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Design and implementation of duty cycle-based futuristic clustering technique in WSN

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ABSTRACT

In recent times, wireless sensor networks (WSNs) and their applications have exhibited a remarkable surge. These networks strive to devise and implement strategies that optimize network energy utilization, thereby extending their operational lifespan. An energy efficient network can be achieved using renewable source of energy and by controlling the duty cycle of nodes. The pivotal role of duty cycle in curtailing energy consumption in WSNs cannot be overstated. In this work, we introduce a novel duty cycle based futuristic clustering technique (DCBFCT) employing a nearest neighbor approach. This technique selectively induces sleep and awake modes in nodes, effectively minimizing the network's overall energy consumption and, consequently, prolonging its lifespan. It calculates optimal node duty cycle values based on distance. Results demonstrate a substantial reduction in energy consumption, exhibiting an improved network lifetime. Empirical results presented in this study not only affirm the effectiveness of DCBFCT but also contribute valuable insights toward the development of sustainable and resilient WSNs in the era of burgeoning sensor network applications. The experimentation is conducted using the MATLAB/Simulink tool, considering diverse cases. The scalability and versatility of DCBFCT make it suitable for deployment in real-world applications, ranging from environmental monitoring to industrial automation.

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1. INTRODUCTION

Advancements in engineering and technology have unlatched wide scope of study in the arena of wireless sensor networks (WSNs) WSNs that explore efficient means of clustering data and communicating the information WSNs demonstrate gargantuan technical potential for it to be espoused in versatile applications like healthcare, bio diversity mapping, surveillance, agriculture, smart industries, and smart homes. Considering the vitality of WSNs in multipurpose applications and its paramount role in internet of things (IoT), researchers are incessantly working on design of modules that efficiently utilize energy while maximizing the lifetime of the network. In this work, duty cycle of nodes is varied depending on the distance of the node from cluster head (CH). Each node will be in awake mode or sleep mode for different durations. This technique can be implemented in WSNs to increase the energy efficiency of network. Duty cycle of each sensor node in the network can be varied based on any one of the parameters viz, transmission time, distance between nodes and speed of dynamic nodes. Tagare and Narendra [1] we proposed an energy efficient clustering technique with the use of renewable solar energy. The CH would be selected based on probability approach which was dependent on distance and residual energy. The heterogeneity concept was introduced by energizing only those CHs whose energy was less than 5% of their initial energy E0 (E0 = 0.2 J). MATLAB was used to simulate a WSN scenario with 100 nodes in 100×100 sq.m area for 5,000 rounds. The first node was dead at 473rd round and last node was dead at 3,459th round. The total energy consumed by the network was 31.2892 J and was energy efficient compared to the previously existing techniques.

Many researchers have proposed energy efficient algorithms in WSN which are available in the literature [2] proposed a queue-based scheduling algorithm for diverse traffic situations. Network simulator (NS) - 2 simulation tool was used to evaluate the network performance. Based on data priority, the duty cycle scheduling was implemented. The results showed that no critical data was lost using the technique, when any high priority data was sensed. Duty cycle approach based on the data using Cooja simulator [3], implemented an optimal forwarding strategy. They considered different network sizes by changing the network density for mobile users and energy consumption was recorded low with 50% threshold. Shaojun [4] considered schedules for sleep and working time slots for all nodes according to the data link status in such a way that, the constraints available on delay were satisfied. MATLAB implementation, for a circular area of 50 m radius deployed with 600 nodes showed that, the network's lifetime would reduce when the stringent delay constraints were imposed. Saraereh *et al.* [5] implemented, neighbour discovery method to overcome the problems faced by nodes in a low-duty cycle network. It reduced the delay and energy consumption. Wang *et al.* [6] worked on setting optimal duty cycle for asynchronous mode to reduce communication latency and increase energy efficiency. Delay was reduced by choosing a constant value for the forwarding set of nodes. The results showed a marginal end to end delay.

