FTDCH-DCPSO – A fault tolerant dual CH selection mechanism with delay constrained particle swarm optimization for energy balancing

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Abstract

Wireless Sensor Networks (WSNs) include numerous nodes that can be used to collect the data from different environments. The major challenging issue is consumption of more energy in WSNs. Recharging of sensor nodes is not possible as the sensor operates based on battery. Hence, each sensor node lifetime and energy consumption are the main problems of wireless sensor networks. For improving the battery lifetime and balancing the energy consumption of sensor nodes, various existing clustering protocols have proposed. But, these protocols result in the excessive overhead owing to the repeated clustering and higher power consumption. Thus, the communication disrupts as the cluster heads fail unprecedentedly. In WSNs, it's essential to handle such fault cluster heads and required to provide an alternate solution for data communication. A dynamic and distributed dual cluster head election algorithm (PCH- Proxy CH; MCH – Main CH) is proposed based on two-level clustering scheme and fault tolerance capabilities. The delay-energy-trade-off (DET)& the residual energy of the node are taken into account for dual CH selection.The role of cluster head is played by PCH automatically when MCH is failed in communication after detecting the current cluster head failure. For choosing an efficient relay node, the delay constrained PSO (DCPSO) is used that leads to the balancing and minimization of energy consumption. To achieve an efficient relay selection, end-to-end delay and cost of a node are considered for DCPSO. The proposed technique DCH-DCPSO is showed superior performance than the existing methods based on the analyzation of simulation results.

Keywords: WSN, PSO, Relay node, Cluster head, Fault tolerance, Delay.

I. Introduction

WSNs contain a wide range of small sensor nodes with a limited energy. It is a self-organizing autonomous distributed system with the limitation of energy, and capacity of process and calculation of nodes. WSNs include various applications, such as security, industry automation, data collection, monitoring of environmental conditions, military, and assessment of weather conditions [1]. For sending gathered data to the BS or sink, sensor nodes are cooperated in this network. It's require to deal with fault tolerance and scalability for management of WSNs and energy-efficient solutions are provided. The sensor nodes' position is not pre-determined necessarily in WSNs [2]. The self-organizing algorithms and protocols should be developed.

The wireless sensor network energy consumption reduction is possible effectively using clustering method. A network sub-categorized into smaller groups known as clusters and each cluster has a cluster head (CH), while other nodes are considered as cluster members [3]. Based on a hierarchy of CHs, data packets forwarded by member nodes to CH and they are processed and transmitted to SINK. The number of data packet transmissions reduces by processing the data packets at CH [4]. Due to the transmission is more costlier than the node computation, the energy consumption is reduced significantly. For spatial reuse of bandwidth, clustering is also used owing to the scalable and robust node clustering in the topological changes that caused by insertion, or removal, and node failure [5]. Figure 1 shows the clustered WSN.

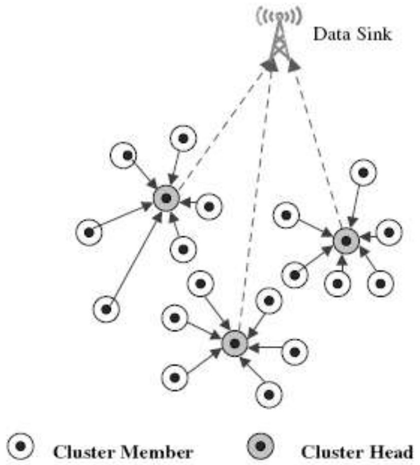

Fig1: a clustered WSN

The advantages of clustering a WSN includes: (1) data aggregation is ensured at CH level that reduces the energy consumption while discarding the redundant data. (2) As special nodes like CHs require to maintain the local route setup of other CHs, routing can be managed easily and small routing data is required. The network scalability will improve significantly. (3) Due to the communication of sensor nodes with the respective CH, the communication bandwidth is conserved and the redundant messages exchange is avoided [6].

Uneven energy consumption problem raised in the conventional clustering algorithms, where the energy of cluster heads consume much faster than the cluster members [7]. Thus, the network lifetime is minimized. The CH role should be backed up among cluster members for prolonging the network lifespan and balancing the energy consumption [8]. By using some probability function, the CH role rotates among member nodes periodically based on various schemes in sensor network. CHs are also resulted in software or hardware failures. For proper functioning of a network, some fault-tolerant mechanism is needed to deal with these faulty CHs [9].

