# A Novel Quantum Beetle Swarm Optimization based Route Selection and Hybrid Data Transmission in Wireless Sensor Networks

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## Abstract

Energy efficiency remains a major issue in the design of wireless sensor networks (WSN). Earlier studies reported that the routing techniques can be employed to reduce energy consumption and lengthen the lifetime of WSN. Numerous routing techniques with dissimilarfeaturesareproposed in the literature to design an energy-efficient WSN. This paper presents a novel quantum beetle swarm optimization based route selection and hybrid data transmission (QBSOR-HDT) protocol for WSN. The BSO algorithm is presented to enhance the effectiveness of the swarm optimization by the foraging principle of beetles. The presented model chooses the possible routes to destination based on the fitness function involving residual energy, distance to base station (BS), and node degree. Besides, the presented model follows hybrid data transmission process where the data is transmitted at periodic time duration and reactive way. Moreover, a thresholding mechanism is applied for reactive data transmission. This process helps to balance the load properly and thereby achieves energy efficiency. In order to validate the performance of the QBSOR-HDT protocol, extensive set of experimentations were carried out. The experimental values ensured the energy efficiency and network lifetime performance of the QBSOR-HDT protocol under different numbers of nodes.

**Keywords:** Wireless sensor networks, Routing, Beetle swarm optimization, Thresholding concept, Quantum Computing

## 1. Introduction

In last decades, rapid progression in wireless sensor networks (WSN) has stimulated the development of cost-effective and low energized tools. Generally, sensors are composed of signal processing materials, and sensing device with numerous potentials to compute WSN nodes and initialize wireless networks. Also, sensor networks are applicable in numerous applications namely chemical plant, disaster region, as well as nuclear reactor. WSN is

assumed to be a network with diverse nodes for collecting data from adjacent node and send the senses data to sink node or Base Station (BS) in sovereign fashion [1]. Therefore, WSN is capable of monitoring the physical environments and transform the sensed data into user-readable form. Ultimately, WSN is applied in numerous functions like home, armed force, weather prediction, and medical sector [2]. In addition, future application for huge-scale WSN is assumed in diverse fields like environment prediction, civilian forces, and surveillance. Furthermore, sensors are low-cost, donate minimum battery power, and restricted with energy constraints.

One of the significant problems in WSN is to enhance the network lifespan if the initial node is unfit to send the data to BS. For data collection, every node is accountable for sending the data packets to BS node. The procedure of combining data intends to reduce the data traffic and power consumption by unifying various input data packets as single packets. Hence, massive applications are developed to expand the network lifespan [3]. The power efficiency is also a major issue in WSN because the sensor nodes are simulated with the help of battery. Therefore, power consumption is balanced to extend the network lifespan. The routing modules [4, 5] are essential in WSN due to their simplicity and their reduced power consumption, delay, Quality of Service (QoS), as well as data throughput.

Cengiz and Dag [6] proposed a protocol called energy-efficient multi-hop routing protocol to route the data in WSN. In this approach, green routing protocol has been developed for limiting the additional burden. It is applicable to extend the network lifespan and mitigates the load simultaneously with the help of energy effective protocol. Additionally, relay nodes are employed to transmit accumulated cluster data under the application of inter-cluster transmissions.Purkait and Tripathi [7] introduced a protocol termed energy-efficient cluster based routing protocol based on Fuzzy Logic (FL) with the help of multi-hop routing scheme where the cluster size is dynamic. The outline of cluster size and FL method is applied for protocol implementation. Hence, the working function is estimated according to the protocol developed with active nodes count and neighboring protocols. As a result, the network lifetime is increased and limited the premature death of nodes. The processing time is greater in this approach.

Selvi et al. [8] established a delay constrained energy-effective routing method for multi-hop routing in WSN. This model has achieved delay minimization and offered trusted routing to reduce power consumption by organizing effective clusters with no increase in delay. Finally,

enhanced performance is achieved by means of network lifespan and overload caused by this method is handled significantly. But it does not consider mobility parameters to enhance the QoS service relied upon congestion control, flow control, and routing.Sajwan et al. [9] presented Hybrid energy-efficient multi-path routing mechanism which has reduced the power utilized by nodes, however, the distance is a major factor which affects the working function.