Dynamic allocation of duty cycle [7], was based on distance. Here, nodes far from the CH where active for shorter time and others were active for longer time duration. Results showed better performance w.r.t number of rounds, latency and data packets transmitted. Li *et al.* [8] provided details on green communication and proposed Bi-adjustable duty cycle scheme. This low duty cycle design implemented was able to achieve low latency and delay. Saraswat and Bhattacharya [9], a scheme was proposed to obtain an optimum duty cycle using MATLAB. The results indicated more energy consumption when network lifetime was minimized and vice-versa. Li *et al.* [10] designed duty cycle for nodes based on threshold energy. Here, the nodes with more energy consumption would be put to sleep mode which resulted in extended lifetime. Further, Razaque and Elleithy [11] explained the importance of optimal duty cycle value to reduce collisions and overhearing problems. Results closely followed the experimental values with a longer network lifetime. Next, Tripathi *et al.* [12] discussed a strategy to set node's duty cycle based on the its remaining active time and energy. It suggested to extend the work for duty-cycle based clustering protocols for better performance of the network. In Song *et al.* [13], a reliable clustering-based duty cycle approach was designed. Here, location-aware nodes were considered. The network considered here was dynamic. This technique presented energy savings and improved reliability of data transmission. However, location aware nodes are expensive and dynamic nodes need more maintenance. From the literature of existing duty-cycle based techniques, it is learnt that appropriate selection of duty cycle for nodes helps in achieving energy efficiency. However, identifying and implementing an appropriate technique for changing the duty cycle of the nodes is a challenge problem. There are number of comparative studies made on selection of the appropriate tools [14]–[29] in simulating WSN environment. The final selection of the tool is made depending on the problem statement under study and its suitability to get reliable results [6].

The requirement of a WSN is to achieve an energy efficient WSN with improved network lifetime [30], [31]. Even though many optimization techniques and algorithms are implemented [32], still there exists a need to identify more energy efficient algorithms for WSN with duty cycle approach. Thus, the objective of this work is to identify a novel technique to vary the duty cycle for nodes based on distance and implement the duty cycle based futuristic clustering technique (DCBFCT), simulate DCBFCT and evaluate its performance using MATLAB tool. Finally conclude how the proposed technique is better than existing technique in terms of network lifetime and energy efficiency. This paper provides simulated results of minimum duty cycle of each node, thereby achieving energy efficiency and longer network lifetime. The results are compared with other existing technique. This paper is organised as follows: section 2 gives the detailed process for design of the futuristic clustering technique (FCT), with detailed mathematical equations and algorithm. Next, section 3 presents the detailed simulation considering different cases and trials. In section 4 presents the results for the different cases, trials and comparison with existing techniques. Finally, section 5 presents the concluding remarks for the entire work.

2. THE PROPOSED METHOD

2.1. Design of DCBFCT

The model is presented in Figure 1 as the basis for implementing the duty cycle-based approach [1]. In Figure 1, a monitoring area of 100×100 sq.m is considered with 100 sensor nodes randomly dispersed [1]. The neighbor node distances are calculated using Euclidean distance formula. Based on the number of neighbors and the distance, certain nodes are maintained in awake mode and others are switched to sleep mode. The nodes in awake mode carry out the steps as in [1] for CH selection, data packets transfer to CH, data aggregation and then the data packets transfer to BS. Depending on the residual energy of CH, solar energy is used for re-energizing the CH. Next, the nodes in sleep mode are checked for certain conditions about the mode and energy status of the neighboring node. Accordingly, a decision is taken whether to continue them in sleep mode or switch them to awake mode. The technique regulates duty cycle of each node depending on its distance. Nodes closer to CH are in awake mode for longer duration than the nodes far away from the CH. This leads to conservation of the node energy in faraway nodes and extends lifetime. Network performance is evaluated for following performance parameters: duty cycle of nodes for various cases namely; when CH is considered at minimum distance, mean distance, and maximum distance from the nodes. The results obtained are compared with [1] results and analyzed. All the assumptions, pre-set simulation parameters are maintained as in [1] to establish a comparative result analysis.