A dynamic and distributed dual cluster-head election algorithm using two-level clustering is proposed with fault tolerance capabilities to address the fault tolerance clustering and energy-efficient routing issues. For dual CH selection, the residual energy and delay-energy of a node are considered. After finding the current cluster head failure, the role of cluster head is played by PCH when the MCH is failed to communicate. The delay constrained PSO (DCPSO) is used for efficient relay node selection. The DCPSO takes into account node cost & end to end delay for efficient relay selection. Thus, the energy consumption is balanced and reduced.

Our contributions

- The dual CH selection method selects two CHs namely master CH (MCH), Proxy CH (PCH) for every clusters. Whenever the MCH fails to communicate or fails due to hardware failure, the cluster head role is taken over by PCH automatically and start aggregating data from cluster members. This gives the fault tolerance to clusters and an uninterrupted data aggregation at CHs.
- The parameters used for dual CH selection is delay-energy-trade-off (DET) & residual energy of the node. The DET parameter helps for choosing the reliable CH and improving the energy balancing among nodes.
- The delay constrained PSO (DCPSO) is used for efficient relay node selection. It helps to minimize and balance the energy consumption in sensor nodes. The DCPSO takes into account node cost & end to end delay for efficient relay selection.
- The proposed technique has major benefits, such as increased throughput, extended network lifetime, energy efficiency, scalability, and link quality.

II. Literature survey

Yifan Hu et al., (2014) has proposed an IOLPSOA-based routing recovery protocol for providing fast routing recovery from path failure. Based on the establishment of an efficient and immune clone mechanism, the particles can fly in better directions. The IOLPSOA-based routing method is outperformed than the other previous methods in providing improved network lifetime, and reliable communication [10].

Yifan Hu et al., (2015) has presented a study based on a novel routing protocol using ECPSOA with multiple mobile sinks. For packet delivery, an alternative reliable path is established if the earlier path is broken because of the nodes failure or sinks movement. The proposed routing recovery model is showed better results in delay, energy, and the network robustness than the existing protocols [11].

Quing Yi Zhang et al., (2015) has proposed a fault-tolerant QoS routing mechanism using SA and PSO algorithms. It's very difficult to build a perfect network model due to the strong spatial and temporal complexity and the algorithm itself impacting the efficiency [12].

Abhijit A. Rajguru and S. S. Apte et al., (2018) has proposed EDFHOA algorithm for QoS efficiency. An efficient clustering methodology has used to improve the performance of different QoS parameters. By comparing with DPSO based task scheduling FTAOA, the proposed hybrid algorithm provides improved results in task scheduling, network lifetime, energy consumption, and efficient resource utilization [13].

Hong Zhang and Zhanming Li et al., (2020) have proposed an energy-aware data gathering mechanism based on particle swarm optimization for mobile sink in WSNs. To avoid falling into the premature local optimal solution, a strategy of particle swarm optimization with adaptive elite mutation. Based on the simulation results, the proposed mechanism is outperformed in terms of running time, network lifetime, and average energy exhaustion than the existing methods [14].

III. Proposed system

Preliminaries

Network model

- The heterogeneous sensor nodes in terms of processing power and initial energy are involved in WSN.
- The Euclidean distance is used to compute the distance between sensors.
- Random deployment of sensor nodes in the sensing area is considered and their position is constant after deploying them.
- The mobile sinks are moving in GRID mobility pattern in the network.

Energy model

For radio electronics, the energy serves by receiver and the energy serves by the transmitter for power amplifiers and radio electronics in the radio energy dissipation model.. The free space model energy dissipation is given as d^2 when the threshold is lesser than the distance 'd' between sender and receiver. The energy dissipation for multi-path fading is given as d^4. The energy consumption Es for a k-bit packet transmission is as follows equation (1):

$$E_s = \begin{cases} k * (E_{ec} + E_{frs} * d^2); & d \le d_0 \\ k * (E_{ec} + E_{mpf} * d^4); & d \ge d_0 \end{cases} \quad (1)$$

