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Employing Swarm Intelligence for Optimizing Latency and Energy Consumption for Routing in WSNs

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Abstract- Efficient routing is crucial for many practical applications in wireless sensor networks. Nevertheless, they encounter the unavoidable obstacle of restricted energy resources, which underscores the need of developing data transmission mechanisms that optimize the allocated energy to enhance the longevity of the networks and minimize the system's latency. Implementing efficient clustering and energy management strategies can enhance the longevity of the network while concurrently decreasing the observed delay. The present study introduces a two-tier methodology for reducing unnecessary transmissions in conjunction with particle swarm optimization (PSO). The objective is to minimize the distances inside clusters in order to reduce both latency and energy usage. The evaluation parameters for the proposed method include the delay in the first hop, the latency in the network, and the energy usage. This empirical method has been employed to determine the optimal fitness function so as to optimize latency and energy consumption in WSNs.

Index Terms- Routing, Clustering, Swarm Intelligence, Latency, Energy Consumption.

I. INTRODUCTION

With large scale automation and smart networks, the domain of WSNs is witnessing unprecedented evolution and applications. Usually, physical parameters are detected tailored to the specific environment that the WSN is intended to detect. Wireless sensor networks form a subset of WANETs that find usage in various applications where human involvement is impractical [3].

One of the most challenging constraints when developing a wireless sensor network is the limited and typically non-replenishable energy resources available. This imposes a significant constraint on the Wireless Sensor Network (WSN) for many applications when regular replenishments are not feasible to maintain the requested application performance [5]. Hence, the energy efficiency and minimization of energy dissipation are crucial for making the Wireless Sensor Network (WSN) available for use (6).

Clustering is a method employed to reduce the communication distance between nodes of a Wireless Sensor Network (WSN) and the base station. It also aims to decrease the energy consumption within each cluster and ultimately mitigate the latency of the network [7]. The typical data transport types for a Wireless Sensor Network (WSN) are illustrated in the image below [8].

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

- Intra Cluster
- Inter Cluster
- CH-BS

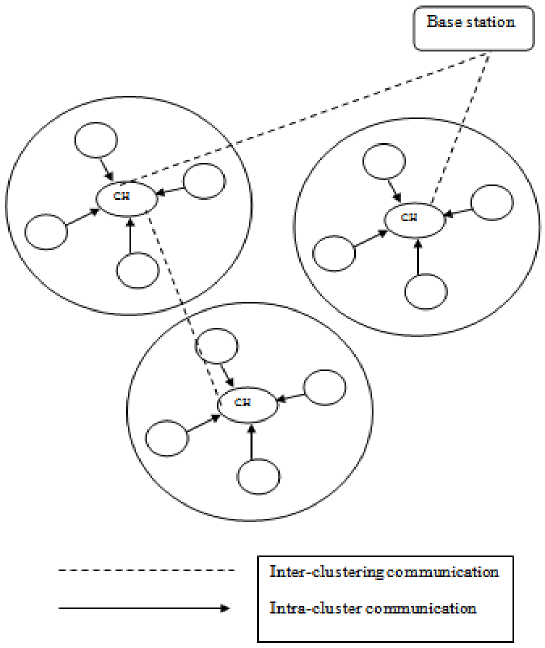

Fig.1 Types of data transfer in clustered networks.

Existing work in the domain has offered a number of clustering techniques, including LEACH, TEEM, HEED, etc. [8]. Each method is best suited to a different problem and has its own set of advantages and disadvantages [9]. Heterogeneous networks, in which nodes do not necessarily have the same properties, have recently taken center stage [10]. According to [11], the clustering mechanism divides the total number of WSN nodes into smaller groups called clusters. The data from clusters are collected and sent to the control station or sink. The WSN's essential accessible energy resources are preserved as a result [12]. During each round's start-up phase, the base station employs particle swarm optimization (PSO) to optimize the cluster size and heads in an effort to decrease energy usage [13]. Also, a two-tier transmission protocol can significantly cut down on the network's power usage by lowering the amount of real transmissions [14].

II. SYSTEM MODEL

The network model with periodic data aggregation for the measured physical parameters [15] is the WSN model utilized in this research. All of the nodes, whether mobile or stationary, contribute data to the WSN's central sink, the base station. When developing the system model, we keep in mind the following details:

- Data can be delivered to the sink node from the sensing modules at regular intervals.
- The data is aggregated by the sink or base station.
- Nodes experience real-time energy constraints. Nodes can modify the transmitted power according to the routing specifications.
- As a cluster head or a basic sensor nodule, nodes can operate in two modes simultaneously. The power consumption of the WSN can be reduced through data aggregation.

Also, the relation the fading of the data while being transmitted in a WSN is given by Friss' relation as [17]:

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

Here,
P_{Rx} is the received power
P_{Tx} is the transmitted power
G_{Tx} is the gain of the transmitting antenna
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.