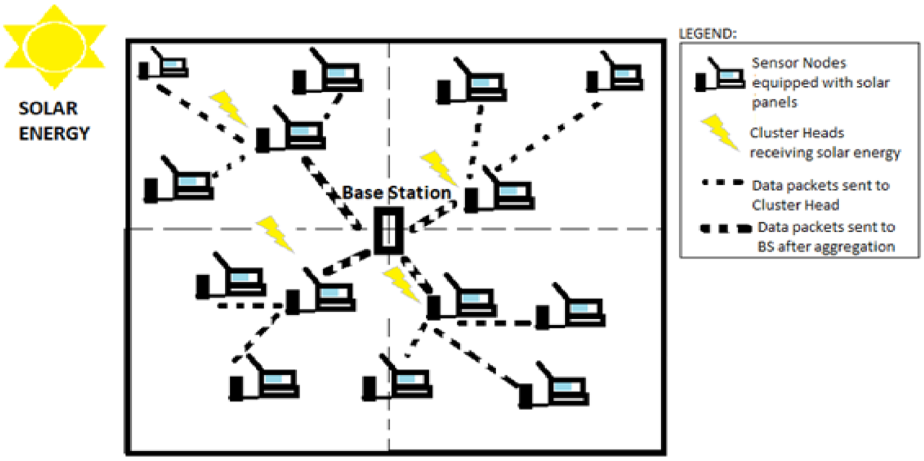


Figure 1. Overview of the scenario for implementing DCBFCT in WSN [1]

2.2. Mathematical equations

Euclidean distance formula is used to estimate the distance between nodes to measure the neighbour node distance and between nodes and CHs to set the duty cycle. The formula is as (1),

$$d(x,y) = \sqrt{(x2-x1)^2 + (y2-y1)^2} \quad (m) \tag{1}$$

where, $d(x,y)$: the Euclidean distance measure between two nodes located at (x1, y1) and (x2, y2) in the monitoring area.
Equation to calculate the percentage duty cycle of each node is given by [7],

$$DC_n = \frac{f(Dist_n)}{\sum_{\forall\, n\in N} f(Dist_n)} \times 100 \quad (\%) \tag{2}$$

DC_n: duty cycle of node with id 'n', N: maximum number of nodes.

$$\text{Were, } f(Dist_n) = \frac{1}{\text{a+b}\tanh(\frac{Dist_n}{T})} \tag{3}$$

With T, boundary is calculated using in (4) and 'a' and 'b' are constants chosen such that the duty cycle value can be increased or decreased.

If 'a' and 'b' is set high, value of (3) is low and hence, value of duty cycle from (2) is low and vice versa. Thus, values of 'a' and 'b' are inversely proportional to the duty cycle of the node.

$$T = \alpha \times Dist_{mean} \quad (4)$$

With α, being a constant and set using in the (5).

$$\frac{Dist_{nearest\_node}}{Dist_{mean}} \leq \alpha \leq \frac{Dist_{farthest\_node}}{Dist_{mean}} \quad (5)$$

Were, $Dist_{nearest\_node}$: distance of the nearest node to CH (m), $Dist_{farthest\_node}$: distance of the farthest node to CH (m), $Dist_{mean}$: average value of the distances of all the nodes w.r.t CH (m).

2.3. Algorithm: DCBFCT

Considering the design and implementation of energy efficient clustering technique discussed in [1], the following additional steps are carried out to design a DCBFCT as shown in Algorithm 1.

Algorithm 1. DCBFCT
1. Calculate the nearest neighbor for each node using equation (1), the nodes in range of less than 10 m are considered neighbor nodes in this study.
2. The algorithm implemented discussed in [1] is applied here w.r.t CH selection, residual energy calculation and re-energizing of CH from solar energy if required.
3. Out of two neighbouring nodes, one node is maintained in awake mode while the other is switched to sleep mode.
4. The awake nodes sense the physical parameter and transmits it to CH.
5. CH aggregates and transmits data to the BS.
6. Transitioning of mode of the sleep nodes is based on its neighbour's status. The following are the conditions that are tested for a node in sleep mode:
– The neighbour node is CH, then the node continues to be in sleep mode.
– The neighbour node has greater residual energy than the test node, then the node continues to be in sleep mode.
– The neighbour node is dead, then the node is switched to awake mode.
– Residual energy of neighbour node is less than test node, then node is switched to awake mode.