E_{ec} refers to the required energy for the electronic circuit of SN. For detecting the amplifier energy of multipath fading (E_{mpf}*d^4) or free space model (E_{frs}* d^2), the tolerant bit error rate and the distance between sender and receiver have used. Here, E_{mpf} and E_{frs} indicate the requisite energy to send a bit into free space and multipath fading channel while d is the distance between sender and receiver. The threshold distance dthresh is given by equation (2):

$$d_{thresh} = \sqrt{\frac{E_{frs}}{E_{mpf}}} \quad (2)$$

The below equation represents the consumed energy for a received packet of k bits in equation (3):

$$E_{rec} = k * E_{ec} \quad (3)$$

The spent energy at CH for data aggregation is given by equation (4):

$$E_{agg} = l_{Eagg} * k * n \quad (4)$$

Where, 'k' indicates the number of bits in a packet, l_{Eagg} refers to the amount of energy for aggregating bits, and 'n' represents the number of messages.

Proposed method

We introduce a distributed and dynamic dual cluster head election algorithm using two-level clustering scheme based on fault tolerance capabilities. The delay-energy-trade-off & the residual energy of the node are taken into account for dual CH selection. If the MCH fails to communicate, then the cluster head role is taken over by PCH automatically after identifying the current cluster head failure. The delay constrained PSO (DCPSO) is used for efficient relay node selection. The DCPSO takes into account node cost & end to end delay for efficient relay selection.

Clustering & Dual CH selection

In this phase, the network nodes categorize into 'n' clusters and a CH is assigned for each cluster. The sensed data is received and aggregated by the chosen CHs and deliver to the destination. In order to provide fault tolerance, in our work dual CHs (MCH, PCH) are selected for each cluster. The MCH act as the primary cluster head and start aggregating the data initially. Based on the delay-energy trade-off (DET) and residual energy (RE), the dual CHs are chosen. The node is chosen as MCH if it satisfies this criteria and the node is selected as PCH that comes second in meeting the criteria. Whenever the MCH fails to communicate with the member nodes due to various circumstances (Ex: hardware failure), automatically the selected PCH will take over the role of MCH and continue to aggregate the data from the cluster members. The dual CH selection parameters are explained as follows:

Residual energy: -initially all the sensor nodes have different levels of energy due to the network heterogeneity. The residual energy of every sensor node is calculated as followsequation (5):

$$E_{res} = E_{total} - (E_C + E_T + E_R + E_A) \quad (5)$$

Here E_{total} is total energy, E_C is energy utilized during data collection, $E_T \& E_R$ are the energy utilized during data sending and receiving respectively and E_A is energy utilized for aggregating the data in the equation (6).

$$RE = \frac{1}{M} * \sum_{i=1}^{N} E_{res}(N) \quad (6)$$

Delay-energy-trade-off (DET): - For selecting the cluster head node and balancing the clusters, the DET value is computed that uses for balancing of energy consumption and end-to-end delay between communication of nodes. It can be calculated as follows equation (7) and (8):

$$DET_i = \left\{ \left(\frac{RE_i}{E_{total}}\right)^{\alpha} + \left(\frac{1}{NCN(i,j)}\right)^{\beta} \right\} \quad (7)$$

$$NCN(i,j) = \frac{\sum_{i=1}^{n} \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}}{n} \quad (8)$$

Where, $E_{total}$is the total energy of cluster head node, RE_i refers to the cluster head node's remaining energy, and DET_i indicates the delay-energy-trade-off of the node i. α, β are random numbers between (0,1), $NCN(i,j)$ represents the node centrality.

Finally, a score will be calculated for each and every node in the cluster based on the evaluated metrics as per the below equation (9):

$$SC_i = \frac{1}{E_{res}(i) + DET(i)} \quad (9)$$

On calculating the node score, the nodes sending their scores to neighbouring nodes based on an advertisement packet, which is illustrated as follows in figure 2:

$node_{id}$	SC_i	k

Fig 2: format of advertisement packet

The sensor nodes are aware of their own score and that of their neighbours after broadcasting advertisement packets. Their values are compared and the node that has highest score is advertised as a MCH itself. The node advertises itself as PCH if it comes second in satisfying the criteria. A node chooses and join the packet sender as its MCH when a node is received only one MCH advertisement packet. The node will join with the one that has the highest score value if two or more MCH advertisement packets are received. One of the received packets is chosen randomly upon receiving the packets from the nodes with same score values. The same process is followed when choosing PCH.