Sert et al. [10] projected a framework called Two-Tier Distributed FL Based Protocol (TTDFP) to extend the survival rate of WSNs by estimating the routing proficiency. This model is named as distribution adaptive protocol that implements in sensor network domains. Followed by, the technique utilized in fuzzy clustering to optimize the WSN performance. Unfortunately, it is not suitable for alternate optimization models like Particle Swarm Optimization (PSO) [11] and requires excess WSN embedded parameters.

Chen and Shen [12] implied a scheme called grid-based dependableon multi-hop routing protocol to perform routing in WSN. It is capable of managing the power consumption and optimized cluster head (CH) election dependent on Residual Energy (RE) and node position. Also, the stability duration is improved and depicted a better performance based on power, delays, and assured scalable transmission. Eventually, nodes with maximum energy are completely suitable for working as relays. Moreover, the power consumption of transmitter and receiver is combined for modeling the link weight between the nodes. Finally, Dijkstra algorithm is applied to search the path in cost-effective process. In addition, 2Multi-Hop(MH) protocols were originated according to the Balanced and Energy Efficient Multi-Hop (BEEMH) approach.

Fawzyet al. [13] developed a method BEEMH for computing multi-hop routing in WSN. It is deployed from Dijkstra algorithm. A node with maximum power is applied to transmitter and receiver node to offer inter-CH communications between clustering routing protocols. Furthermore, it is an effective platform to optimize the CH election by using numerous attributes like power and position. But it is unfit for grid optimization and defected the scalable communication between nodes which has resulted in inferior performance. The network duration is enhanced, however, it becomes a complex process in routing tradeoff among the attributes. Hence, energy effective clustering has improved the network duration, where the throughput is non-reliable[14].

This paper presents a novel quantum beetle swarm optimization based route selection and hybrid data transmission (QBSOR-HDT) protocol for WSN. The presented model chooses the possible routes to destination based on the fitness function (FF) involving residual energy (RE), distance to base station (BS), and node degree (ND). Also, the presented model follows hybrid data transmission process where the data is transmitted at periodic time duration and reactive way. Besides, a thresholding mechanism is applied for reactive data transmission. This process supports balancing the load properly and thereby achieves energy efficiency. A detailed set of simulations were performed under varying scenarios. The experimental results portrayed that the QBSOR-HDT protocol has maximized the energy efficiency and lifetime of WSN.

## 2. The Proposed QBSOR-HDT Model

The multi hop routing in WSN is utilized for optimizing the network transmission. Usually, multi hop routing is applied for computing effectual data transmission. But power is one of the major constraints in multi hop routing. To overcome these problems, the newly developed QBSOR-HDT applies multi hop routing where the source node forwards the data to CH by using intermediate nodes within a cluster. In this framework, a source node in a cluster forwards the data to adjacent node and reduces the transmission energy. Also, QBSOR-HDT has gained maximum hops according to the newly developed FF to perform routing in WSN. Hence, solution encoding process represents the solution accomplished from QBSOR-HDT approach. Fig. 1 demonstrates the overall working process of the proposed QBSOR-HDT model.
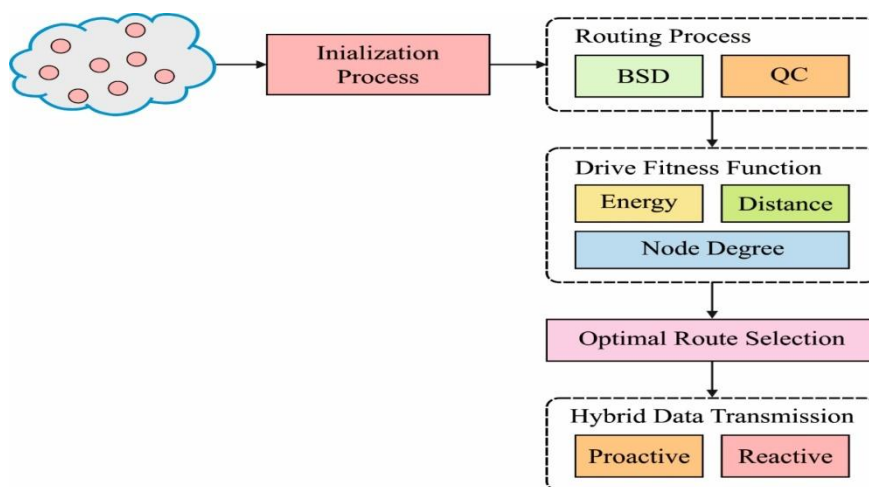


