IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 3, February 2026 Impact Factor: 8.2

An Energy Aware Optimal Routing Mechanism for Wireless Sensor Network Energy and Latency Minimization

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Abstract: *Several real life applications in wireless networks as well as IoT rely on routing of wireless sensor networks. However, they face the invariable challenge of limited energy resources which makes it critical to design data transfer mechanisms which utilize the available energy in a manner to increase the networks lifetime and reduce the latency of the system. Effective clustering and energy management can increase the lifespan of the network while reducing the delay incurred simultaneously. In the proposed work, a two tier approach for minimizing redundant transmissions has been proposed in conjugation with the particle swarm optimization (PSO), which tries to minimize the intra cluster distances to minimize the latency and energy consumption too. The evaluation parameters for the proposed approach are the one hop delay, network delay and energy consumption. This heuristic approach has been used to find the best fitness function to optimize both the network lifetime as well as the latency.*

Keywords: Wireless Sensor Network (WSN), Network Lifetime, Clustering, One hop delay, network delay, two tier approach, PSO

I. INTRODUCTION

Wireless Sensor Network (WSNs) can be considered as an interconnected system of sensing nodules collecting data and sharing with a base station or control station [1]. Typically physical parameters are sensed for the type of environment that is to be sensed by the WSN [2]. The wireless sensor networks are a category of wireless ad-hoc networks (WANETs) which are being used for diverse applications where human intervention is not feasible [3]. While designing a wireless sensor network, the most stringent bound that one needs to face is the limited resources of energy which are generally non-replenishable at one's disposal [4] This puts up a critical limitation on the WSN for several applications where frequent replenishments are not possible for the sake of the performance of the application intended [5]. Hence the energy efficiency and minimization of energy dissipation is of utmost importance to make the WSN viable for use [6]

Clustering is a technique used with the aim to minimize the distance of communication between nodes of the WSN and the base station, also minimizing the intra-cluster energy consumption and finally the latency of the network [7]. The types of data transfer typical for a WSN are depicted in the figure below [8].

The basic types of data transfer that occur in a WNS are:

- Intra Cluster
- Inter Cluster
- CH-BS

DOI: 10.48175/IJARSCT-31316

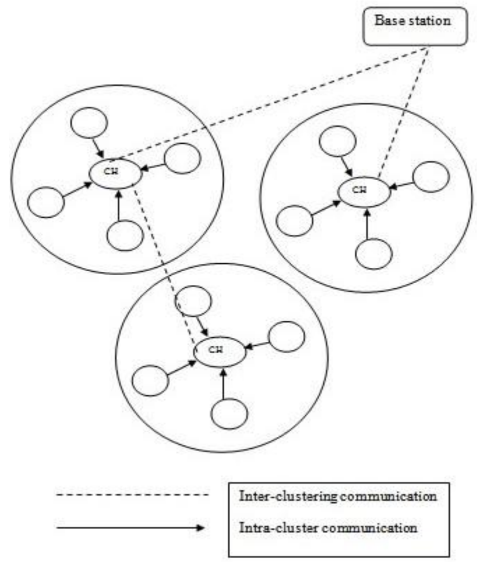

Fig.1 Types of data transfer in clustered networks.

Several clustering algorithms have been proposed in relevant literature such as the LEACH, TEEM, HEED etc. [8]. Each of the approaches has its own merits and limitations and are suited for specific applications [9]. Most of the focus of late has shifted to heterogeneous networks wherein the nodes need not have identical parameters [10]. The clustering mechanism partitions the number of nodes in the WSN into groups or clusters which do not send their data to the base station directly but send it to the cluster head of each cluster [11]. The cluster heads of the clusters then send the data to the base station. This results in the saving of the vital available energy resources of the WSN [12]. The proposed approach uses the particle swarm optimization (PSO) at the base station at the initialization phase of each round which tries to optimize the cluster size and heads to minimize the energy consumption in each round [13]. Moreover, a two-tier transmission protocol is designed to minimize the number of actual transmissions thereby substantially reducing the energy consumption of the network [14].

