(t)) = 0 \),
Then
   \( N_i \) refuses to forward
End if

**E Overall algorithm**

**Step 1**
The swarm intelligence technique is utilized to perform the process of route discovery.

**Step 2**
In the discovered route, the nodes with maximum power level are chosen as controller nodes (CN) and remaining nodes are selected as non-controller nodes (NCN). This is done for the purpose of data aggregation.

**Step 3**
The controller node gather the data packets received from the source nodes and forwards it to nearby controller nodes and this process proceeds till the packet reaches the sink and the controller nodes always remain awake since it makes all decisions related to routing.

**Step 4**
In every round of route discovery, the power level of the controller nodes in checked. When there is decline in the power level, then another node with higher power level is chosen as the controller node. This implies that the controller nodes keep changing adaptively in every round.

**Step 5**
After successful transmission of the data packet, the game theory is applied to determine the energy consumed during data aggregation.

**Step 6**
In game theory, the utility function is calculated based on the number of data packets transmitted, number of successful transmission and forwarding of the data performed by other nodes. Based on this function, the energy compensation value is then calculated for forwarding the data packets.

**Advantages of this approach**
1) This data aggregation technique saves communication overhead which occurs due to additional computation and memory resources.
2) As the controller nodes selected for data aggregation are based on their energy level and also it keeps changing adaptively in each round, the power consumption in the network can be reduced to larger extent.

3) Use of game theory, helps to estimate the forwarding cost in terms of energy consumption.

IV. Simulation Results

The proposed Power Efficient Data Aggregation using Ant (PEDA-ANT) agents, is evaluated through NS2 [19] simulation. We consider a random network of sensor nodes deployed in an area of 500 X 500m. The number of nodes is varied as 20,40,60,80 and 100. Two sink nodes are assumed to be situated 100 meters away from the above specified area. The simulated traffic is CBR with UDP source and sink. The number of controller nodes is selected as 4 for two different scenarios.

Table 1 summarizes the simulation parameters used:

<table>
<thead>
<tr>
<th>Table 1: Simulation Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Nodes</td>
</tr>
<tr>
<td>Area Size</td>
</tr>
<tr>
<td>Mac</td>
</tr>
<tr>
<td>Routing protocol</td>
</tr>
<tr>
<td>Simulation Time</td>
</tr>
<tr>
<td>Traffic Source</td>
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<tr>
<td>Packet Size</td>
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<tr>
<td>Rate</td>
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<tr>
<td>Transmission Range</td>
</tr>
<tr>
<td>No. of Sources per cluster</td>
</tr>
<tr>
<td>Transmit Power</td>
</tr>
<tr>
<td>Receiving power</td>
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<tr>
<td>Idle power</td>
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<tr>
<td>Initial Energy</td>
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</tbody>
</table>

A Performance Metrics

The performance of PEDA-ANT is compared with the “Energy Efficient Scheme for Data Gathering Using Particle Swarm Optimization” (EEDG-PSO) [12] scheme. The performance is evaluated mainly, according to the following metrics.

- **Average end-to-end delay**: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.
- **Average Packet Delivery Ratio**: It is the ratio of the number of packets received successfully and the total number of packets transmitted.
- **Energy**: It is the average energy consumed for the data transmission.
A. Based on Nodes

In our initial experiment, we vary the number of nodes as 20, 40, 60, 80 and 100.

![Nodes Vs Delay](image)

**Fig. 3** Nodes Vs Delay

![Nodes Vs Delivery Ratio](image)

**Fig. 4** Nodes Vs Delivery Ratio

![Nodes Vs Energy](image)

**Fig. 5** Nodes Vs Energy

When the number of nodes in the network is increased, generally it will result in increase of end-to-end delay, since the number of hops may increase, in the routing path. Figure 3 shows that the delay is linearly increased for both the schemes when the number of nodes is varied from 20 to 100. It shows that our proposed PEDA-ANT protocol has an average of 83% lower delay than when compared to EEDG-PSO, since the controller nodes are always awake in PEDA-ANT, the sleep waiting time is minimized.
When the number of nodes in the network is increased, it leads to more packet drops due to increased number of hops and contention. Hence the average packet delivery ratio decreases when the number of nodes is increased. Figure 4 gives the packet delivery ratio for both the schemes when the number of nodes is increased. It shows that our proposed PEDA-ANT protocol achieves delivery ratio more than 18% of EEDG-PSO in average. This is because of the fact that the transmission failure is minimized by using the controller nodes as aggregation point in PEDA-ANT.

Since the sleep duty cycle is adaptively changing and controller nodes are selected based on power level, PEDA-ANT protocol utilizes 16% lower energy when compared to EEDG-PSO. Figure 5 shows this.

b. Based on Sources

In our second experiment we vary the number of sources as 1, 2, 3 and 4.

Fig. 6 Sources Vs Delay

Fig. 7 Sources Vs Delivery Ratio
When the number of sources in the network is increased, it will result in increase of end-to-end delay, since the traffic load may increase, in the routing path. Figure 6 shows that the delay is increased for both the schemes when the number of sources is varied from 1 to 4. We can see that our proposed PEDA-ANT protocol has an average of 42% lower delay than when compared to EEDG-PSO, since the controller nodes are always awake in PEDA-ANT, the sleep waiting time is minimized.

When the number of sources in the network is increased, it leads to more packet drops due to increased traffic load and congestion. Hence the average packet delivery ratio decreases when the number of nodes is increased. Figure 7 shows the packet delivery ratio for both the schemes when the number of sources is increased. It shows that our proposed PEDA-ANT protocol achieves delivery ratio more than 41% of EEDG-PSO in average. This is because of the fact that the transmission failure is minimized by using the controller nodes as aggregation point in PEDA-ANT.

Figure 8 gives the energy consumption when the number of source is increased. It shows that our proposed PEDA-ANT protocol utilizes 6% lower energy when compared to EEDG-PSO, Since the sleep duty cycle is adaptively changing and controller nodes are selected based on power level.

**V. Conclusion**

In this paper, we have proposed a power efficient data aggregation based on swarm intelligence and game theoretic approach for wireless sensor networks. In this approach, swarm intelligence based ant colony optimization is utilized to execute route discovery. In the discovered route, nodes with maximum energy level are chosen as controller nodes and remaining nodes are chosen as non-controller nodes to perform data aggregation. The controller nodes always remain awake since it makes all decisions related to routing. In every round of route discovery, the power level of the controller nodes in checked. When there is decline in the power level, then another node with higher power level is chosen as the controller node. This implies that the controller nodes keep changing adaptively in every round. After successful transmission of the data packet, the game theory is applied to determine the energy consumed during data aggregation. By simulation results, we have shown that the proposed approach reduces the energy consumption and increase the packet delivery ratio when compared with the existing approach.
References