The steps 1 to 6 are repeated for rmax rounds set for the simulation of the network.

7. The duty cycle of each node is calculated based on the distance of CH from the node.
8. Different network parameters are evaluated.

3. METHOD AND SIMULATION

The simulation is carried out using MATLAB 2020a version tool [15]. A total of 100 nodes are placed randomly in 100×100 sq.m area. BS is at (50, 50) location. All nodes are considered with 0.2 J of initial energy (as in [1]). The simulation is run for 5000 rounds. The nodes are grouped into clusters and a maximum of 10 CHs can be selected in every round (in this approach). The neighbor node distance is calculated. The nodes within a range of 10 m are considered neighbors. Between two neighbors, one is maintained in awake mode and other is switched to sleep mode. The awake nodes participate in CH selection and sensing. The CHs are selected based on a probability value dependent on the node's distance w.r.t BS and its residual energy. Once a CH is selected, it aggregates the data and transmits to BS. Residual energy in CH is examined to satisfy the criteria to be re-energized using in (19) to (23). Re-energizing of only few CHs in the network implements the Level–2 heterogeneity in the network. Next, the nodes in sleep mode will be continued to be kept in sleep mode or switched to awake mode depending on the conditions discussed. The switching is necessary to reduce the delay and packet loss in the network. Next, the duty cycle of each node is calculated using in (2) to (5). In this study, we consider three cases for node duty cycle calculation. Using in (5), α can be selected as,

$$\text{Lower bound value} = \frac{Dist_{nearest\_node}}{Dist_{mean}} \quad (6)$$

$$\text{Mean bound value} = \frac{lower\ bound\ value + upper\ bound\ value}{2} \quad (7)$$

$$\text{Upper bound value} = \frac{Dist_{farthest\_node}}{Dist_{mean}} \quad (8)$$

CASE 1: α1 is considered lower bound value
CASE 2: α2 is considered mean bound value
CASE 3: α3 is considered upper bound value

Next, consider (4) to set T , boundary around the cluster can thus take on three values using in (4).

$$T1 = \alpha 1 \times Dist_{mean}, \text{ when the boundary is set close to the nearest node to CH} \quad (9)$$

$$T2 = \alpha 2 \times Dist_{mean}, \text{ when boundary is set in between the node and CH} \quad (10)$$

$$T3 = \alpha 3 \times Dist_{mean}, \text{ when boundary is set close to the farthest node to CH} \quad (11)$$

Consider, (3). The values for ‘a’ and ‘b’ are chosen for three trials to control the duty cycle values. A minimum value for nearest, maximum value for farthest node and a mean value.
TRIAL 1: a = 1, b = 10 resulting in a/b = 0.1
TRIAL 2: a = 10, b = 1 resulting in a/b = 10
TRIAL 3: a = 1, b = 2 resulting in a/b = 0.5
All the cases and trials are simulated and the duty cycle for each node is evaluated using in (2). Further other network parameters namely., energy consumption, lifetime, data packets are estimated.

4. RESULTS AND DISCUSSION

4.1. Results of DCBFCT for different values ‘a’ and ‘b’

Simulation of DCBFCT obtained using MATLAB tool are discussed in this section. Table 1 presents the graph details of the proposed DCBFCT for different trials of ‘a’ and ‘b’ with the duty cycle of nodes varied based on distance criteria as explained in the DCBFCT algorithm. Table 2 shows the graph for DCBFCT w.r.t distance of nodes from CHs (for the different boundaries set for three cases).