**Fig. 1.** Working process of QBSOR-HDT model

In this approach, the solution is best route selected for data transmission. Also, optimization models apply the presented QBSOR-HDT framework according to the newly developed multi-objective FF to determine optimal hop from collection of hops in WSN. Therefore, FF value is measured to identify best solution by applying collective parameters. Hence, fitness estimated for QBSOR-HDT applies 3 parameters called power, distance, and ND. In this module, fitness is assumed as a maximization metric. Certainly, the solution which poses higher ND, low power, and distance is employed for routing. Thus, solution implying higher fitness value is referred to multihop routing. Finally, fitness of newly developed QBSOR-HDT is expressed as,

$$Fitness\ function = W_1 \times E + W_2 \times D + W_3 \times ND \tag{1}$$

Where $W_1, W_2 and\ W_3$ represents the weights, E, D, and ND shows the power, inter-cluster distance, and ND correspondingly.

**Energy:** The summary of power in all hops is referred to be the system energy which points the RE in nodes. Hence, energy should have maximum value and depict as,

$$P = \frac{1}{b} \sum_{k=1}^{b} E(J_k) \tag{2}$$

Where, b implies the count of hops considered in multihop routing, and $E(J_k)$ depicts the power of k$^{th}$ hop.

**Inter-cluster distance:** The ratio of distance amongst 2 clusters are named as inter-cluster distance which has to be maximum to offer effectual routing and it is expressed by,

$$X^* = \left( \frac{\sum_{x=1}^{n} \sum_{t=x+1}^{n} X(G_x, G_t)}{\beta} \right) \tag{3}$$

Where, $X(G_x, G_t)$ refers the distance amongst 2 clusters, and $n$ illustrates the overall CH count.

**Node degree:** It describes the count of sensor nodes from CH. A CH with minimum sensors are decided as CHs with maximum Cluster Members (CM) drops the power within a short duration. And, ND is represented in Eq. (4).

$$ND = \sum_{i=1}^{m} I_i \tag{4}$$

Where I$_i$ signifies count of sensor nodes from $CH_i$.

## 2.1. QBSOR Algorithm

To achieve the above process, the QBSO algorithm is applied by integrating the concepts of BSO with quantum computing concept. In past decades, it is defined that beetle antenna search (BAS) models are effective in dealing with high-dimension functions with considerable performance and the iterative outcome depends upon the location of a beetle. Besides, position is a major factor in BAS which affects the proficiency of optimization. It is evolved by swarm optimization method where further enhancements are deployed in BAS model by extending the version named BSO framework [15]. Here, a beetle is considered as a potential solution for optimization issues, and every beetle corresponds a fitness value computed by FF. As same as PSO mechanism, beetles share the data, however, the distance as well as direction of beetles are evaluated by the speed and data intensity to be predicted by the prolonged probes.

In numerical format, the principle of PSO has been followed. Consider a population of n beetles depicted as $X = (X_1, X_2, \cdots, X_n)$ in S-dimensional search space, in which $i$ th beetle shown S-dimensional vector $X_i = (x_{i1}, x_{i2}, \cdots, x_{iS})^T$, indicates the location of $i$ th beetle in S-dimensional search space, and defines a capable potential solution to the applied problem. Based on the target function, fitness value of a beetle position is estimated. The robustness of $i$ th beetle is represented as $V_i = (V_{i1}, V_{i2}, \cdots, V_{iS})^T$. This, separable extremity of beetle is denoted by $P_i = (P_{i1}, P_{i2}, \cdots, P_{iS})^T$, and set of extreme value in population is illustrated by $P_g = (P_{g1}, P_{g2}, \cdots, P_{gS})^T$. The numerical method for simulating the behavior is provided in the following:

$$X_{is}^{k+1} = X_{is}^k + \lambda V_{is}^k + (1 - \lambda)\xi_{is}^k \tag{5}$$

Where $s = 1,2,\cdots,S$; $i = 1,2,\cdots,n$; $k$ defines the recent number of iterations. $V_{is}$ illustrates the efficiency of beetles, and $\xi_{is}$ implies the update in beetle position. $\lambda$ defines positive constants. Afterward, speed value is computed by:

$$V_{is}^{k+1} = coV_{is}^k + c_1r_1(P_{is}^k - X_{is}^k) + c_2r_2(P_{gs}^k - X_{gs}^k) \tag{6}$$

Where $c_1$ and $c_2$ defines 2 positive constants, and $r_1$ and $r_2$ demonstrates 2 random functions from [0,1]. $\omega$ indicates the inertia weight. In PSO method, $\omega$ is considered as a fixed constant, however, with gradual enhancement of a model, developers have presented a changing inertia factor.