Delay constrained relay node selection using DCPSO

Delay is defined as the elapsed time between a collected data packet departure from a source (S) and the arrival to the destination. The average of queuing delay (D(Q)) per intermediate data disseminator, propagation delay (D(P)), and transmission delay (D(t)) are included in a delay D(S), which formulates as follows equation (10):

$$D(S) = \left(D(Q) + D(t) + D(P)\right) * HOPCOUNT_S \tag{10}$$

$$i.e\ D(S) = K * HOPCOUNT_S$$

Where $K = D(Q) + D(t) + D(P)$, which is a constant for sensor network. Delay directly impacts the timely delivery of the data also affects the network QoS such as energy consumption, throughput, network lifetime...etc., So minimizing the delay during data transmission is important to enhance the network quality.

Delay constrained Particle swarm optimization

The random search methods of evolutionary algorithm, fish schooling, and bird flocking are inspired to develop and improve the particle swarm optimization (PSO). We can observe that the animals, fishes, birds, etc. will always travel in groups without colliding each other. In this way, PSO has developed by each member adjusts its velocity and position based on the group information. The individual effort reduces for searching the shelter, food, etc.

A swarm of a predefined size of particles include in PSO algorithm. A complete solution is given for multidimensional optimization problem by each particle. The equal dimension D of all particles is considered. In the dth dimension of hyperspace, a particle $P_i, 1 \leq N_p$ is included with the position Xid and velocity Vid. To represent the ith particle Pi of the population, the below notation is adopted in the equation (11):

$$P_i = [X_{i,1}, X_{i,2}, X_{i,3} \ldots\ldots X_{i,D}] \tag{11}$$

To investigate the solution quality to the problem, a fitness function is evaluated by each particle. The particle Pi considers its own best values like Pbesti and Gbest to reach the global best position by updating the position and velocity. Below equations are used to update the position Xid and velocity Vid in each iteration in the equation (12).

$$V_{i,d}(t) = w * V_{i,d}(t+1) + C_1 * R_1 * \left(Xpbest_{i,d} - X_{i,d}(t-1\right.$$
$$\left. * \left(XGbest_{i,d} - X_{i,d}(t-1)\right)\right)$$

$$X_{i,d}(t) = X_{i,d}(t-1) + V_{i,d}(t) \tag{12}$$

Where, R1 and R2 represent two different uniformly distributed random numbers ranging in [0, 1], C1 and C2 indicate the two non-negative constants known as acceleration factor, and w is the inertial weight. Until achieving an acceptable Gbest or a fixed number of iterations, the update process is continued iteratively.

Relay selection using DCPSO

Fitness function derivation.

For evaluating the population individual particle, a fitness function is constructed to update the global best and personal best of the particles periodically. In the proposed algorithm, two objectives are considered such as minimizing the node cost between two nodes and reducing the end-to-end delay in the equation (13).

$$objective\ 1: \min\{NCOST_i\};\ 1 \leq i \leq n$$

$$objective\ 2 = \min\{NDELAY_i\};\ 1 \leq i \leq n \tag{13}$$

Node cost: The cost is calculated for route between cluster head node based on the below equation (14):

$$NCOST_{i,j} = \left(\frac{1}{(E_{trans}+E_{recv}+E_{aggr})}\right) + E_{res} \quad (14)$$

Where, E_{res} refers to the node's remaining energy, E_{aggr} indicates the node's expanded energy based on all messages aggregation from members, E_{recv} is the spent energy by the node i to receive the message from other nodes, and E_{trans} refers to the node i's expanded energy for messages transmission over the distance from one to another node.

End-to-end delay: It is measured for a route based on the delay between source and destination nodes. However, it considers queuing delay, transmission delay, processing delay, and propagation delay in the equation (15).

$$NDELAY_{i,j} = \sum_{i,j}\left(\left(\frac{1}{\alpha 1-\alpha 2}\right) + \frac{1}{BW_{link}} + \frac{D(i,j)}{Pro_{SPEED}}\right) \quad (15)$$

Where, Pro_{SPEED} refers to the propagation speed, BW_{link} is the bandwidth link, $\alpha 1 \& \alpha 2$ are the constants, and D(i,j) indicates the distance between nodes.

