International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Bat Swarm Algorithm for Wireless Sensor Networks Lifetime Optimization

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Abstract: ***Challenges of wireless sensor networks under-optimization in field of research have been globally concerned. Generally, lifetime extension is still considered to be the most dominant challenge for WSNs. Clustering and routing protocols have been proposed as optimization solutions to extend WSNs lifetime. In this paper, we introduce a newly meta-heuristic population based soft computing algorithm as an optimization technique to extend the WSNs lifetime. The proposed technique applies the population-based meta-heuristic bat swarm optimization algorithm. It optimizes the network as a nonlinear problem to select the optimum cluster head nodes across number of generations. The objective; fitness function, employed to minimize the intra-cluster compactness with minimum distance between nodes in same cluster. The proposed technique is simulated and applied into four different wireless sensor networks deployments and compared with the LEACH hierarchal clustering and routing protocol. Results show that this proposed technique outperforms the classical LEACH. It efficiently optimizes the selection of cluster head nodes that ensure optimum coverage and connectivity based on intra-cluster distances. This reduces the energy consumption on each node level and hence increases the lifetime for each node, causing a significant extension in the wireless sensor network lifetime. The comparison between the hard or crisp LEACH routing and the soft or elastic proposed routing technique boasts the performance even more. The paper introduces a performance numerical analysis with the metrics of number of packets sent to sink, number of dead nodes, sum of WSN energy and the network lifetime.***

Keywords: Wireless Sensor Networks; Energy Optimization; LEACH; Bat Swarm Algorithm.

1. Introduction

Wireless sensor network in context of computing is defined as a complex efficient system consisting of small distributed constrained entities. The extensive complexity of this system comes out of the system limitations and challenges. This is due to the fact that WSNs are multi constrained in terms of energy consumption, communication rage, links costs, low bandwidth, limited processing and storage [1].

This paper focuses on the comprehensive optimization of energy consumption. Clustering and routing protocols based on energy optimization have been addressed as conventional solution to optimize WSNs. However, the classical existing WSNs` routing protocols suffers from a main problem; once there is an optimal route investigated and determined by the chosen routing protocol, network will keep using it for every transmission [2]. This gradually drives to massive loss in the route nodes` energy. Consequently, this causes network partitioning because of the dramatic loss of the nodes power. The static development of these classical protocols does not assure the optimal global optimization for WSNs` lifetime extension. Optimal route selections and power consumption management have been introduced as solution for WSNs` lifetime optimization. Scarcity in sensors` power is the highest challenge in WSN; therefore, power awareness and energy consumption routing algorithms are always introduced. With the ambiguity and uncertainty of the data in complex WSN`s environments nowadays, classical routing protocols are not capable anymore to cope efficiently [3].
As a solution, smart and intelligent compatible different techniques are urging to overcome WSNs` limitations. Soft computing paradigms proved its great efficiency to reach local and global optimization for complex systems. It conquers the complexity of traditional optimization methods such linear, nonlinear and quadratic programming techniques and methods. Soft Computing (SC) paradigms are currently examined in order to tackle the energy challenging factor in WSNs. The inheritance of soft algorithms from biological nature addressed to prove its efficacy as a solution to achieve optimal global optimization in complex problems. Applying these soft techniques over the hard classical techniques help to reach better optimization of power consumption and hence increase the WSNs longevity. Paper [4] provides a good insight to future research directions in routing WSNs based on Soft Computing paradigms. It introduces and explores the great compatibility and efficiency of applying these paradigms in WSNs.

In this paper, simulations of four WSNs` different deployments are examined in MATLAB to introduce a newly meta-heuristic population based soft computing algorithm as an optimization technique to extend the homogenous WSNs lifetime. The proposed technique applies the population-based meta-heuristic bat swarm optimization algorithm. The objective; fitness function, employed to minimize the intra-cluster compactness with minimum distance between nodes in same cluster. Section II introduces the previous related works in WSNs` lifetime optimization based on population-based optimization techniques. Section III discusses in details the bat swarm optimization algorithm. Section IV concerns with the classical LEACH protocol, it explains the WSNs` energy optimization based on clustering. The proposed technique is discussed and explained in details in section V. Simulation environment and results are supported with performance numerical analysis to verify the proposed technique in section VI. Section VII concludes and insight the new directions of WSNs` global optimization based on soft computing paradigms.

2. Related Works

This section introduces a selection of the finest research papers that address the problem of WSNs` lifetime optimization, based on population-based optimization techniques. These naturally inspired or bio-mimic algorithms are the most recent suitable methods for global optimization [5]. The selection of the proper bio-mimic or meta-heuristic algorithms that efficiently propose the best solution of any problem is very critical. Hence there is no one single algorithm ensures reaching the best solution for all problems; there exist a number of these optimization algorithms including ACO (Ant Colony Optimization), GA (Genetic Algorithm), PSO (Particle Swarm Optimization) and newly BSO (Bat Swarm Optimization).

2.1 Ant Colony Optimization

ACO (ant colony optimization) [6] is based on pheromone deposition of ants to solve computational problems. The contribution of applying ACO techniques in WSNs` energy efficient clustering and routing, is that it is converge the lifetime of WSNs` to better performance as well as maximize the data delivery from nodes to base station [5].

Paper [7] introduces three different ant colony optimization (ACO) algorithms for energy efficient routing in WSNs. The proposed technique counts on the density and the rate of communications between nodes. This effects the energy consumption and hence the WSNs` lifetime. ACO routing model applied by the representing the ant`s movement in network to find optimize path.

Paper [8] designed an energy-efficient transmission strategy to save energy consumption based on ant colony algorithm-MIMO (ACAMIMO) a new heuristic ant colony transmission scheme has been proposed based distance and the residual energy of the adjacent nodes to build a heuristic factor. It searches for optimal multi-hop transmission route for inter-cluster transmission. This reduces energy consumption, balance load consumption and extend lifetime of network effectively compared to a single-hop transmission.

Paper [9] extends the WSN`s lifetime by minimizing the communication overheads in the context of ants colony optimization. An Energy Efficient Ant-Based Routing (EEABR) was designed to efficiently select the optimized route based on minimum consumed energy and minimum number of hops. A set of probabilistic rules used to derive this optimization in order to maximize energy savings.
Paper [10] a clustering routing algorithm based on ACO has been proposed. It designed to find the optimal routes between cluster heads in WSN. The idea of energy saving comes from the fact that clusters near to base station will be small in size while others far will occupy bigger sizes. The average energy consumption as well as the survival rate are efficiently optimized comparatively to the LEACH. This greatly extend the WSN lifetime.

