CHAPTER 7

CUCKOO BASED PARTICLE APPROACH FOR SENSOR NETWORKS

7.1 INTRODUCTION

Data collection strategies in life time constrained sensor networks is a critical issue as sensor networks are resource constrained. Dynamic programming and multi criterion optimization techniques are proposed to tradeoff the quality of data collection for energy efficiency in Wireless Sensor Networks. In this research, Cuckoo Based Particle Approach (CBPA) is proposed to achieve energy efficient Wireless Sensor Network with multimodal objective functions. Cuckoo search is applied for cluster head selection and formation of clusters among sensor nodes. The Generalized Particle Approach transforms the network shortest path problem into kinetics and dynamics with hybrid energy equations to obtain optimal solution.

7.2 GENERALIZED PARTICLE APPROACH ALGORITHM

Generalized Particle (GP) Model given by Shuai and Feng (2005), finds its application in many fields of network oriented applications. It is similar to Swarm Intelligence (SI) technique. This algorithm eradicates the unknown empirical performance and much computation time. The algorithm controls the parameters in parallel for multiobjective optimization problems. The approach incorporates hybrid energy functions to maintain the advantages of the traditional approaches and eliminate the deficiencies of the same.
The GP model consists of numerous particles and forces, with each particle having its own dynamic equations to represent the network entities and force having its own time-varying properties to represent various social interactions among the network entities. Shuai et al (2006) states that the gravitational force produced by the force field tries to drive a particle to move towards boundaries of the force-field, which embodies the tendency that a particle pursues maximizing the aggregate benefit of systems. The particles may move concurrently in a force-field under the exertion of the resultant forces (Shuai et al 2005). When all the particles reach their equilibrium states, optimization of the objective function is obtained.

Feng et al (2006) states the four main characteristics that each particle in GP is influenced with:

1. Each particle in GP has an autonomous self-driving force, to embody its own autonomy and the personality of network entity.

2. The dynamic state of every particle in GP is a piecewise linear function of its stimulus, to guarantee a stable equilibrium state.

3. The stimulus of a particle in GP is related to its own objective, utility and intention, and to realize the multiple objective optimizations.

4. There is a variety of interactive forces among particles, including unilateral forces, to embody various social interactions in networks.
In Figure 7.1, the pushing or pulling forces produced by other particles to embody social coordination is depicted. The particles are driven by numerous forces that are produced by the force-field, other particles and by own.

The Generalized Particle Model is suitable for Multi Agent System’s problem-solving for more complex environment: multi-autonomy agents, multi-type coordination, multi-objective optimization, higher-degree parallelism, and random and emergent events (Shuai and Feng 2006). The concept of GP can be extended for solving any network entity like bandwidth allocation, task allocation, energy utilization, call admission, fairness estimation, etc. The assignment matrix of task allocation and resource assignment in multi agent systems is given as in Equation (7.1).

\[ S(t) = [s_{ij}(t)]_{n \times m}, \]  

(7.1)
where, \( s_{ij}(t) = (a_{ij}(t), p_{ij}(t), \zeta_{ij}(t)) \)

‘\( a_{ij}(t) \)’ refers to the agents at time \( t \), ‘\( p_{ij}(t) \)’ refers to the payment for unit resource of the agent, ‘n’ refers to resource agents, ‘m’ refers to task agents and ‘\( \zeta_{ij} \)’ is a constant that determines the intention strength for agent to provide social coordination among agents. This concept can be well related to estimation of energy cost (or) energy expenditure in transmission of data in a path. The mathematical modeling of generalized particle model is described below. The set of equations are calculated to optimize the network entity.

### 7.2.1 Total Utility

\( u_k(t) \) is the distance from the current position of the path particle \( T_k \) to the upper boundary of the demand force-field \( F_D \) at time \( t \), and let \( J_D(t) \) be the total utility of all the path particles in \( F_D \). \( u_k(t) \) and \( J_D(t) \) are defined respectively as stated below;

\[
\begin{align*}
  u_k(t) &= \zeta_1 \exp \left[ -\sum_{i=1}^{m} \frac{a_{ik}(t)}{\rho_{ik}(t)} \right] \\
  J_D(t) &= \alpha_1 \sum_{j=1}^{p} \sum_{k=1}^{n} u_k(t)
\end{align*}
\]  