II. SYSTEM MODEL

The WSN model used in this study is the planar network model with periodic aggregation of data for the physical parameters sensed [15]. The WSN has the sink of the base station in which the data is sent by the various mobile or immobile nodes. The following considerations are made while designing the system model [16]:

- The sensing modules sense the data in a periodic fashion and have data to be sent to the sink node.
- The sink or base station aggregates the data collected.
- Nodes are energy constrained in real time.
- Nodes have the competence to adjust the transmitted power as per routing requirements.
- Dual mode operation of nodes is possible i.e. as cluster head or as a simple sensing nodule.
- Aggregation of data saves the power consumption of the WSN.

Moreover, the wireless transmission follows the Friss' free space equation given by [17]:

$$P_{Rx} = P_{Tx} G_{Tx} G_{Rx} (\frac{\lambda}{4\pi})^2 \qquad (1)$$

Here,

P_{Rx} is the received power

P_{Tx} is the transmitted power

G_{Tx} is the gain of the transmitting antenna

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G_{Rx} is the gain of the receiving antenna
λ is the wavelength of transmission
d is the distance between the transmitting end and the receiving end.
Thus it can be clearly seen that the received power in the near field region of the WSN follows the d–2 law. For larger distances, i.e. in the far field region, the d–4 law is applicable [18]. What is worth noting is the fact that the received power decreases exponentially with the increasing distance between the transmitting and receiving end [19]. The energy expenditure of the system for the successful transmission of a message whole length is 'l' and for a Tx-Rx separation of 'd', we have [20]:

$$E_{TX}(l,d) = lE_l + l\varepsilon_{NF}d^2; d < d_0 \qquad (2)$$

And.

$$E_{TX}(l,d) = lE_l + l\varepsilon_{FF}d^4; d \geq d_0 \qquad (3)$$

Here,
E_{TX} is the transmitted energy
l is the length of the message in bits
d is the distance between the transmitting and receiving ends
εNF and εNF are the near field and far field amplifier boosting parameters
$d0$ is the distance separating the near field and far field zones [21].

III. PROPOSED APPROACH

There are two fundamental approaches to minimize the energy consumption in the proposed approach which are [22]:
1) A Two-tier transmission scheme to reduce the number of overall transmissions
2) The particle Swarm Optimization (PSO) method to optimize the clustering mechanism in the WSN.

3.1 Two Tier Transmission Scheme:

The fundamental consideration in computation of the energy is the fact that not all regular transmissions are necessary even though periodic sensing is mandatory. This stems from the known fact that the information of redundant data is less or high probability occurrences render low information mathematically given by [23]:

$$I = P_i log_2 \frac{1}{P_i} \qquad (4)$$

Here,
I represents the information associated with any random event, which in this case is the aggregation of information
Pi is the probability of occurrence
Thus, if the probability of occurrence is high, then the information rendered is low and vice versa. This for a range of values for transmission, a two-tier process can be designed where the tiers are:
Tier1: This is a threshold after which the actual transmission starts, although the sensing is continual.
Tier 2: This is the threshold after which a re- transmission occurs when the value of the physical parameter sensed reaches a stable point or pre-defined value.
The tow tier process is implemented as:
Sense data continually
If (Tier1 threshold exceeds)
{
Start actual transmission
If (Value stabilizes & Tier 2 Threshold ~ reached & delay ~ exceeded)
{
Do no re-transmit data

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}
Else if (Value stabilizes & Tier 2 Threshold reached)
{
Re-Transmit Data
}
Else if (delay reached)
{
Re-transmit stored data
}
Else
{
Remain in idle state
}

This process of choosing a two-tier approach is typically critical for heterogeneous or even homogenous networks where continued transmission may not be needed even for continued sensing. A security delay time d is decided for re-transmissions in case thresholds are not exceeded to ensure reliability of the

3.2 The Particle Swarm Optimization

The particle swarm optimization generally referred to as the PSO is an extremely effective optimization tool for multi-variate or multi- dimensional functional optimization problems. In this pretext, the particle refers to a single valid solution and the swarm is referred to as the N-dimensional set of all possible valid solutions. In the beginning phase, all the particles are allocated some initial weights and flown through the multi-variate functional space to generate the swarm. Further the particles utilize the previous and current best weights or positions to decide upon optimizing the cost function. The particle velocity is updated as [24]:

$$v_{id}(t) = w \times v_{id}(t-1) + c_1\varnothing_1(p_{id}\text{-}x_{id}(t\text{-}1)) + c_2\varnothing_2(p_{gd}\text{-}x_{id}(t\text{-}1)) \quad (5)$$