This work applies the principle of reducing inertia weight, and it is formulated by:

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{K} * k \qquad (7)$$

Where $\omega_{\min}$ and $\omega_{\max}$ implies minimum and maximum value of $\omega$. $k$ and $K$ depict present and maximum number of iterations. Here, higher value of $\omega$ is 0.9, and low value is 0.4, thus the model is applicable to search maximum range and identify best solution. When $\omega$ is reduced, beetle's speed is also minimized and enters into local search. The $\xi$ function defines the incremental function and is evaluated as given below.:

$$\xi_{is}^{k+1} = \delta^k * V_{is}^k * sign\left(f(X_{rs}^k) - f(X_{rs}^k)\right) \qquad (8)$$

This module is extended to high dimension. $\delta$ implies the step size. Therefore, search behaviors of right as well as left antenna are demonstrated as:

$$X_{rs}^{k+1} = X_{rs}^k + V_{is}^k * d/2 \qquad (9)$$

$$X_{ls}^{k+1} = X_{ls}^k + V_{is}^k * d/2$$

The search path is visualized by using minimum population size and implied the change in position of 3D space. Under the existence of factors like step length and inertial weight, coefficient is reducing in iterative process, and algorithm does not cover the target point and eliminates the group falling within a local optimum. Initially, BSO simulates a collection of random solutions. In all iterations, search agent upgrades the position relied on search mechanism and optimal solution is accessible. The pseudo-code of BSO approach has been projected. Here, the BSO model is composed of exploration and exploitation process which comes under global optimization. Moreover, linear combination of speed as well as beetle search improvises the robustness and accuracy of population which results in stable approach. Fig. 2 showcases the flowchart of BSO model.
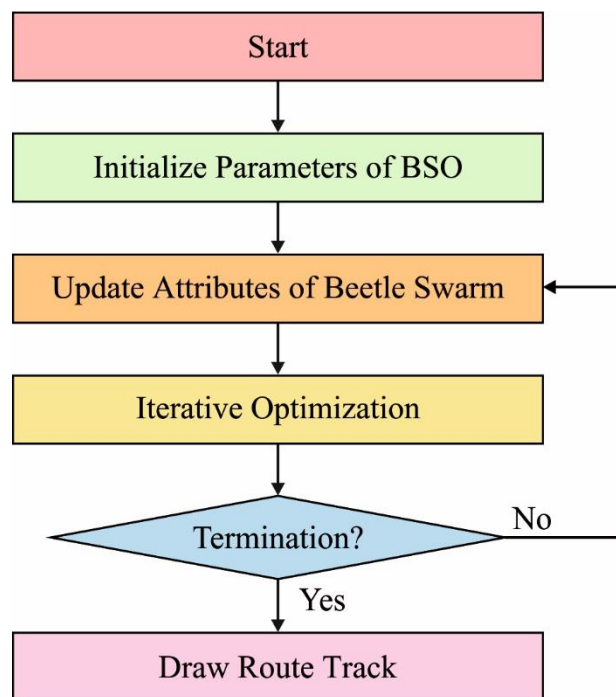
**Fig. 2.** Flowchart of BSO algorithm

In order to improve the performance of the BSO method, quantum computing concept is incorporated into it. Quantum computing is defined as domain in computer science marketed in quantum computers under the application of quantum mechanics like state superposition, entanglement as well as quantum gate [16]. The basic data unit in quantum computing is Q-bit. A Q-bit might be in a state $|0>$, or in a state $|1>$ or in a superposition of states $|0>$ and $|1>$ concurrency. Based on the Dirac function, Q-bit is expressed as the unification of states $|0>$ and $|1>$ as given in the following:

$$|Q> = \alpha|0> + \beta|1> \; such \; that \; |\alpha|^2 + |\beta|^2 = 1 \qquad (10)$$

where $\alpha$ and $\beta$ define complicated value. $|\alpha|^2$ (resp. $|\beta|^2$) depicts the possibility of identifying Q-bit in state 0 (resp. in state 1). The quantum register of size $n$ is limited from set of $n$Q-bits. It is actually composed of $2^n$ possible values at the same time. Additionally, quantum register is illustrated by the given function:

$$\Psi = \sum_{x=0}^{2^n-1} C_X |X> \qquad (11)$$

The amplitudes $C_x$ meet the given property:

$$\sum_{x=0}^{2^n-1} |C_X|^2 = 1 \qquad (12)$$

The state of Q-bit is modified by a quantum gate (Q-gate). The Q-gate is a reversible gate which is depicted as a unitary operator $U$ that is facilitated on Q-bit basis states by meeting the $U^+U = UU^+$, where $U^+$ refers the Hermitian adjoint of $U$. Various Q-gates are available in this approach namely *NOT* gate, controlled *NOT* gate, rotation gate, Hadamard gate, and so on.

## 2.2. Hybrid Data Transmission

When the data aggregation is computed by CH, hybrid data transmission is initialized [17]. First, CHs broadcast the adjacent parameters:

**Attribute (A):** It is defined as user-based attribute for accomplishing the data.

**Threshold values:** It is composed of Hard Threshold (HT) and Soft Threshold (ST). HT is defined as specific parameter value and value that exceeds HT is transmitted. Thus, ST refers a small difference in parameter value, which simulates the data transmission.

**Schedule:** In scheduling process, Time-division multiple access (TDMA)is applied in that a slot has been declared for all nodes.

**Timer:** It describes greater duration among 2 subsequent reports forward by a node. It has several TDMA schedule lengths and employed for proactive data conversion.

Under the application of hybrid data transmission, irregular and repeated data transmission is ignored. Finally, higher power efficiency and throughput enhancement have been accomplished.

## 3. Experimental Evaluation

The QBSOR-HDT model is executed by applying MATLAB R2014a. In order to point the efficiency of QBSOR-HDT, series of processes has been performed under various testing scenarios.In order to validate the consistency of QBSOR-HDT approach, it is sampled in 3 diverse scenarios on the basis of BS as depicted by S1, S2, and S3 correspondingly.

- S1- BS is suited at middle of target area
- S2- BS is placed in the corner of target area

- S3- BS has positioned far away from target area

In order to make sure the effective function of protocols, average power application of S1, S2, and S3 are processed and demonstrated in Figs. 3-5.
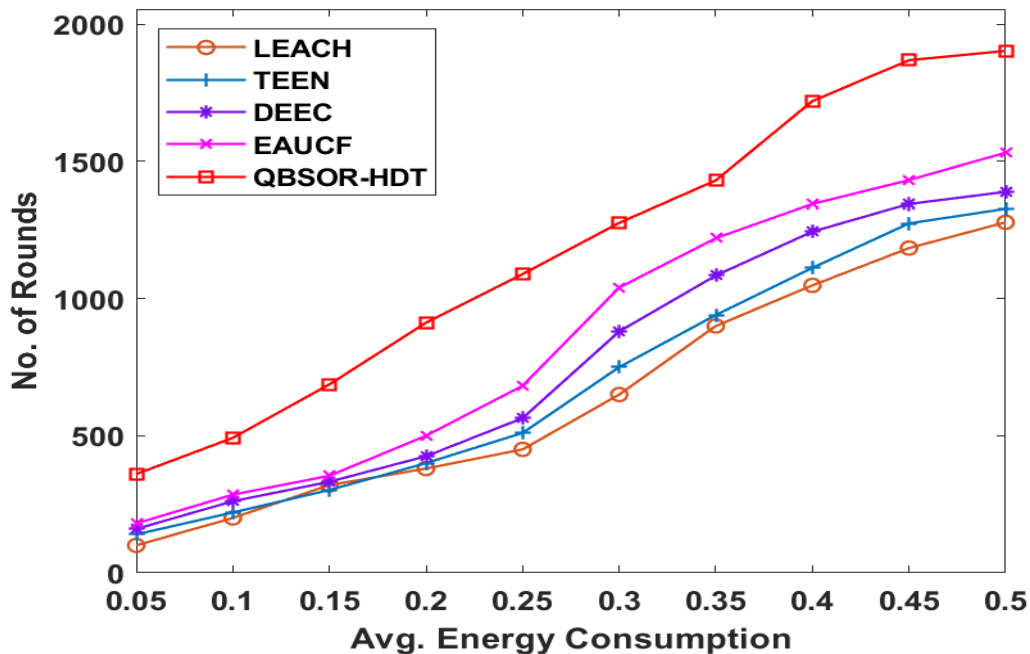