(7.2)  

(7.3)

\( u_i(t) \) is the distance from the current position of the link particle \( A_i \) to the upper boundary of the resource Force-field \( F_R \) at time \( t \), and let \( J_R(t) \) be the total utility of all the link particles in \( F_R \). \( \zeta_1 \) and \( \zeta_2 \) are the constants to determine the intention strength among the particles. ‘\( a_{ik}(t) \)’ refers to the agents at time \( t \), ‘\( p_{ik}(t) \)’ refers to the payment for unit resource of the agent. ‘\( n \)’ refers to links, ‘\( m \)’ refers to paths and ‘\( p \)’ refers to channels in the shortest path allocation. \( u_i(t) \) and \( J_R(t) \) are defined respectively as stated below;
\[ u_i(t) = \zeta 2 \exp \left[ -\sum_{j=1}^{p} \sum_{k=1}^{n} p_{ik}(t)/a_{ik}(t) \right] \]  
\[ (7.4) \]

\[ J_R(t) = \alpha 2 \sum_{i=1}^{m} u_i(t) \]  
\[ (7.5) \]

\( \zeta, \zeta > 1 \) and \( 0 < \alpha_1, \alpha_2 < 1 \). These constants are related to the constraint of network entity estimation like bandwidth, energy, QoS, etc.

### 7.2.2 Potential Energy

At time \( t \), the potential energy functions, \( P_D(t) \) and \( P_R(t) \), that are caused by the upward gravitational forces of the force-fields, \( F_D \) and \( F_R \), are defined respectively as stated below:

\[ P_D(t) = \epsilon^2 \ln \left[ -\sum_{j=1}^{p} \sum_{k=1}^{n} \exp \left[ (u_k(t))^2 / 2 \epsilon^2 \right] - \epsilon^2 \ln(n) \right] \]  
\[ (7.6) \]

\[ P_R(t) = \epsilon^2 \ln \sum_{i=1}^{m} \exp \left[ (u_i(t))^2 / 2 \epsilon^2 \right] - \epsilon^2 \ln(m) \]  
\[ (7.7) \]

At time \( t \), the potential energy functions, \( Q_D(t) \) and \( Q_R(t) \), that are caused by the interactive forces among the particles in force fields \( F_D \) and \( F_R \) are defined respectively as stated below:

\[ Q_D(t) = \beta_1 \sum_{j=1}^{p} \left[ \sum_{k=1}^{n} a_{ik}(t) - d_j(t) \right]^2 + E_D(t) \]  
\[ (7.8) \]

\[ + \rho \sum_{j=1}^{p} \left[ \sum_{k=1}^{n} \sum_{i=1}^{m} a_{ik}(t) p_{ik}(t) - \epsilon^2 \right] \]  
\[ (7.8) \]

\[ Q_R(t) = \beta_2 \sum_{i=1}^{m} \left[ \sum_{k=1}^{n} \sum_{j=1}^{p} a_{ik}(t) - r_j(t) \right]^2 + E_R(t) \]  
\[ (7.9) \]

\( 0 < \epsilon < 1, 0 < \beta_1, \beta_2, \rho < 1 \); are constants related to the constraints of
link capacity. \( d^j \) signifies the network entity that the channel can requires and \( r^j \) signifies the maximum capacity of the link.

\( E_D(t) \) and \( E_R(t) \) are the potential energy functions that involve other kinds of the interactive forces among the particles in \( F_D \) and \( F_R \), respectively.

### 7.2.3 Stability

Dynamic equations for path particle \( T_k \) and link particle \( A_i \) are defined respectively as stated below:

\[
\frac{d u_k(t)}{d t} = \varphi_1(t) + \varphi 2(t) \tag{7.10}
\]

\[
\varphi_1(t) = -u_k(t) + \gamma_1 v 1(t) \tag{7.11}
\]

\[
\varphi 2(t) = [\eta_1 + \eta_2 dJ_D(t)/d u_k(t) + \eta_3 dP_D(t)/d u_k(t)
+ \eta_4 dQ_D(t)/d u_k(t)] *
\]

\[
\sum_{i=1}^{m} [d u_k(t)/dq_{ik}(t)]^2 \tag{7.12}
\]