A weight value Wi multiplies with each objective in this method. All these multiplied values added for converting the multi objectives into a single scalar objective function:

$$F(i) = W_1 * NCOST_i + W_2 * NDELAY_i$$

The value of $W_1 \& W_2$ *are* maintained between [0, 1].

. The particle Pi evaluates using the fitness function after knowing the new position. When the current fitness value is better than its fitness value only, its personal best ($Pbest_i$) replaces by itself. The updating process is given by equation (16):

$$pbest_i = \begin{cases} P_i & if\ (F(P_i) < F(pbest_i)) \\ pbest_i & otherwise \end{cases} \quad (16)$$

The updating of global best is as follows equation (17):

$$pbest_i = \begin{cases} P_i & if\ (F(P_i) < F(Gbest)) \\ Gbest & otherwise \end{cases} \quad (17)$$

The positions and velocity are updated iteratively unless the termination criteria is satisfied. The final routing solution is represented by the particle Gbest after terminating the DCPSO relay selection algorithm.

Mobile SINK and data aggregation

After the CH selection, each cluster member nodes send the data to their respective CHs through the DCPSO selected relay nodes. To save energy of CHs from sending to the sink, in our proposed approach, multiple mobile sinks are deployed. Each mobile sink is equipped with high computing resources such as energy, buffer size. From these cluster heads, the data collects by the mobile sink via a single-hop range, and deliver the collected data to the BS once they return to the starting point.

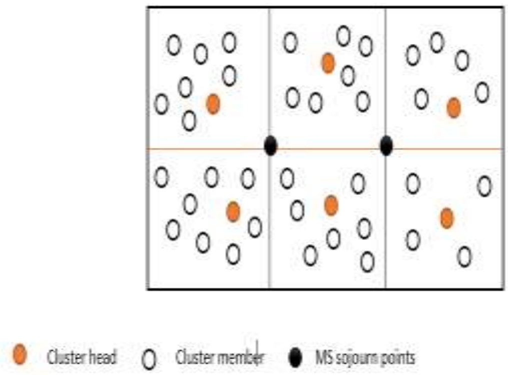

Fig 3: grid mobility pattern of mobile sinks

The mobile sinks move by following grid mobility pattern and advertise its movement and location through advertisement messages. Once the one-hop connectivity with CHs established the mobile sinks decide the sojourn point and stay until it collects the data from CHs. Then it continues the journey and decide the sojourn time and location based on CHs location and connectivity. Figure 3 shows the grid Mobility pattern of mobile sinks.

Algorithm

E_{res} – Residual energy; DET = delay energy trade-off; MCH – main CH; PCH – proxy CH;

##

For all the nodes n

Divide the network as 'k' clusters

For each node 'i'in cluster 'k'

DCH selection

Estimate $E_{res}(i)$

Estimate $DET(i)$

Calculate $SC(i)$

If $SC(i) > SC(j)$

$MCH = i$

$PCH = j$

End for

Data transmission phase DCPSO

Initialize particles $P_i \quad 1 \le i \le N_p$

$For\ i = 1\ to\ N_p$do

Calculate fitness $F(P_i)$

$pbest = P_i$

If $F(P_i) < F(Pbest_i)$

$Pbest_i = P_i$

If $F(Pbest_i) < Gbest$

$Gbest = F(P_i)$

End

Compute relay nodes using $Gbest$

End for

II. Result and discussion

We evaluated the performance of the proposed mechanism via simulations using NS2 . The sensor nodes are randomly deployed in a field with dimensions $1000mX1000m$, and the initial energy of sensor node is set from 80j to 100j. The network size is varied from 100 to 500 nodes. Besides, we assume that there is no energy constraint with mobile sink. The mobile sink followed GRID mobility pattern to visit CHs. The values of the experimental parameters are shown in Table 1.The performance analysis of proposed system compared with [15], [16] and [17].