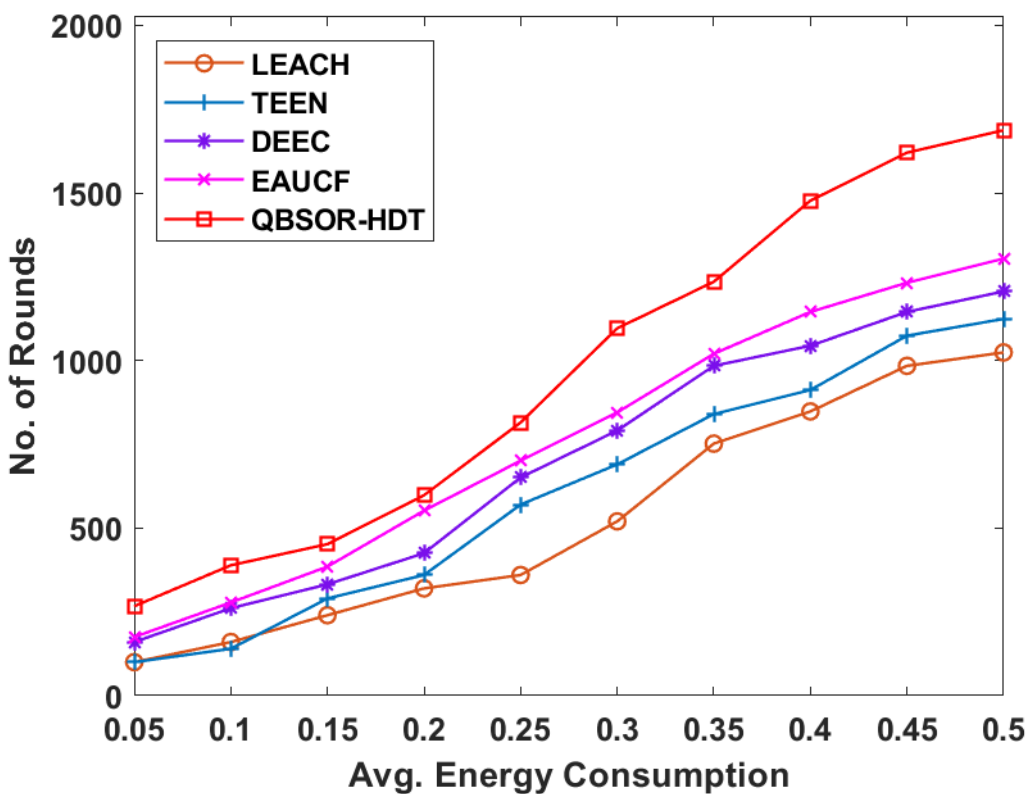**Fig. 3.** Average energy consumption: Scenario 1