2.2 Genetic Algorithm

GA (genetic algorithm) [11] is mimicking the process of natural evolution by heuristic search. Applying genetic algorithms on clustering wireless sensor networks ensure the optimization of optimal clusters numbers and positions based on heuristic approach. The contribution of applying GA techniques in WSNs energy efficient clustering and routing, is the ability of controlling the process of clusters formation and predefined the number of desired clusters. This greatly affects the cost of communication links in WSNs [5].

Paper [12] proposed an optimized LEACH based on genetic optimization. It optimizes the probability prediction by minimizing the nodes` total energy consumption required for completing one round in the sensor field. This achieves good performance in terms of lifetime of network in wireless sensor networks comparatively with the classical LEACH.

Paper [13] increased the WSN`s lifetime by optimally using genetic algorithm to re-cluster the nodes` of the network. Two fitness functions were applied based on the distance and energy for each node in each round. This effectively enhances the selection of cluster heads with maximum energy and minimum distance to BS.

Paper [14] proposed a new model for WSNs` lifetime extension based on genetic algorithm. This model converge the selection of the new generation to better life taking into account the energy balance of the network. Simulation examined and compared for different four energy efficient routing schemes for WSNs. Results proved that the optimal energy constrained route can be guaranteed and can converge faster to better optimization than other classical models.

2.3 Particle Swarm Optimization

PSO (particle swarm optimization) [15] is based on the swarm behavior of fish, and bird schooling in nature has a great optimization in energy aware clustering for WSNs. The contribution of applying PSO techniques in WSNs energy efficient clustering and routing, is that it is optimally select the cluster head nodes based on the maximum residual energy. Moreover, finding the optimal shortest route to the base stations that inspired form the nature of particle swarm will significantly extend the WSN`s lifetime [5]. Equalizing the number of WSN`s nodes and nominating a proper cluster head objective to minimum energy based on PSO was firstly introduced in [16]. Such clustering method was effectively maximize the network lifetime and minimize the data transmission costs.

Paper [17] proposed an energy-aware clustering for wireless sensor networks using particle swarm optimization. It works by applying the Divided Range Particle Swarm Optimization (DRFSO) algorithm to the dense mobile nodes distribution. This restricts the selected number of cluster head nodes to provide efficient medium access control. The proposed objective function takes into account a combined effect of the ideal degree, transmission power, mobility, and battery power of the nodes. Results show a good optimization over the previous applied methods especially for the flexibility of assigning different weights to the nodes.

Paper [18] used the weighted graph and particle swarm optimization to optimally elect cluster heads nodes for multi-hop wireless sensor networks. The minimum spanning tree of the weighted graph of WSN used to calculate the distance between nodes. Selection of the best cluster head counts on the maximum residual energy. The selection of optimal route between nodes and cluster heads derived from all the optimal trees on the basis of energy consumption. The results show that the PSO-based clustering methods ensure WSNs` lifetimes extension.

3. Bat Swarm Algorithm

Bat Swarm Optimization Algorithm (BSO) is of the most recent invented and efficient meta-heuristic population based soft computing algorithms. It solves nonlinear optimization problems with single or multi-objective functions. It exposed as a meta-heuristic swarm intelligence optimization method developed for the optimal numerical optimization. This algorithm naturally inspired from the social behavior of bats [19]. The capability of echolocations of these bats composed a great competent manner to detect prey, avoid obstacles, and to locate their roosting crevices in the dark based on sensing distances. In order to formalize the bat swarm algorithm optimally, the following approximated bats` echolocation characteristics should be idealized:

a. Objects` distances are always perfectly sensed by the echolocation system on bats. This considers the ability to differentiate between different objects even in darkness.
b. Bats are flying randomly with velocity v_i, fixed frequency f_{min} at position x_i, and fluctuating wavelength λ, and loudness from A_0 to A_{min} to search for its prey. wavelength or frequency can be changed spontaneously by adjusting the pulse emission rate $r \in [0, 1]$, based on the closeness of the bat`s objective.
c. Variation of the loudness parameter takes vales between large loudness (A_0) and minimum loudness (A_{min}).

Figure 1 from [19] describes the pseudo code of the bat swarm algorithm. It starts with the initialization of all the echolocation system variables. Initial location of all bat swarm should be initialized as initial solutions. Values of pulse and loudness set randomly as well as the value of the frequency. With number of iteration bats try to find the best optimized solution(s) move from their initial state solutions toward the optimal best solution(s). Bats solutions are automatically updated in the sense of finding better solution. Both pulse emission rate and loudness are updating gradually as closer as bats reach their best solution(s). Solutions keep updated as a result of the continuous flying iterations till the termination criteria are satisfied. Finally, when all criteria successfully met the best so far solution is visualized. While initialization of bat population produced randomly, new solutions can be generated by the motion of bats with the following functions:

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (1)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x^*) f_i \quad (2)$$

$$x_i^t = x_i^{t-1} + v_i^t \quad (3)$$

Where;

β: Random vector drawn from uniform distribution $\beta \in [0, 1]$.

x^*: Current global best location (solution) which is located after comparing all the solutions among all the bats.

f_i : Frequency which is drawn uniformly from $[f_{min}, f_{max}]$

A random walk with direct exploitation is used for the local search that modifies the current best solution according the equation:

$$x_{new} = x_{old} + \varepsilon A^t \quad (4)$$

Where;

ε : is a random number $\in [-1, 1]$.

A^t: is the average loudness of all the best at this time step.

r_i: is the rate of pulse emission.