Table1: The experimental parameters

Parameter	Value
Network area	1000x1000
Number of nodes	100 to 500
Initial energy	80j to 100j
Packet size	1024
MS mobility pattern	GRID

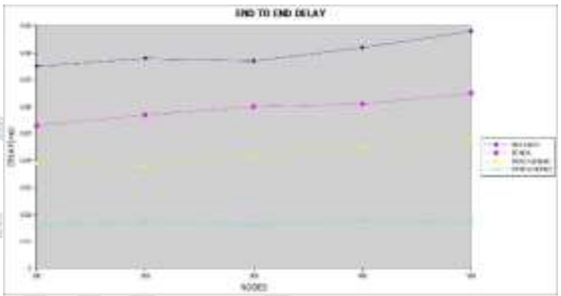

Fig 4: End to End Delay

End-to-end delay refers to the time taken for a packet to be transmitted across a network from source to destination.. The consideration of DET for CH selection and relay selection using delay constrained method helps to minimize the end to end delay in the proposed method.

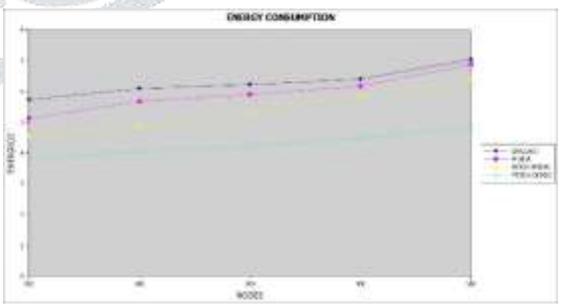

Fig 5: Energy consumption

The sensor nodes are equipped with initial energy to perform in network activities. The energy is depleted during every network activity. The energy should be optimized in every network for prolonged network activity. The efficient CH selection using DET and the optimal relay selection scheme included in the proposed method saved considerable amount of energy during execution.

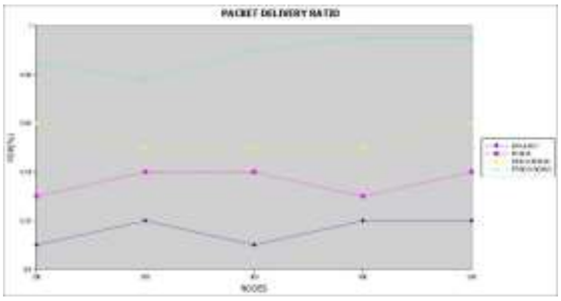

Fig 6: Packet delivery ratio

The PDR can be described as the ratio of data packets that are actually received at the receiver end to those which were originally sent by sender. The selection of stable and dual CHs using DET, the fault tolerance of the proposed using proxy CH and the optimal relay selection using delay-constrained PSO helps the sensor nodes to forward the data very successfully.

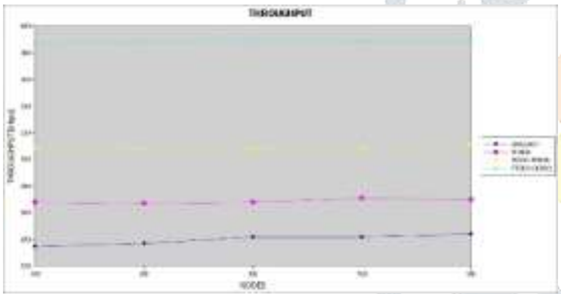

Fig 7: Throughput

Throughput is a measure of total number of data units a node can process in a given amount of time. The optimal relay selection using delay constrained PSO and the CH selection using DET helps for optimal data aggregation. The above listed table proves that the proposed method gives high throughput rate compared with existing methods.

Conclusion

In this paper, a new dual cluster head (MCH, PCH) selection mechanism is introduced to provide fault tolerance during CH failure and data aggregation. The parameter called delay-energy-trade-off DET and residual energy of the node are taken into consideration of MCH, PCH selection. The parameter DET is considered to minimize and balance the energy consumption of CHs. If the MCH fails to communicate, then the CH role is played by PCH automatically after detecting the current cluster head failure. For choosing efficient relay node, the delay constrained PSO is exploited that reduces and balances the power consumption. The node cost and end-to-end delay are considered for efficient relay selection in the DCPSO. The proposed algorithm DCH-DCPSO is outperformed than the existing relevant protocols by assessing the simulation results.

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