**Fig. 4.** Average energy consumption: Scenario 2

Here, the power utilization is estimated by processing the overall power consumed by a sensor node, for all iterations. Hence, the newly developed framework is considered as energy effective when compared with traditional methodologies. It is due to the fact of productive forwarding set selection with the help of QBSOR-HDT. It makes sure that a node with maximum power and minimum distance would be selected as relay nodes. Eventually, the volume of energy expended for data transmission is reduced. LEACH demonstrates poor action when compared with alternate models by means of features like random routes selection makes feasible transmission for a node to become a CH when a node with minimum RE is considered as CH. Also, CH does consider parameters which are suitable for best path selection. Moreover, the inexistence of multi hop data transmission generates maximum power consumption. The reactive behavior of TEEN protocol intends in minimum power utilization when compared with LEACH and simultaneously the single hop data transmission tends to fail than DEEC, EAUCF, and QBSOR-HDT models. Even though EAUCF applies FL for CH election, probability based tentative CHs selection reduces the complete performance. Afterward, network lifespan is an important factor for calculating the movement of clustering in WSN. Network duration is called a number of rounds completed until the nodes in WSN drain the energy.
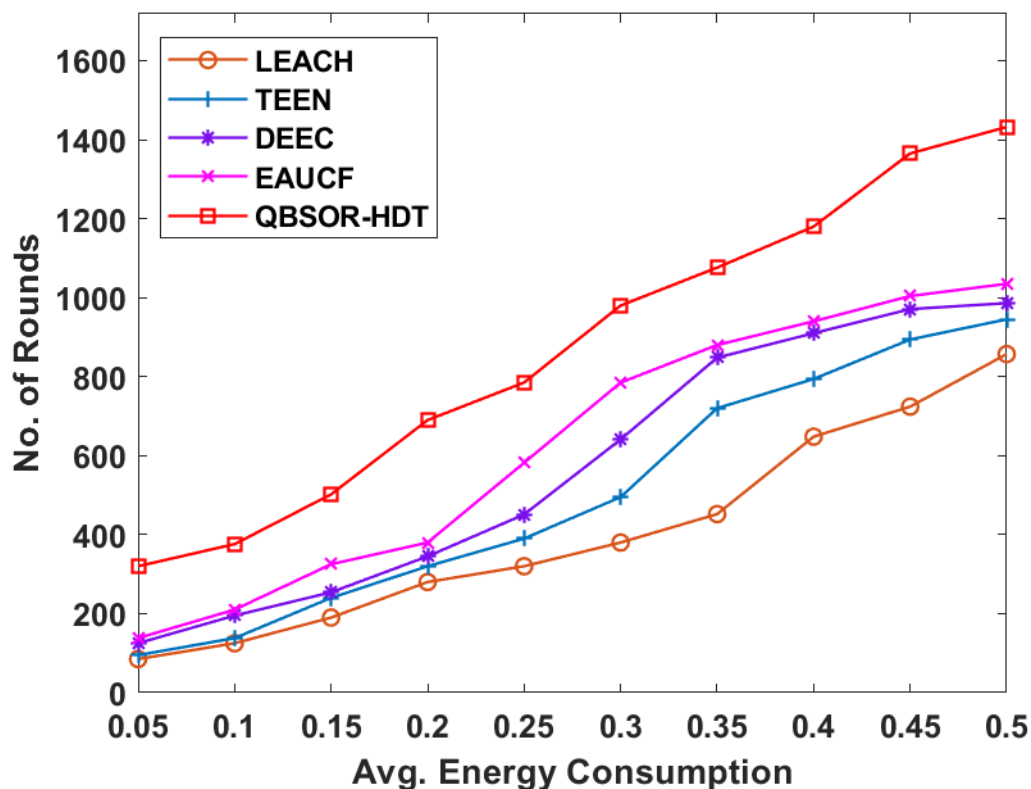


**Fig. 5.** Average energy consumption: Scenario 3

**Table 1** Comparison of existing with proposed QBSOR-HDT method interms of FND, HND and LND

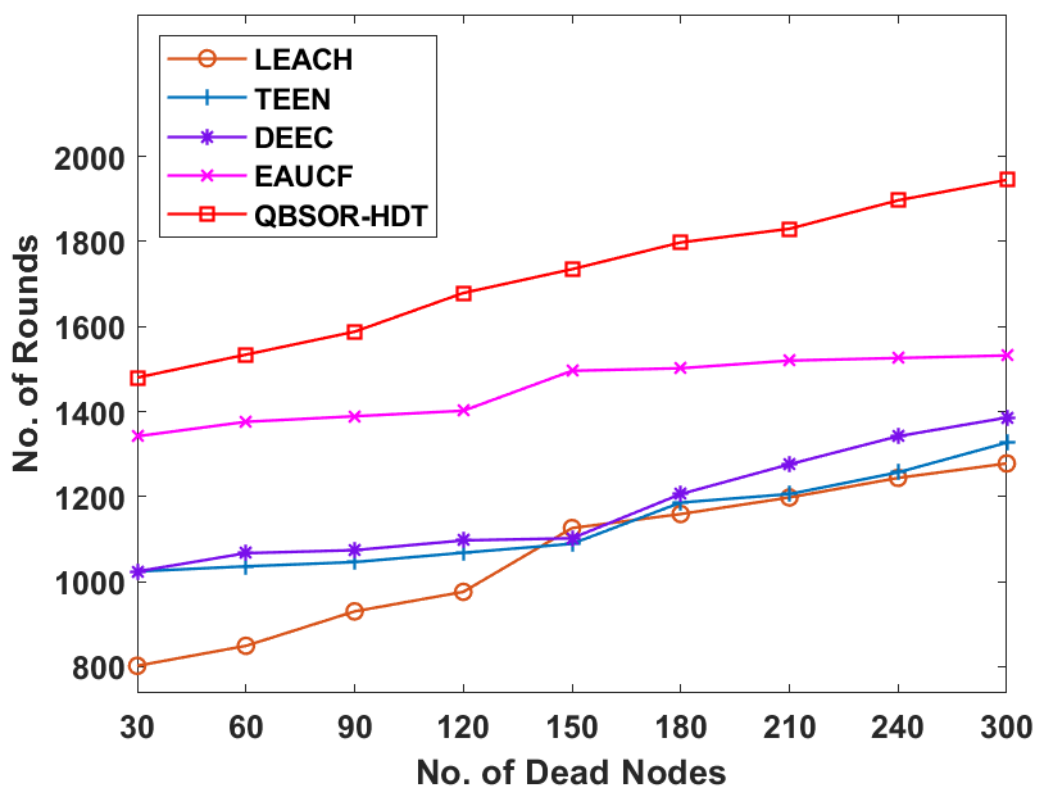| Algorithms | Scenario 1 | | | Scenario 2 | | | Scenario 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | FND | HND | LND | FND | HND | LND | FND | HND | LND |
| LEACH | 802 | 1126 | 1278 | 542 | 849 | 1024 | 452 | 614 | 857 |
| TEEN | 1024 | 1089 | 1327 | 768 | 889 | 1124 | 389 | 602 | 945 |
| DEEC | 1088 | 1102 | 1386 | 948 | 1041 | 1206 | 894 | 948 | 986 |
| EAUCF | 1342 | 1496 | 1532 | 1196 | 1274 | 1304 | 941 | 988 | 1035 |
| QBSOR-HDT | 1399 | 1735 | 1945 | 1213 | 1480 | 1679 | 989 | 1245 | 1401 |