And

$$x_{id}(t) = x_{id}(t-1) + v_{id}(t) \quad (6)$$

Table.1 Variable List for PSO

v	particle velocity
x	particle position
t	Time
c1,c2	Learning factors
Φ1 ,Φ2	Random numbers between 0 and 1
pid	Particle's best position
pgd	Global best position
w	Inertia weight

The PSO is used at the base station with ample resources of energy and is applied centrally to the WSN. The PSO is applied at the set-up phase of each round of transmission, followed by the steady state data exchange phase. Next, the base station runs the PSO algorithm to determine the best K cluster heads that can minimize the cost function, as defined by:

$$cost(t) = \beta f_1 + (1-\beta) f_2 \quad (7)$$

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Here,
f1 is the maximum average Euclidean distance of nodes to their associated cluster heads
f2 is the ratio of total initial energy of all nodes ni, i=1,2,…,N in the network to the total current energy of the cluster heads candidates in the current round.

$$f1 = \max\{\sum_{\forall n \in C_{p,k}} \frac{d(n_i, CH_{p,k})}{|C_{p,k}|} \qquad (8)$$

And

$$f2 = \frac{\sum_{i=1}^{n} E(n_i)}{\sum_{k=1}^{n} E(CH_{p,k})} \qquad (9)$$

Here,
f1 represents the maximum Euclidean distance
Ck represents the number of nodes of cluster C corresponding to the particle solution p.
f2 is the ratio of the total initial energy to the present energy of the WSN
CH represents a cluster head
The selection of the cluster head (CH) is made based on the residual energy of nodes given by:

$$E_{residual} = E_{initial} - \sum_{t=1}^{n} E_t \qquad (10)$$

Here,
Eresidual signifies the residual energy
Einitial signifies the intial energy
Et is the energy expended per transmission.

IV. EVALUATION PARAMETERS

The average energy estimation is given by:
Thus average energy for round k can be given by

$$\bar{E}(k) = \frac{1}{L} E_{Tot}\left(1 - \frac{k}{R}\right) \qquad (11)$$

Here
R is an indicative of the aggregate rounds of the lifetime of the WSN.
M is the total number of transmissions
L is the number of nodes
While the nodes can be either active or in the idle state, the condition is evaluated based on the duty cycle given by:

$$DC = \frac{T_{ON}}{T_{ON} + T_{OFF}} \qquad (12)$$

Here,
DC represents duty cycle
T0N represents the time for which the node is transmitting
T0FF is the time while the node is not transmitting
Clearly, with the increase in the duty cycle, the energy consumption would increase. The total energy consumption of the network is computed as:

$$E_{ToT} = (\int_i^f E(t)_{LPL} + \int_i^f E(t)_T + \int_i^f E(t)_R)dt \qquad (13)$$

Here
i represents the initial time
f represents the final time

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E(t) is the energy as a function of time
LPL is low power listening i.e. energy expended in sensing alone
R stands for the reception energy
T stands for the transmitted energy
Moreover, the delay of the network is computed as

$$D = \sum_{i=1}^{m}[D_f^i + D_t^i] \quad (14)$$

Here,
D represents the delay
f represents the find mode
t represents the transmission mode
m is the number of hops for data to reach from source to sink
The overall latency in the WSN is mathematically expressed as:

$$L = \frac{1}{n}\sum_{i=1}^{n} T_i^S - T_i^r \quad (15)$$

Here,
L is the average latency
n is the number of nodes
TS represents the time at which data is sensed by node i
Tr represents the time at which node i's data is received by data sink
The evaluation parameters help us to evaluate the performance of the proposed system quantitatively.

V. RESULTS

The obtained results are depicted in the form of graphs shown below.