For each bat, as soon as the pray found, the bat loudness decrease and the pulse emission rate increase. Both loudness and pulse emission expressed mathematically as follows:

$$A_i^{t+1} = \alpha A_i^t \quad (5)$$

$$r_i^{t+1} = r_i^0 \, [1 - exp(-\gamma t)] \quad (6)$$

$$A_i^t \rightarrow 0 \text{ and } r_i^t \rightarrow r_i^0 \quad \text{as } t \rightarrow \infty \quad (7)$$

Where;

α : is constant $0 < \alpha < 1$

γ : is constant $\gamma > 0$

```
Begin
  Step 1: Initialization
        Set the generation counter t = 1;
        Initialize the population of NP bats P randomly and each
        bat corresponding to a potential solution to the given
        problem;
        Define:
        Loudness Ai;
        Pulse frequency Qi;
        Initial velocities Vi(i = 1, 2, . . . , NP);
        Pulse rate ri.
Step 2: Loop
      While (the termination criteria are not satisfied or
      t < MaxGeneration)
      Do Generate new solutions by adjusting frequency, and
      updating velocities and locations/solutions [(4)–(6)]
If (rand > ri) then
        Select a solution among the best solutions;
        Generate a local solution around the selected best solution
End If
        Generate a new solution by flying randomly
If (rand< Ai & f(xi) < f(x*)) then
        Accept the new solutions
        Increase ri and reduce Ai
End If
        Rank the bats and find the current best x*_t = t + 1;
Step 3: End While
Step 4: Post-processing the results and visualization.
End.
```

Figure 1: Bat Swarm Algorithm Pseudo code [19].

4. Low-energy adaptive clustering hierarchy

LEACH is a hierarchal clustering and routing algorithm that mainly proposed to extend WSNs` lifetime based on low energy adaptive clustering method. The LEACH relies on cluster formation and selection of a head for each cluster. WSN is divided into a number of clusters randomly and based on the available energy in each node; nodes elect themselves to be chosen as a cluster head (CH). LEACH selects number of cluster heads based on the highest energy of nodes. After clusters heads selection, the remaining nodes in the network can be assigned to join clusters based on their distances from the CH. Nodes in each cluster send data packets directly to the cluster head and hence each cluster head communicate with the base station (BS)/sink node. LEACH algorithm operates a number of rounds and each round is divided to two phases. Setup phase, for CH selection, clusters formation, CSMA advertisement messages for the nominated CH and generating transmission schedule. Steady phase, for data packets aggregation, compression process and data packets transmission from CH to sink node. In each round a prior setting of the CH percentages P is used in the current round to select cluster head that neither its total energy is less than zero (dead node) nor it was a cluster head in the previous *1/P* rounds. If the number of CHs $<T(n)$, a sensor n becomes a CH for the current round, where $T(n)$ is a threshold given by:

$$T(n) = \begin{cases} \frac{P}{1-P*(r \bmod \frac{1}{P})} & n \in G \\ 0 & otherwise \end{cases} \quad (8)$$

Where;
P: is the desired percentage of cluster heads.
r: is the current round.
G: is the set of nodes that have been cluster- heads (CHs) in the last 1/P rounds.

5. Proposed Technique

In this section, we briefly describe and explain the proposed technique.

5.1 Network Model

Homogenous WSNs are modeled where all the deployed nodes have the same initial energy level (*uniform initial energy*). Number of nodes *"N"*, are randomly distributed across the *(M*N)* region and all are energy constrained. All nodes are constrained that no longer movement for any node after deployment (*static deployment*). Nodes are always having data to send to the end user and nodes located close to each other, have correlated data. Numbers of neighbored nodes are grouped into cluster. Cluster formation is based on the bat swarm optimization. In here, bat swarm searches for optimal distribution of nodes on clusters. The objective; fitness function, employed by bat swarm is to minimize the intra-cluster compactness with minimum distance between nodes in same cluster.

$$J = \sum_{j=1}^{x} \sum_{i=1}^{k} \left\| x_i^j - c_j \right\|^2 \quad (9)$$

Where;
x_i^j: is the senor node *i* that belongs to the sensor *j*.
c_j: is the cluster head node for the cluster *j*.
$x_i^j - c_j$: is the distance between station position and cluster center.

So the goal of bat swarm optimization is to find the number of cluster centers *(N)* that minimize the above equation. Each cluster head is directly connected to the sink node (*base station*) which is a high-energy node, located far away from the sensor nodes in the point (X_{sink}, Y_{sink}). Sensor nodes transmit their data packets directly to cluster head. Each CH receives data from all of its cluster nodes and performs some necessary iteration for compression. It is directly connected to the sink node (*base station*) to forward the aggregated data packets. All network nodes are stationary and hence we don't have dynamic network topology. Nodes die only when they are out of energy.

5.2 Energy Model

This section explains the adopted first order radio frequency energy consumption model in our simulation [20]. This model can be divided into two sections based on the distance between sender and receiver. First section is the free-space model while the other is the multi-path fading model. It assumes that communication channel is symmetrical, energy consumed for k bits message between two nodes with a distance of *d* [21].

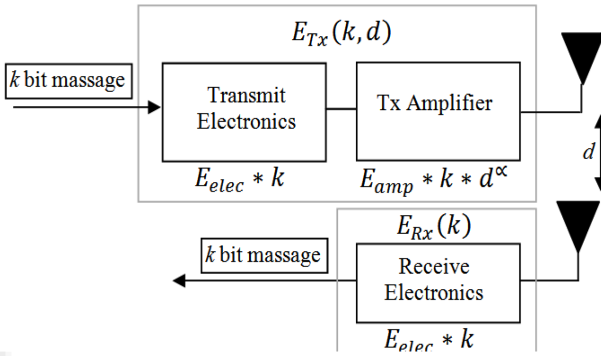

Figure 2: First order radio frequency energy consumption model $\propto = (2, 4)$ [20].

Radio model dissipates E_{elec} energy to run either transmitter or receiver circuitry. The amount of energy E_{amp} is used for the transmit amplifier. For any message consist of k number of bits, each node dissipates a radio transmission energy $E_{Tx}(k,d)$ based on distance d, the running energy for transmitter circuitry $E_{Tx_{elec}}(k)$ and the transmitter amplifier energy $E_{Tx_{amp}}(k,d)$. This can be mathematically expressed as follows:

$$E_{Tx}(k,d) = E_{Tx_{elec}}(k) + E_{Tx_{amp}}(k,d) \quad (10)$$

$$E_{Tx}(k,d) = \begin{cases} E_{elec} * k + E_{amp\_fs} * k * d^2 & d < d_0 \\ E_{elec} * k + E_{amp\_mp} * k * d^4 & d > d_0 \end{cases} \quad (11)$$

$$d_0 = \sqrt{\frac{E_{amp\_fs}}{E_{amp\_mp}}} \quad (12)$$

Where;
$E_{Tx}(k,d)$: is the transmission energy consumption k bits data to a node.
E_{amp_fs}: is the amplifier parameter of transmission corresponding to the free-space.
E_{amp_mp}: is the amplifier parameter of transmission corresponding to the two-ray models.
E_{elec}: is the energy dissipations per bit used to run the transmitter or receiver circuitry.

d: is the distance between sender and receiver nodes.
d_0: is the transmission distance threshold.