(OR)

\[
\frac{d u_i(t)}{d t} = \psi 1(t) + \psi 2(t) \tag{7.13}
\]

\[
\psi 1(t) = -u_i(t) + \gamma 2 v 2(t) \tag{7.14}
\]

\[
\psi 2(t) = -[\lambda_1 + \lambda_2 dJ_R(t)/d u_i(t) + \lambda_3 dP_R(t)/d u_i(t)
+ \lambda_4 dQ_R(t)/d u_k(t)] *
\]
\[
\sum_{k=1}^{n} \sum_{j=1}^{p} \left[ \frac{d u_{i}(t)}{d a_{ik}(t)} \right]^2
\]

(7.15)

\(v_1(t)\) and \(v_2(t)\) is a piecewise linear function. \(du_{i}(t)/dt\) and \(du_{i}(t)/dt\) are aggregated speed increments for link and path particles. \(\varphi_2\) and \(\varphi_1\) are speed increments for path particle. \(v_1(t)\) and \(v_2(t)\) are speed increments for link particles. \(v_1\) and \(v_2\) are piecewise linear functions.

\[\lambda_1, \lambda_2 > 1; \quad 0 < \lambda_{1}, \lambda_{2}, \lambda_{3}, \lambda_{4}, \eta_{1}, \eta_{2}, \eta_{3}, \eta_{4} < 1\]

are constants of proportionality when path particle changes its price in accordance with potential energy, kinetic energy of particles.

\[
dp_{ik}(t)/dt = \eta_{1} [du_{ik}(t)/dp_{ik}(t)] - \eta_{2} [dJ_{D}(t)/dp_{ik}(t)]
\]

\[-\eta_{3} [dP_{p}(t)/dp_{ik}(t)] - \eta_{4} [dQ_{p}(t)/dp_{ik}(t)]\]

(7.16)

\[
dp_{ik}(t)/dt = \lambda_{1} [du_{i}(t)/da_{ik}(t)] - \lambda_{2} [dJ_{R}(t)/dp_{ik}(t)]
\]

\[-\lambda_{3} [dP_{R}(t)/dp_{ik}(t)] - \lambda_{4} [dQ_{R}(t)/da_{ik}(t)]\]

(7.17)

7.3 IMPLEMENTATION OF CUCKOO BASED PARTICLE APPROACH

Cuckoo Based Particle Approach is modeled with two phases. Cluster formation Phase and shortest path routing phase. Cluster formation is performed by cuckoo Search. The procedure is stated in section 3 of chapter 6. The inter cluster communication is performed by Generalized Particle Model. The objective of using GPM approach is optimization of route and extension of the network lifetime. GPM is given in many types according to the network optimization problems by Dianxun Shuai. Normally, communication between
two Wireless Sensor Nodes happens, when there is no other interfering node between two nodes. It is assumed that there exists wireless path and link between two nodes during communication.

The Generalized Particle Model transforms the network shortest path problem into kinematics and dynamics of numerous particles in a force-field. The network entity to be optimized is considered as particles. The utility of particle at a particular time instant, overall utility, potential energy due to gravitational force, potential energy due to interactive force of particles are calculated in each iteration. The calculated energy functions are substituted in hybrid energy function and the particles are tested for stability. It is personified in the described model, as the resultant forces on the particles are high, the particles also move fast. If the particles are stable, then the algorithm is terminated successfully. Else the particles are updated, with the hybrid energy equations to obtain the optimal solution.

The shortest path is calculated by the link cost of each links. The link cost is substituted as the residual energy of nodes; with context to the distance to the communicating nodes. The residual energy of cluster head to communicating cluster head is to be considered for communication of the sensed data. After several numbers of iterations, the optimal path to transmit the data to the base station is being established.