Table 1. Graph details for DCBFCT w.r.t distance of nodes from CHs

Trial	Distance calculation	Graph depicting all the values obtained
1: a=1, b = 10	• $Dist_{nearest\_node}$: 5.0567 m • $Dist_{farthest\_node}$: 36.0269 m • $Dist_{mean}$: 106.1362 m	See in Figure 2
2: a=10, b = 1	• $Dist_{nearest\_node}$: 5.0567 m • $Dist_{farthest\_node}$: 36.0269 m • $Dist_{mean}$: 106.1362 m	See in Figure 3
3: a = 1, b = 2	• $Dist_{nearest\_node}$: 5.0567 m • $Dist_{farthest\_node}$: 36.0269 m • $Dist_{mean}$: 106.1362 m	See in Figure 4

Table 2. Graph details for DCBFCT w.r.t distance of nodes from CHs (For the different boundaries set for three cases)

	Distance of nodes w.r.t. CH in m	TRIAL 1	TRIAL 2	TRIAL 3
Case 1	Nearest	1.2562	1.0207	1.1755
	Farthest	0.9841	0.9985	0.9888
Case 2	Nearest	2.5664	1.0407	1.5976
	Farthest	0.4630	0.9578	0.6477
Case 3	Nearest	2.2461	1.0259	1.4102
	Farthest	0.3848	0.9584	0.6121

4.1.1. Analytical observations

From Table 1, duty cycle of nodes nearest to CH is always high, depicting a longer awake mode for nodes and duty cycle of nodes farthest from CH is always low, depicting a longer sleep mode for nodes. More transmission energy is required for far nodes compared to nearby nodes. This suggests that the technique of DCBFCT is energy efficient as it conserves the energy in far nodes and increases the lifetime of the network. From graphs presented in Figures 2-4, for all trials,
Case 1: when boundary is set towards nearest node of the cluster, show that only the nearest node is having maximum stake of duty cycle and all the remaining nodes have an equal stake of duty cycle.
Case 2: when node is in between the CH and boundary T, show that the stake of duty cycle is assigned to the nodes in the decreasing order as the distance of the node from CH increases.

Case 3: when the boundary is set close to the farthest node to CH, show that the stake of duty cycle for nearest node is maximum and those far away is minimum.

- In Case 2 for all trials, a maximum duty cycle value is reached for nodes closest to CH. In Case 3 for all trials, a minimum duty cycle value is reached for nodes farthest to CH. Thus, depending upon the energy available in the network, either Case 2 or Case 3 can be applied.
- Trial 3 shows an intermediate value for duty cycle of nodes for all cases with respect to Trial 1 and Trial 2

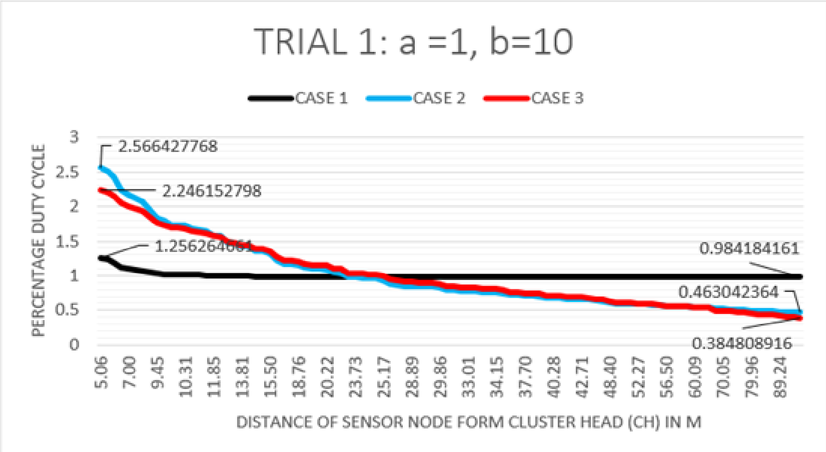


Figure 2. Percentage duty cycle of each node (with T1 = 5.0547 m (black), T2 = 55.5931 m (blue) and T3 = 106.1352 m (red))