On other hand, the reception dissipation energy for message of k bits for any node is expressed by $E_{Rx}(k)$. It can be calculated by the equation below due to running the receiver circuitry $E_{Rx\_elec}(k)$:

$$E_{Rx}(k) = E_{Rx\_elec}(k) = E_{elec} * k \qquad (13)$$

Where;

$E_{Rx}(k)$: is the energy consumption in receiving k bits of data.

The amount of total energy consumption of wireless sensor network can be calculated as follows:

$$E_{total} = E_{node\ to\ CH} + E_{receive\ CH} + E_{CH\ to\ BS} + E_{CH\ fussion} \qquad (14)$$

Where;

$E_{node\ to\ CH}$: is the total consumed energy of all the ordinary nodes to send data to their cluster head nodes.

$E_{receive\ CH}$: is the total consumed energy of all cluster head nodes to receive the data from ordinary nodes.

$E_{CH\ to\ BS}$: is the total consumed energy of all cluster head nodes to send the data to the base station.

$E_{CH\ fussion}$: is the total consumed energy of data fusion for all cluster head nodes.

6. Simulation and Results

In this section, we extensively discuss the simulation environment. The proposed technique use bat swarm optimization algorithm as an energy optimization algorithm to maximize the WSN lifetime. The experiment and proposed technique applied parameters are listed in tables below. Four different deployments for homogenous WSN are applied. This will efficiently verify the validation of the proposed technique. The first order radio model in [20] is applied for energy computations in the proposed simulation. Bat swarm and LEACH parameters are set optimally based on previous best practices. Performance evaluation and numerical analysis of the proposed WSN optimization technique are examined comparatively to the LEACH classic hierarchal clustering and routing protocol.

6.1 Simulation Setup

Simulation of the proposed technique examined with four different WSN deployments (A, B, C and D) using MATLAB runtime environment. Table I sets the parameters of these different deployments. Network ID, Network area, number of nodes and base station location are mentioned. Table II lists the used parameter of the first order energy radio model. It is standard parameters commonly used in WSNs` environments based on the common technical and mechanical devices such as sensors and amplifiers [20]. Table III sets the parameters of bat swarm algorithm. These parameters are set based on the best achieved performance. Table IV sets a maximum allowable number of rounds in LEACH algorithm as well as the percentage of nominated cluster heads.

Table 1: Network Model Parameters

ID	*Area*	*Number of Nodes*	*Base Station Location*
A	70 × 70 m^2	25	(35, 145)
B	100 × 100 m^2	100	(50, 175)
C	250 × 250 m^2	150	(125, 325)
D	300 × 300 m^2	175	(150, 375)

Table 2: Radio Model Parameters [20]

Parameter	*Value*
Initial Energy *(E0)*	0.5 J/node
Minimum Energy	0.0001 J
Packet length from CH to BS	6400 bits
Packet length from sensor node to CH	200 bits
Transmitter Electronics *(Eelec)*	50 nJ/bit
Receiver Electronics *(Eelec)*	50 nJ/bit
Data Aggregation Energy	50 nJ/bit
TransmitterAmplifier $(\sum fs)$ if $d \le d0$	10 pJ/bit/m^2
Transmitter Amplifier $(\sum mp)$ if $d \ge d0$	0.0013 pJ/bit/m^4
Network Threshold	0.1 of nodes be alive

Table 3: Bat swarm Algorithm Parameters

Parameter	*Value*
Population Size	Number of nodes in
Number of Generations	100
Loudness	0.5
Pulse rate	0.4
Minimum Frequency	0
Maximum Frequency	1

Table 4: LEACH Algorithm Parameters

Parameter	*Value*
Maximum number of rounds	9999
P	0.1

6.2 Performance Analysis

The idea of the proposed technique lies on the nodes` available energy and the physical intra-cluster distances between these nodes and their associated cluster head. The objective was to minimizing the distance function of the intra-cluster distance and hence optimizing the wireless sensor network consumed energy. Nodes with high energy have been selected as a cluster heads. Cluster formation placed using bat swarm optimization algorithm based on intra-cluster distance fitness function. The practice of the four different WSNs deployments that vary in the number of sensor nodes shows a great optimization on WSN scalability. The performance of the proposed technique is numerically analyzed in the tables and figure below comparatively with the classical cluster- based LEACH protocol. Simulation results and the performance numerical analysis with the metrics (number of packets sent to sink, number of dead nodes, sum of WSN energy and the network lifetime) demonstrate the better performance and optimization of the proposed technique.

Table V shows comparative numerical analysis of lifetime of WSNs nodes for the four deployed WSNs. The table indicates the respective round number for the death of the first node, death of 50% of nodes and the death of last node in the network. The larger the first node dies the better optimization the proposed technique achieved. This proves the efficiency of selecting the optimal cluster head based on the nodes` residual energy as well as the efficiency in cluster formation based on the intra-cluster distance between nodes that preserve the consumed energy. For the first WSN deployment (A) and according to the results, the first node death in LEACH algorithm occurred in round 335, while the first node death in the proposed Bat swarm optimization technique occurred in round 810. For 50% of nodes availability, LEACH algorithms caused the death of them at round 710 while the proposed Bat swarm optimization technique preserve nodes longer to round 1670. The noticeable increase between round using LEACH comparatively to the proposed Bat swarm optimization technique shows a significant improvement in WSN lifetime extension. The total life time for all WSN nodes, based on LEACH reach 1270 rounds only to reach the total death while the proposed bat swarm optimization technique reaches 1688 rounds. That is, the network lifetime practically increased by 32.91 %.