Hence, the d^{-2} law is clearly followed by the received power in the near field region of the WSN. According to [18], the d^{-4} law can be used for larger distances, where the field is farther away. It should be noted that the received power drops exponentially as the distance between the sending and receiving ends increases [19]. For a Tx-Rx separation of 'd' and an energy consumption of the system for a successful transmission of a whole length of 'l', 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
ε_{NF} and ε_{NF} are the near field and far field amplifier boosting parameters
d_0 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]:

A Two-tier transmission scheme to reduce the number of overall transmissions

The PSO based swarm optimization approach is used for optimized clustering in this case.

Two Tier Transmission Scheme

The most crucial consideration when determining the energy is that not all periodic transmissions are necessary, even when periodic sensing is. Reason being, it's well knowledge that redundant data either doesn't contain much information or has a low mathematical probability of really happening. [23]:

I=P_i 〖log〗 _2 1/P_i (4)

Here,
I represents the information associated with any random event, which in this case is the aggregation of information
P_i 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
  }
 Else if (Value stabilizes & Tier 2 Threshold reached)
  {
 Re-Transmit Data
 }
Else if (delay reached)
{
Re-transmit stored data
    }
Else
{
Remain in idle state
}
```

When dealing with diverse or even homogenous networks, this procedure of selecting a two-tier strategy is usually crucial, as ongoing transmission might not be necessary even for ongoing sensing. In order to guarantee the WSN's reliability, a security delay time d is determined for re-transmissions in the event that thresholds are not exceeded.

The Particle Swarm Optimization

When it comes to optimizing functions over several dimensions or variables, particle swarm optimization, or PSO, is a game-changer. Here, the particle stands for a singular correct answer and the swarm for the full collection of all N-dimensional correct answers. As a first step in creating a swarm, we give each particle a starting weight and send them flying through the multi-variate functional space. Moreover, in order to optimize the cost function, the particles take into account both the past and present optimal weights or placements. According to the weight update rule [24]

v_id (t)=w×v_id (t-1)+c_1 Ø_1(p_id-x_id(t-1))+ c_2Ø2(pgd-x_id(t-1)) (5)

And

〖x〗_id (t)=x_id (t-1)+v_id (t) (6)

Table.1 Variable List for PSO

v	particle velocity
x	particle position
t	Time
c_1,c_2	Learning factors
Φ_1 ,Φ_2	Random numbers between 0 and 1
p_{id}	Particle’s best position
p_{gd}	Global best position
w	Inertia weight

The PSO is implemented centrally to the WSN at the base station, which has abundant energy supplies.

The residual energy in each round is used to decide Cluster Heads and the PSO is used to minimize intra and inter cluster distances while clustering [25]:

$$\mathrm{cost(t)} = \beta f_1 + (1-\beta) f_2 \qquad (7)$$

Here,
f1 denotes Euclidean distance.
f2 is the ratio of total initial energy of all nodes to the total current energy of the cluster heads [26].

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

And

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

Here,