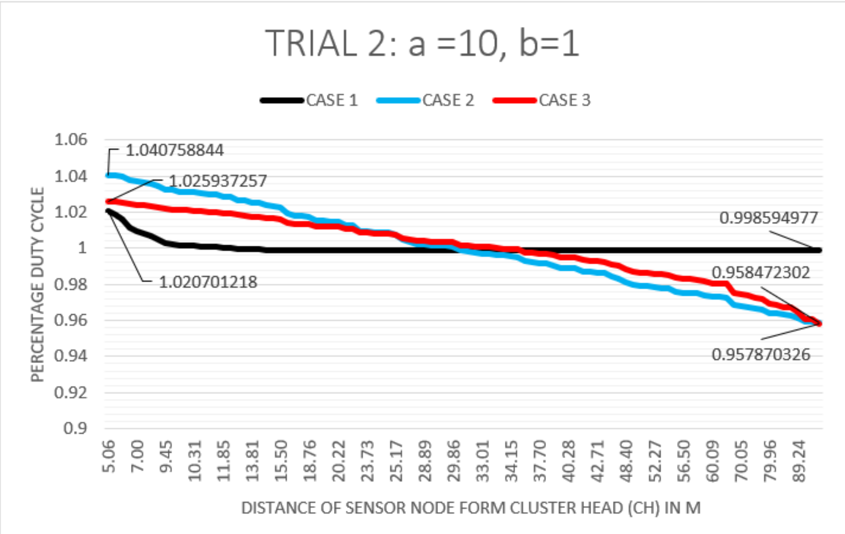


Figure 3. Percentage duty cycle of each node (with T1 = 5.0547 m (black), T2 = 55.5931 m (blue) and T3 = 106.1352 m (red)

4.2. Comparison of proposed DCBFCT with existing technique DBDDCA

The performance of proposed DCBFCT is compared with an existing distance based dynamic duty cycle algorithm (DBDDCA) [7] and analysis is carried out as shown in Table 3. A low percentage duty cycle for nodes is achievable in DCBFCT compared to DBDDCA [7]. In the three trial results observed, DCBFCT achieves almost the same pattern of duty cycle value as the distance of the node increases from the CH as observed in DBDDCA [7]. However, the duration for which the nodes should be in active mode is low in DCBFCT compared to DBDDCA. This makes the DCBFCT more energy efficient and improves network lifetime.