For the second WSN deployment (B) the first node dies using LEACH in round 153, while other 50% of the nodes died in round 420, and the whole network die in round 1194. In contrast, the trend of node death of the proposed bat swarm optimization technique proves better performance. First node dies in round 660, while the other 50% of the nodes dies in round 1255 and the whole WSN dies in round 1701. This implies a better optimization for WSN lifetime. The overall WSN life time has extended by 42.46 %. Moreover, for the other two deployments (C and D), first node dies in LEACH at rounds 19 and 6 respectively to the table below. However, it dies at round 339 and 184 using bat swarm optimization technique. The lifetime maximization of the WSN is 28.99 % for deployment (C) and 16.54 % for deployment (D). Obviously, the proposed Bat swarm optimization technique is greatly superior to LEACH concerning improving the lifetime of wireless sensor network.

Table 5: LEACH Algorithm Parameters

Lifetime of WSN Nodes	*Round Numbers of LEACH Algorithm*	*Round Number of Bat Swarm Algorithm*
A: Area: 70 × 70, Nodes: 25, BSL: (35, 145)		
Round first node dies	335	810
Round 50% node dies	710	1670
Round last node dies	1270	1688
B: Area: 100 × 100, Nodes: 100, BSL: (50, 175)		
Round first node dies	153	660
Round 50% node dies	420	1255
Round last node dies	1194	1701
C: Area: 250 × 250, Nodes: 150, BSL: (125, 325)		
Round first node dies	19	339
Round 50% node dies	116	516
Round last node dies	1469	1895
D: Area: 300 × 300, Nodes: 175, BSL: (150, 375)		
Round first node dies	6	184
Round 50% node dies	59	312
Round last node dies	1862	2170

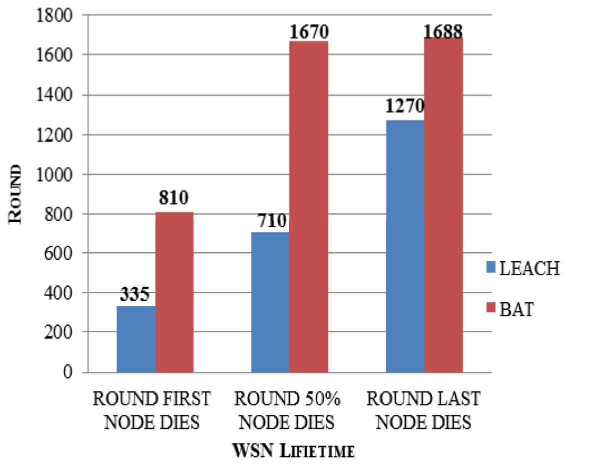

Figure 2: The comparison of lifetime of WSN nodes – Network (A): Area: 70 × 70, Nodes: 25, BSL: (35, 145)

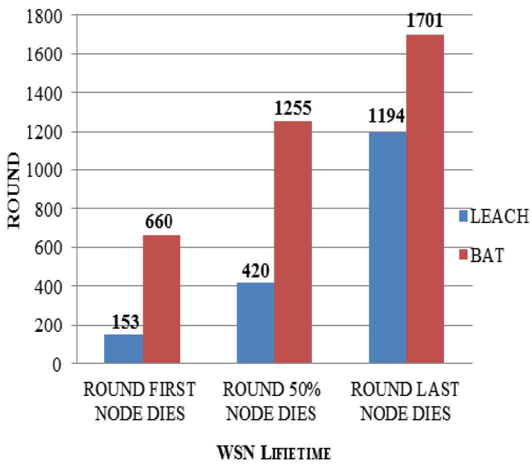

Figure 3: The comparison of lifetime of WSN nodes - Network (B): Area: 100 × 100, Nodes: 100, BSL: (50, 175)

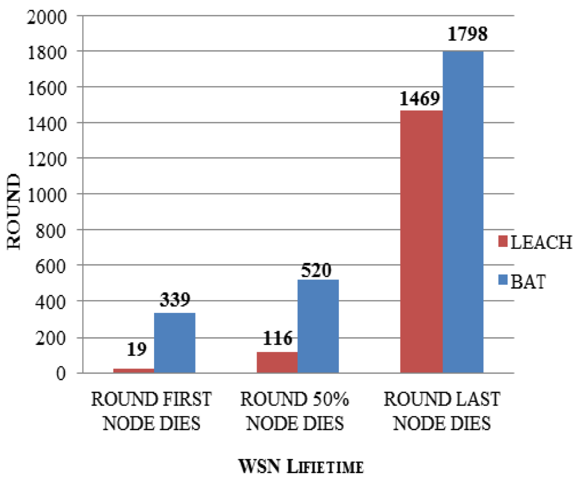

Figure 4: The comparison of lifetime of WSN nodes - Network (C): Area: 250 × 250, Nodes: 150, BSL: (125, 325)

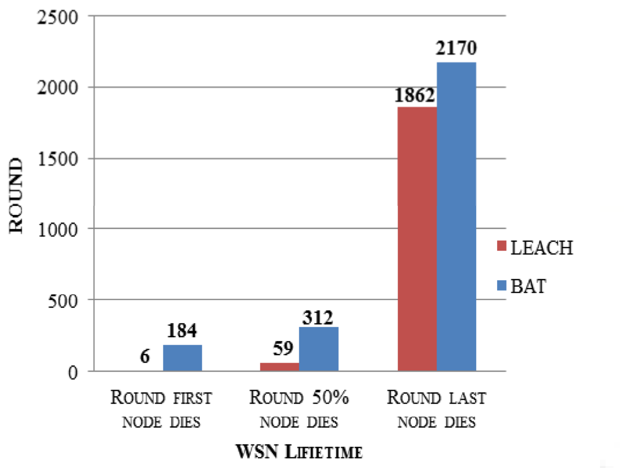

Figure 5: The comparison of lifetime of WSN nodes - Network (D): Area: 300 × 300, Nodes: 175, BSL: (150, 375)

To generalize our results, a fixed number of rounds will be selected to check the total cumulative number of dead nodes based on this round. This considerably effect the percentage of live node and hence the network lifetime. Round 500 have been selected on our experiment. Table VI shows the number of dead nodes at round 500 and percentage of live nodes using LEACH for the simulated four different WSNs deployments. Table VII respectively will elaborate the same numerical analysis for number of dead nodes at round 500 and percentage of live nodes based on the proposed bat swarm optimization technique.