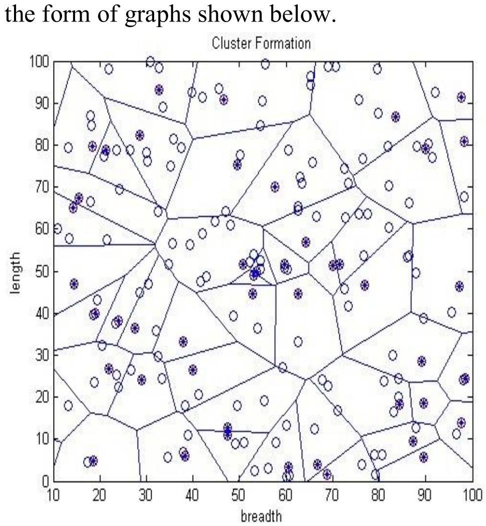

Fig.2 Initial Clustering

The figure above clearly depicts the clustering process in the WSN design.

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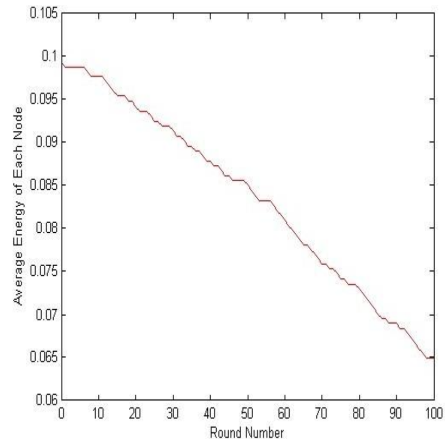

Fig.3 Average Energy of Nodes

The above graph depicts the variation in the average energy of the nodes with the increase in the number of iterations

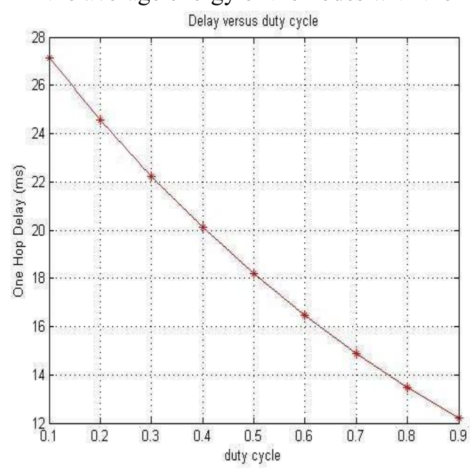

Fig.4 One hop Delay versus duty cycle

The figure above depicts the one hop delay of the data transmission in the wireless sensor network with respect to the duty cycle of the WSN.

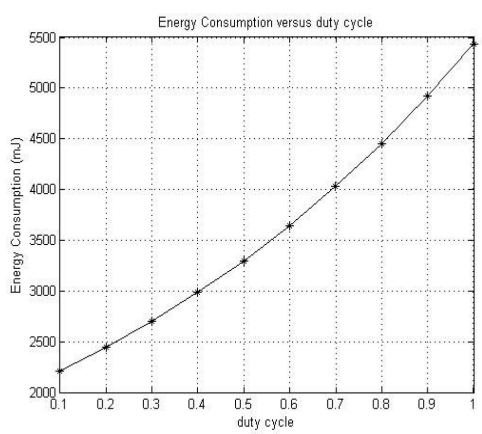

Fig.5 Energy Consumption versus duty cycle for r=80

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The figure above depicts the variation of energy consumption of the wireless sensor network as a function of duty cycle. The above figure represents the energy consumption case for the value of r=80.

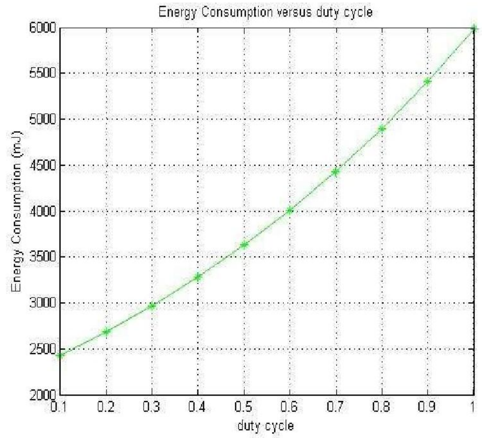

Fig.6 Energy Consumption versus duty cycle for r=100

The figure above depicts the variation of energy consumption of the wireless sensor network as a function of duty cycle. The above figure represents the energy consumption case for the value of r=100.