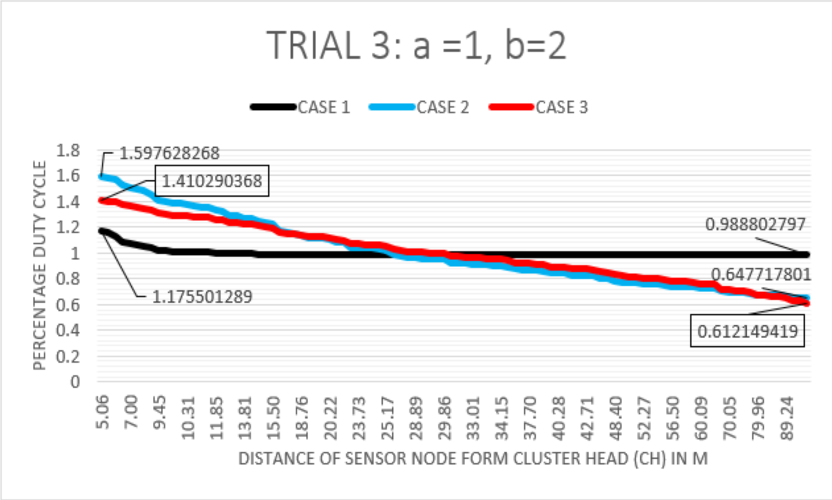
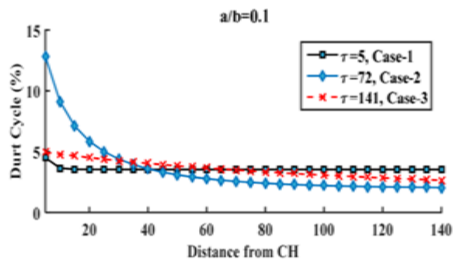
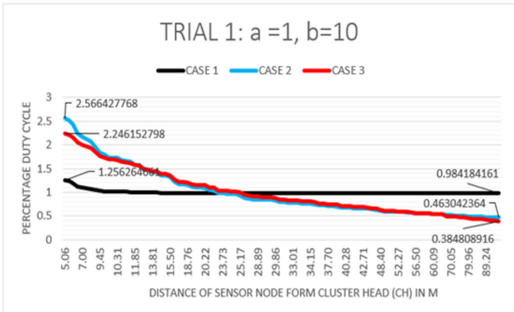
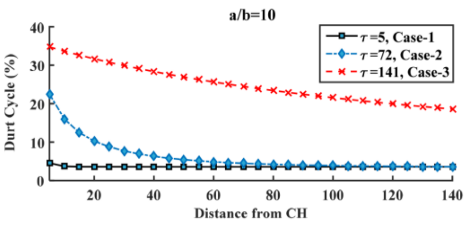
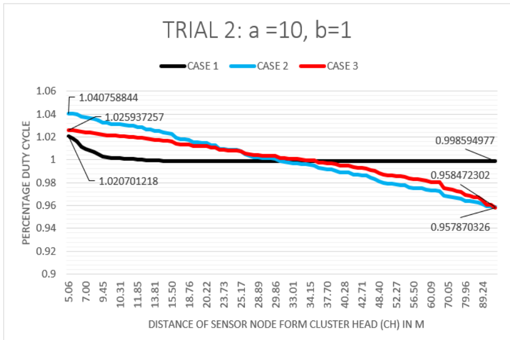
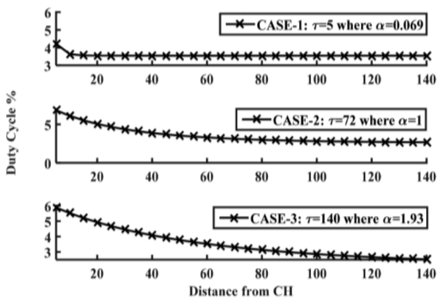
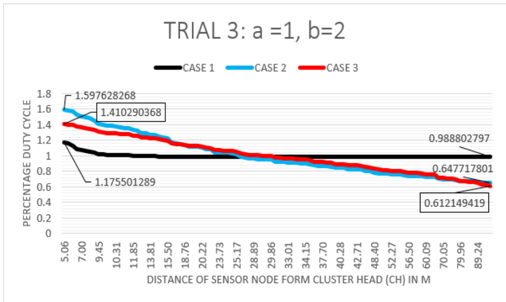


Figure 4. Percentage duty cycle of each node (with T1 = 5.0547 m (black), T2 = 55.5931 m (blue) and T3 = 106.1352 m (red))

Table 3. Comparison of results between existing DBDDCA algorithm and proposed DCBFCT technique

TRIAL	Distance based dynamic duty cycle algorithm [7]	Duty-cycle based FCT
TRIAL 1: a=1, b = 10		
TRIAL 2: a=10, b = 1		
TRIAL3: a = 1, b = 2		

5. CONCLUSION

Based on implementation of existing clustering algorithms and their evaluations, hierarchical based clustering protocols are recommended, particularly those that incorporate heterogeneity, as they are more energy-efficient and provide longer network life. DCBFCT proves to be a dynamic low duty cycle approach based on distance compared to DBDDCA technique. In DCBFCT, the active time of the nodes is very less and hence, the energy of the node is retained for a longer duration. This improves network lifetime and energy efficiency of the WSN. The algorithm's adaptability to diverse settings positions it as a promising solution for achieving energy-constrained WSNs. In future, we can simulate the nodes and examine their actions in dense and sparse networks to appreciate the reliability of the DCBFCT algorithm for scalable applications.

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