Table 6: The number of dead nodes at round 500 using LEACH Algorithm

ID	*Area & Nodes*	*Base Station Location*	*Number of Dead Nodes at Round 500*	*Percentage of Live Nodes at round 500*
A	70 × 70 25 Nodes	(35, 145)	8 nodes	68 %
B	100 × 100 100 Nodes	(50, 175)	59 nodes	41 %
C	250 × 250 150 Nodes	(125, 325)	126 nodes	16 %
D	300 × 300 175 Nodes	(150, 375)	158 nodes	9.71 %

Table 7: The number of dead nodes at round 500 using LEACH Algorithm

ID	*Area & Nodes*	*Base Station Location*	*Number of Dead Nodes at Round 500*	*Percentage of Live Nodes at Round 500*
A	70 × 70 25 Nodes	(35, 145)	0 nodes	100%
B	100 × 100 100 Nodes	(50, 175)	0 nodes	100%
C	250 × 250 150 Nodes	(125, 325)	58 nodes	61.33%
D	300 × 300 175 Nodes	(150, 375)	81 nodes	53.71 %

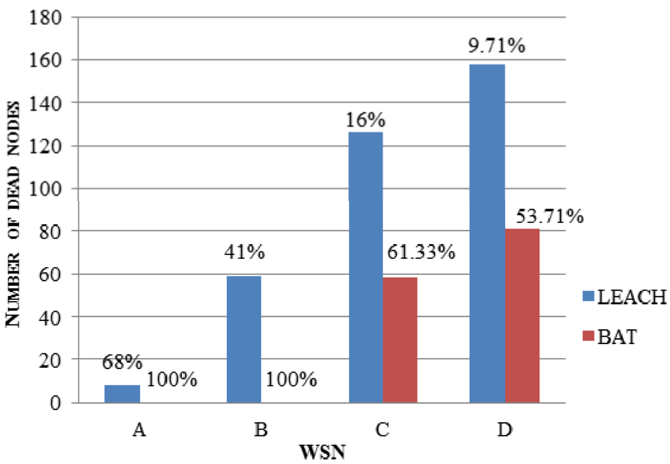

Figure 6: The number of dead nodes at round 500 using both LEACH and BAT Swarm Algorithm

For performance evaluation, the following performance metrics are examined:

- Number of packets sent to BS that measure the performance of data gathering in WSN and ensures the success of data packets transmission across the network.
- Number of dead nodes that mainly measure the lifetime of WSN as well as the optimization of consumed energy, this includes:
  1. The death of first node: this measure the time period since the WSN deployment of nodes to the death of the first node. This time interval measures the start of the WSN coverage reliability degradation.
  2. The death of 50% of the nodes: this measure the time period since the WSN deployment of nodes to the 50% node deaths. The metric indicates the consumed amount of the initial energy.
  3. The death of all the nodes: this measure the time period since the WSN deployment of nodes to the death of the last node. It measure the WSN lifetime.
- Sum of energy of nodes vs. round: this measures the amount consumed energy across the WSN lifetime.

Figures below show the examined performance metrics for the four different deployments.

1) Number of packets sent to BS vs. Round

This metric is practically measure the throughput of the network. It traces the number of received packets to the sink/Base Station node. Increasing number of these packets over the rounds shows the efficiency of the proposed technique. Optimization of throughput is mainly the WSN data aggregation efficiency.

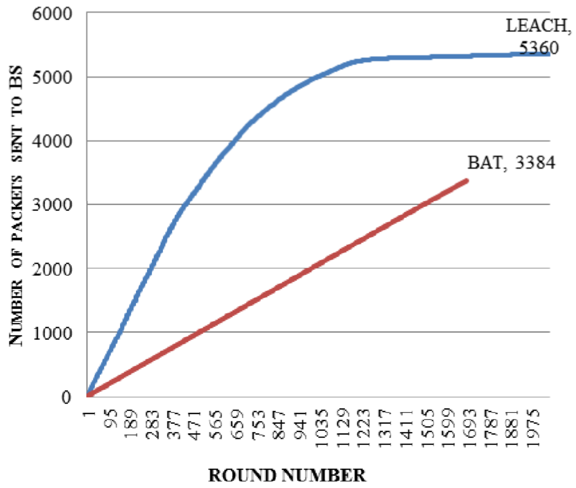

Figure 7: Number of packets sent to BS vs. round using LEACH vs. Bat Swarm Algorithm for WSN deployment (A): Area: 70 × 70, Nodes: 25, BSL: (35, 145)

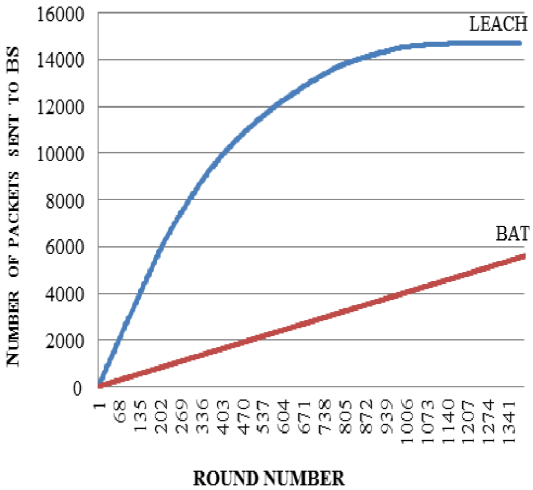

Figure 8: Number of packets sent to BS vs. round using LEACH vs. Bat Swarm Algorithm for WSN deployment (B): Area: 100 × 100, Nodes: 100, BSL: (50, 175)

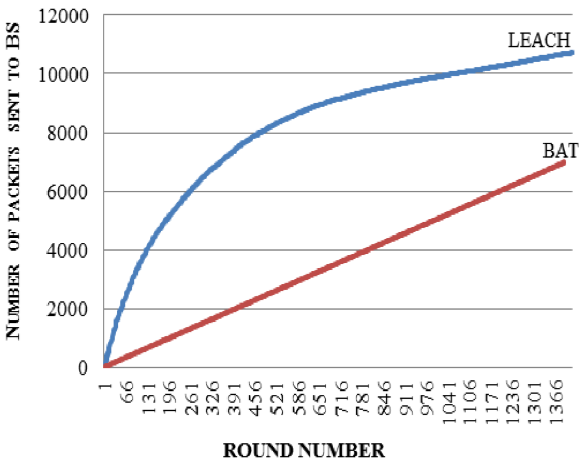

Figure 9: Number of packets sent to BS vs. round using LEACH vs. Bat Swarm Algorithm for WSN deployment (C): Area: 250 × 250, Nodes: 150, BSL: (125, 325)