f 1 represents the maximum Euclidean distance
C_k represents the number of nodes of cluster C corresponding to the particle solution p.
f 2 is the ratio of the total initial energy to the present energy of the WSN
CH represents a cluster head

The residual energy based CH can be expressed mathematically as:

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

Here,
$E_{residual}$ signifies the residual energy
$E_{initial}$ signifies the intial energy
E_t 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 $\bar{E}(r)$ of rth round is as follow:

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

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
T_{ON} represents the time for which the node is transmitting
T_{OFF} 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:

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

Here,
i represents the initial time
f represents the final time
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:

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

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:

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

Here,
L is the average latency
n is the number of nodes
T_i^S represents the time at which data is sensed by node i
T_i^r 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.

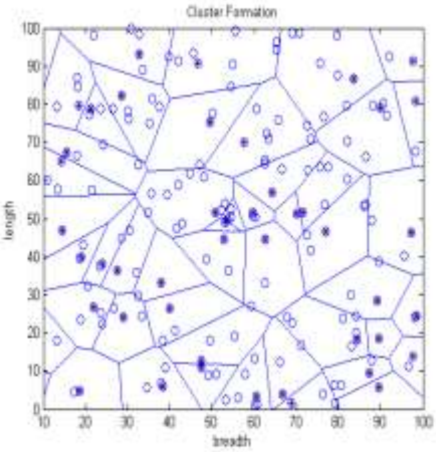

Fig.2 Initial Clustering

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

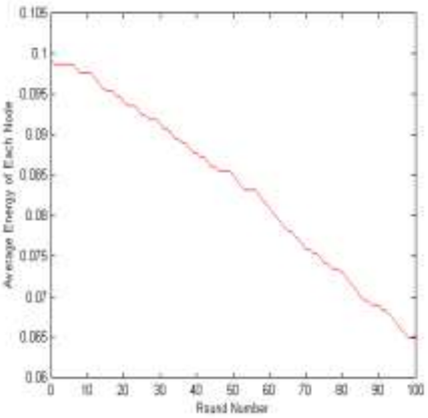

Fig.3 Average Energy of Nodes

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

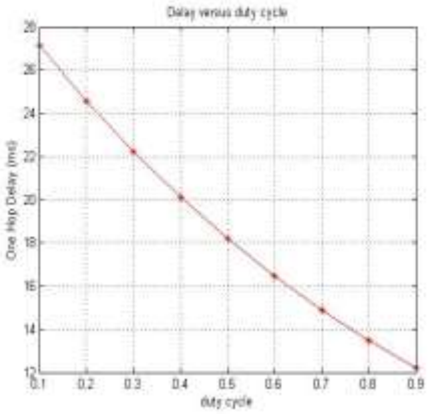

Fig.4 One hop Delay versus duty cycle

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.

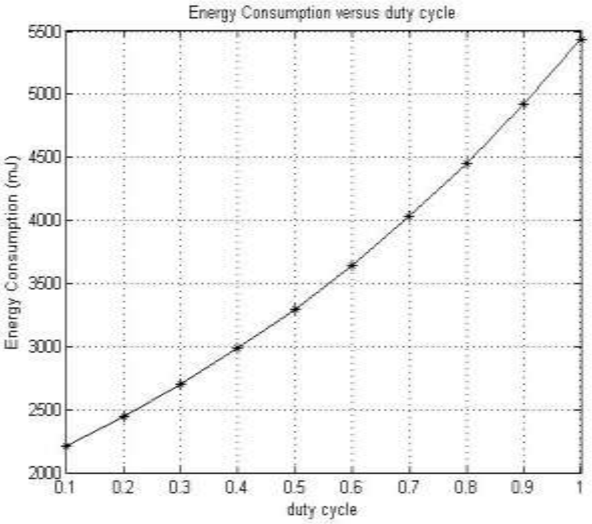

Fig.5 Energy Consumption versus duty cycle for r=80

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.

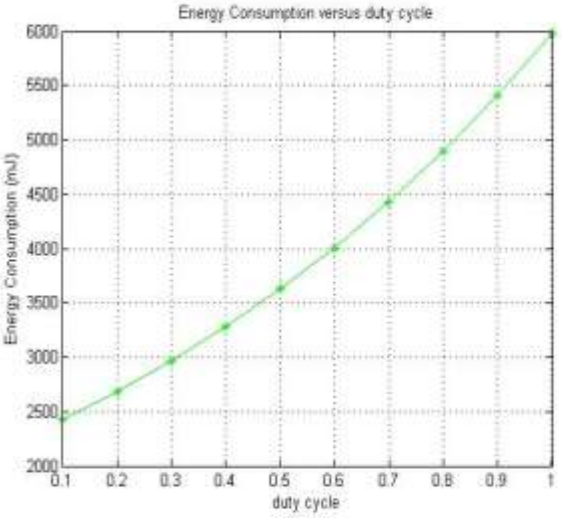

Fig.6 Energy Consumption versus duty cycle for r=100

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.

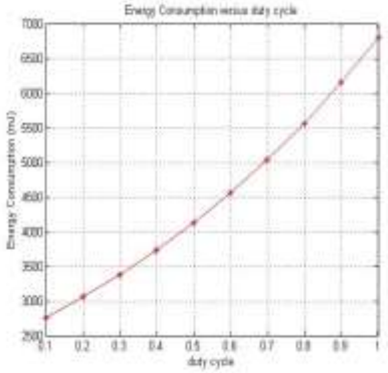

Fig.7 Energy Consumption versus duty cycle for r=120

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.

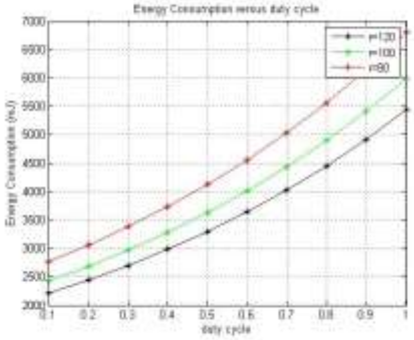

Fig.8 Energy Consumption versus duty cycle for variations in values of r

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.

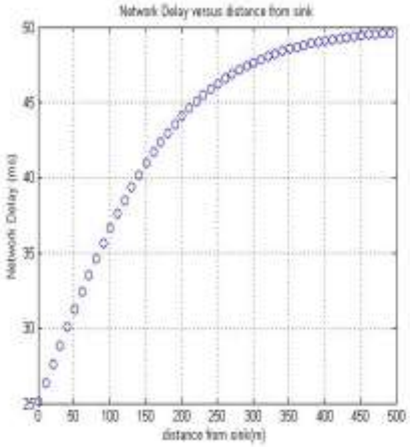

Fig.9 Network Delay versus distance from sink

The figure above depicts the variation in the network delay as a function of the distance from the sink. Clearly the delay increases as the distance from the sink increases for the nodes.

VI. CONCLUSION

With the goal of improving the network lifetime and reducing delay, this research proposes an optimal clustering algorithm for wireless sensor networks. Reducing energy usage has been the primary goal of this strategy, which employs a 2-tier PSO based meta-heuristic method. We have also calculated the delay in terms of the overall network mode and the one hop mode. This work's latency, measured in one-hop and multi-hop delays, guarantees that the system can withstand unexpected, random changes and still provide data to the control center. The comparison of the proposed work with existing research clearly indicates that the approach developed in this research work obtains improved performance metrics compared to previous techniques in the domain of research [1].

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