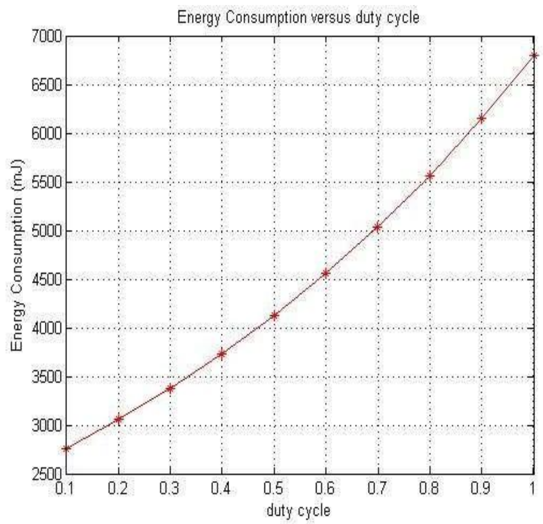

Fig.7 Energy Consumption versus duty cycle for r=120

The figure above depicts the variation of energy consumption of the wireless sensor network as a function of duty cycle. The above figure represents the energy consumption case for the value of r=120.

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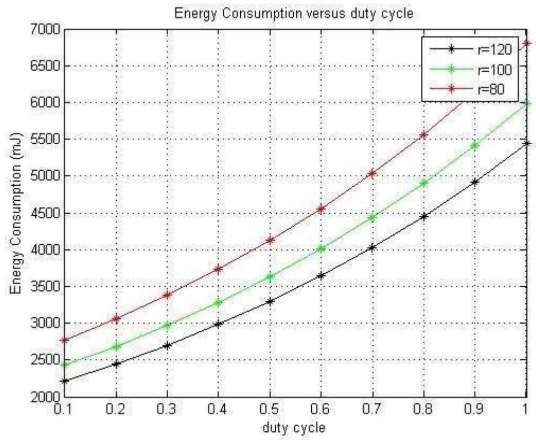

Fig.8 Energy Consumption versus duty cycle for variations in values of r

The figure above depicts the variation of energy consumption of the wireless sensor network as a function of duty cycle. The above figure represents the energy consumption case for variations in the value of r.

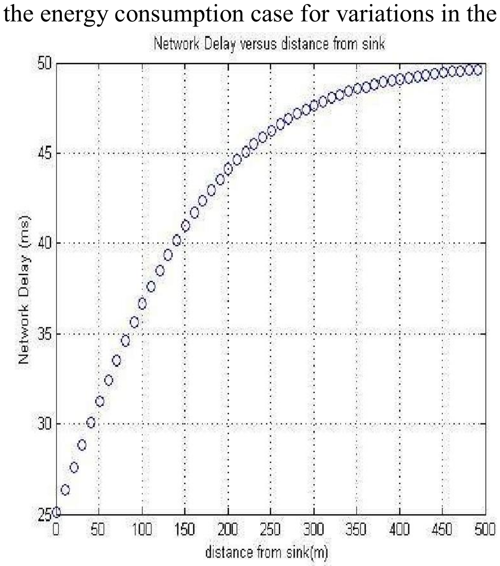

Fig.9 Network Delay versus distance from sink

The above figure depicts the variation of network delay with respect to the distance from the sink node. It can be seen that the network delay increases as the distance from the sink increases. This happens due to the fact that the data needs to be transmitted over multiple hops.

VI. CONCLUSION

In this paper, an optimized clustering method for wireless sensor networks has been proposed with an aim to enhance the network lifetime ad reduce the delay. The approach uses a 2-tier PSO based meta-heuristic approach wherein the aim has been on minimizing the redundant re-transmissions so as to reduce the overall energy consumption. The delay has also been computed in terms of the one hop mode and the overall network mode. The latency of the proposed work in terms of one hop and multi hop delays ensure the fact that the system is robust against sudden sporadic changes and the data can be transmitted to the control station. The lifetime in terms of the number of rounds ensures a high network lifetime for the network.

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