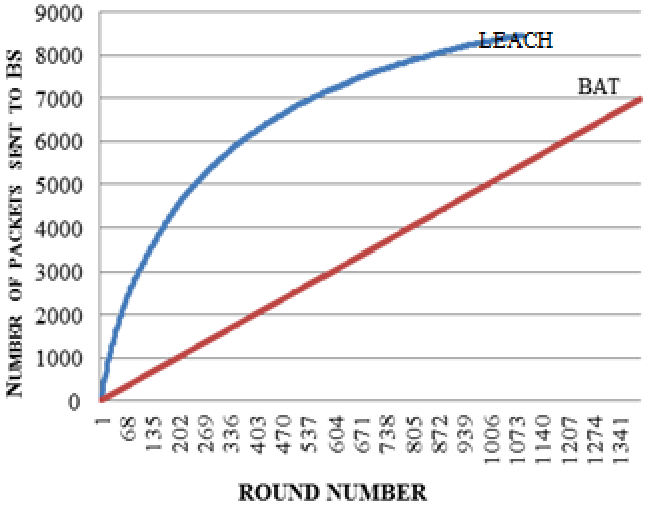

Figure 10: Number of packets sent to BS vs. round using LEACH vs. Bat Swarm Algorithm for WSN deployment (D): Area: 300 × 300, Nodes: 175, BSL: (150, 375)

2) Number of dead nodes vs. round

Simulated results represent network life time by showing number of dead nodes respected to number of rounds. Results show that nodes die out in LEACH quickly and in early rounds most of nodes die while the first node of the proposed technique dies in latter rounds. The proposed technique shows very promising results as the after a number rounds the network reach a stability period with a fixed defined number of live nodes. Death of first node this measures the start of the WSN coverage reliability degradation. The death of 50% of the nodes indicates the consumed amount of the initial energy. The death of all the nodes measures the WSN lifetime. Figures below show comparative graphs of number of dead nodes vs. number of rounds in the three different stages across the WNS lifetime for both LEACH and Bat swarm algorithms. For the different deployments (A, B, C and D) the proposed technique proves its efficiency and scalability. This can greatly applied on different application environments with wide range of different deployments with good stability and scalability.

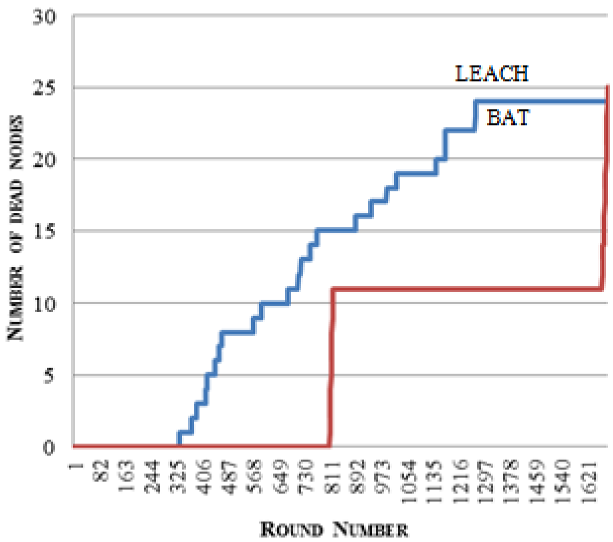

Figure 11: Number of dead nodes vs. round LEACH vs. Bat Swarm Algorithm for WSN deployment (A): Area: 70 × 70, Nodes: 25, BSL: (35, 145)

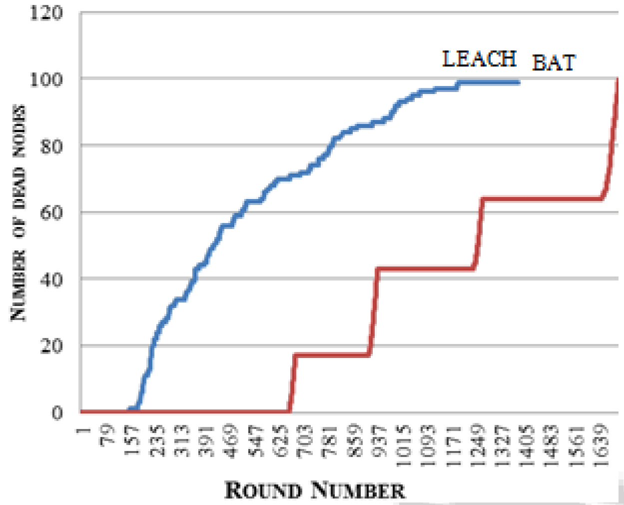

Figure 12: Number of dead nodes vs. round LEACH vs. Bat Swarm Algorithm for WSN deployment (B): Area: 100 × 100, Nodes: 100, BSL: (50, 175)

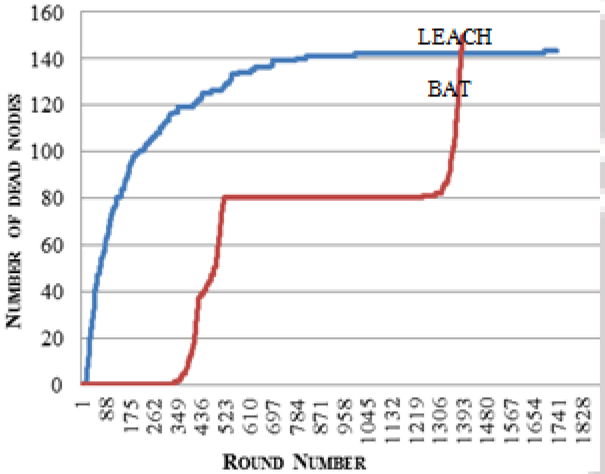

Figure 13: Number of dead nodes vs. round LEACH vs. Bat Swarm Algorithm for WSN deployment (C): Area: 250 × 250, Nodes: 150, BSL: (125, 325)