7.4 RESULTS AND ANALYSIS

Cuckoo Based Particle Approach is developed for achieving energy efficiency in sensor networks. Cuckoo Based Particle Approach is simulated and verified using MATLAB. The sensor nodes are clustered using Cuckoo Search as detailed in chapter 6. Generalized Particle Approach Algorithm has number of parameters to be explored to attain optimal solutions. The simulation Parameters are listed in Table 7.1.
Table 7.1 Simulation Parameters for Cuckoo Based Particle Approach

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor deployment area</td>
<td>100 m x 100m</td>
</tr>
<tr>
<td>Base station location</td>
<td>(50m, 150m)</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>100-200</td>
</tr>
<tr>
<td>Data Packet size</td>
<td>100 bytes</td>
</tr>
<tr>
<td>Control Packet size</td>
<td>25 bytes</td>
</tr>
<tr>
<td>Initial Energy</td>
<td>2 J</td>
</tr>
<tr>
<td>$E_{\text{electrical}}$</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>$\varepsilon_s$</td>
<td>10 pJ/bit/m$^2$</td>
</tr>
<tr>
<td>$\varepsilon_g$</td>
<td>0.0013 pJ/bit/m$^4$</td>
</tr>
<tr>
<td>Mode of Topology configuration</td>
<td>random</td>
</tr>
<tr>
<td>MAC Protocol</td>
<td>IEEE 802.15.4</td>
</tr>
<tr>
<td>Duty cycle duration</td>
<td>1 second</td>
</tr>
<tr>
<td>Cuckoo step size</td>
<td>1</td>
</tr>
<tr>
<td>Round duration</td>
<td>60 seconds</td>
</tr>
</tbody>
</table>

The Generalized Particle Approach Algorithm is modified for energy consumption in sensor networks. The path particles and link particles are updated to the situation of energy utilized in the transmission of network data. To maximize the energy efficiency of the network, the particles assign its minimal energy to the path that pays maximal transmission to the sink. The results are summarized after running several iterations. The proposed approach is compared with LEACH and HEED algorithm. Clustering energy, amount of energy consumed for data transmission, number of nodes alive, are analyzed by using CBPA for sensor networks.

In Figure 7.2, the clustering energy for hundred numbers of nodes is explained. The transition probability of Cuckoo Search to search the next
location aids in simple and faster convergence in clustering process. The application specific LEACH protocol is compared with HEED and Cuckoo Based Particle approach. It is inferred that the proposed CBPA consumes less energy than LEACH. The difference in average clustering energy of Cuckoo approach from LEACH is 0.06108. HEED dissipates more energy than LEACH in clustering.

The number of node deaths indicates the percentage of nodes in a cluster, node density of the network and leads to the estimation of network lifetime. In Figure 7.3, the lifetime of the network is compared for LEACH and Cuckoo Based Particle Approach. The performance of Cuckoo combined with particle approach is better than Cuckoo search. Three to four rounds are enhanced compared to Cuckoo Search. The first node death occurs at round number 63 approximately.
Figure 7.2 Energy consumption for Clustering of nodes
Figure 7.3 Network Lifetime based on initial Node Density

Figure 7.4 shows the number of rounds until the last node death. At round number 240, all nodes are exhausted of energy by Cuckoo Based Particle Approach. Compared to Cuckoo Search, the rounds are slightly decreased due to complex parameters. If the randomness in the hybrid energy equation is improved, then better results can be achieved.
In Figure 7.5, the average energy consumed per rounds is given. The average energy consumption of the network using CBPA is 0.057 joules for 100 rounds. The explorations in search space between links and particles results in updating the hybrid energy equations. The monotonous update of energy function facilitates the particles to autonomously establish the path with minimal energy consumption. The energy consumption varies slightly from LEACH. The iterations can be increased to obtain feasible results. The LEACH protocol expends less energy than HEED. The energy cost of HEED is higher compared to LEACH and CBPA.
Figure 7.5 Average Energy Consumption of the network

The Number of alive (or) active nodes versus number of iterations is given in Figure 7.6. The percentage of nodes alive proves the lifetime of the network. The number of iterations is taken as 100. The parallel implementation of particles and minimal energy consumption in transmission of data, gives better performance than the other approaches.
7.5 CONCLUSION

The cuckoo Based Particle Approach is developed to achieve energy efficient Wireless Sensor Network by incorporating multimodal objective functions. Cuckoo search is applied for cluster head selection and formation of clusters among the Sensor nodes. The proposed CBPA is compared with the standard LEACH protocol and HEED protocol. The simulation results exhibit improved results of CBPA due to optimal search process in cluster formation and allocation of appropriate paths in transmission of sensed data. The developed optimal algorithm reduces complexity in chain formation and prolongs the longevity of the Sensor Network. The results are obtained by running more number of simulations. The hybrid approach offers consistency in the cluster formation, minimal number of clusters, average energy consumption and energy consumption per rounds.