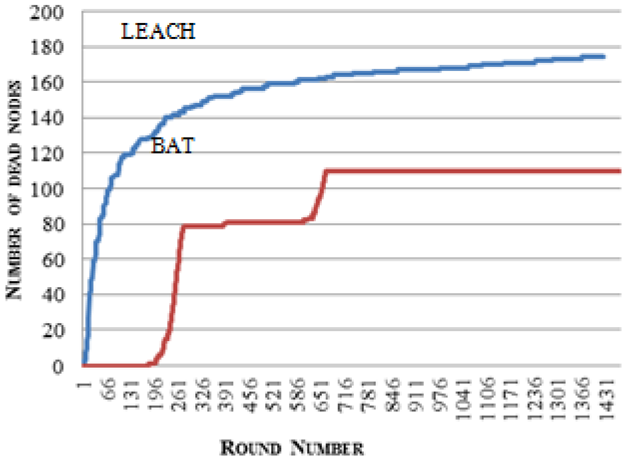

Figure 14: Number of dead nodes vs. round LEACH vs. Bat Swarm Algorithm for WSN deployment (D): Area: 300 × 300, Nodes: 175, BSL: (150, 375)

3) Sum of Energy of nodes vs. Round:

The comparative analysis of the Bat Swarm proposed technique as well as LEACH algorithm shows that LEACH has lower sum of total energy across all the rounds. WSN total energy has drastically drained based on LEACH. This implies that the proposed technique increased the total amount of energy of the WSN and hence provides more power to extend the network lifetime. Moreover, in applying LEACH algorithm, WSN never reach a stability intervals with a fixed number of nodes that preserve an energy level across the network, while based on proposed technique, the network could preserve stable state with a little fluctuation. The proposed technique reached global maximization of WSN lifetime based on applying optimal selection of CH nodes which effectively preserve the global energy.

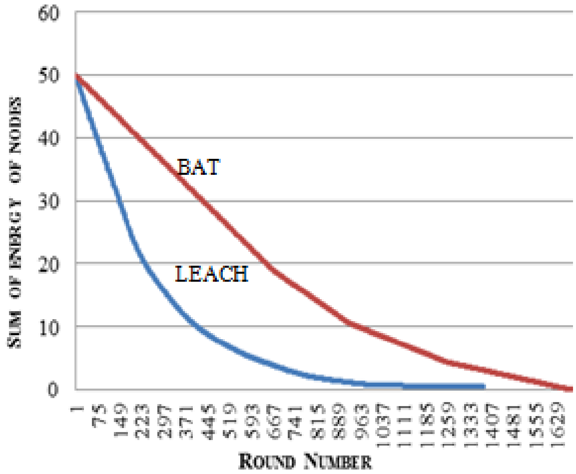

Figure 15: Sum of energy of nodes vs. round using LEACH vs. Bat Swarm Algorithm for WSN deployment (A): Area: 70 × 70, Nodes: 25, BSL: (35, 145)

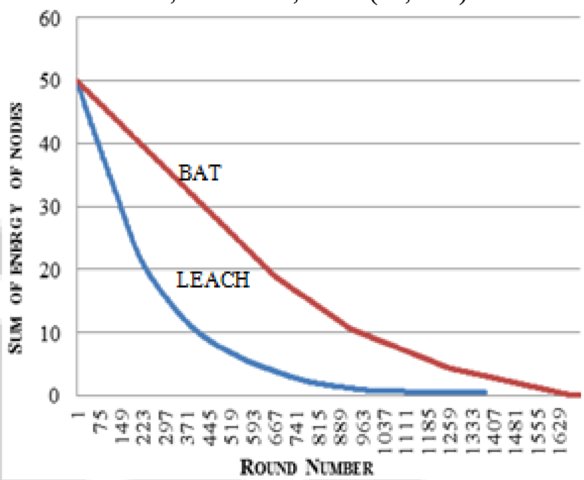

Figure 16: Sum of energy of nodes vs. round using LEACH vs. Bat Swarm Algorithm for WSN deployment (B): Area: 100 × 100, Nodes: 100, BSL: (50, 175)

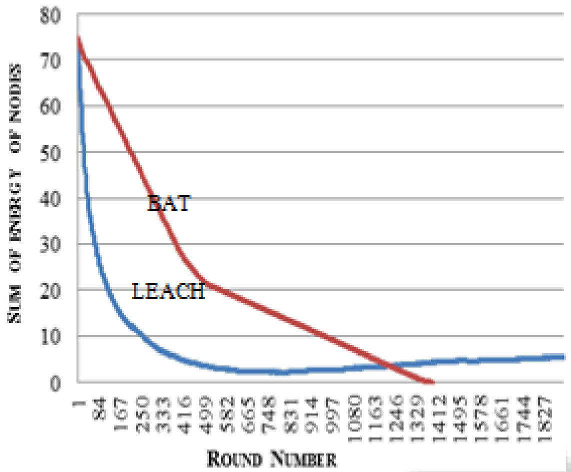

Figure 17: Sum of energy of nodes vs. round using LEACH vs. Bat Swarm Algorithm for WSN deployment (C): Area: 250 × 250, Nodes: 150, BSL: (125, 325)

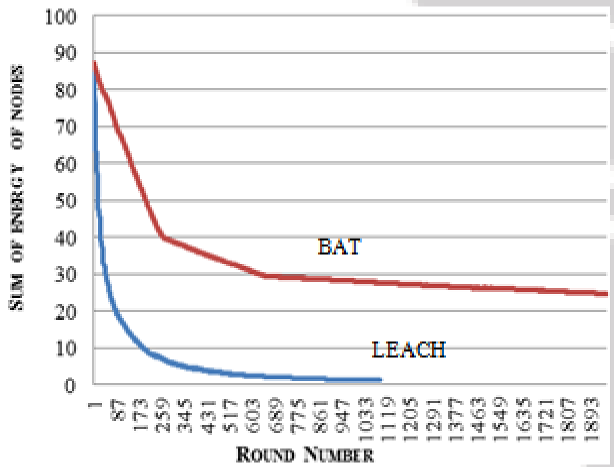

Figure 18: Sum of energy of nodes vs. round using LEACH vs. Bat Swarm Algorithm for WSN deployment (D): Area: 300 × 300, Nodes: 175, BSL: (150, 375)

7. Conclusion

This paper presents and discusses the problem of lifetime extension of WSNs. It introduces and explores all the proposed classical solutions. Simulation experiments are performed using MATLAB environment. Numerical analysis and performance metrics conclude that the bat swarm meta-heuristic proposed technique generates a feasible scalable optimal energy-efficient routing approach to optimize the WSN lifetime. It overcomes the classical low-energy adaptive clustering hierarchy algorithm; LEACH. This effectively extend the WSNs lifetime.

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