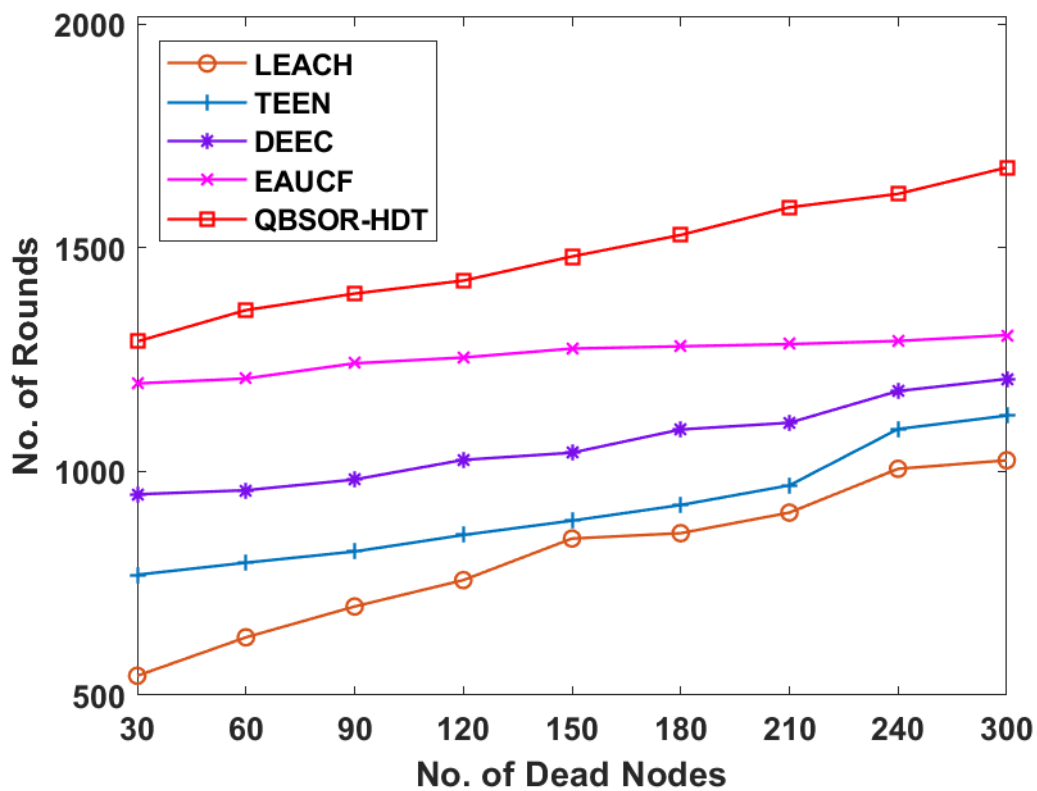**Fig. 6.** No. of dead nodes for several rounds: Scenario 1

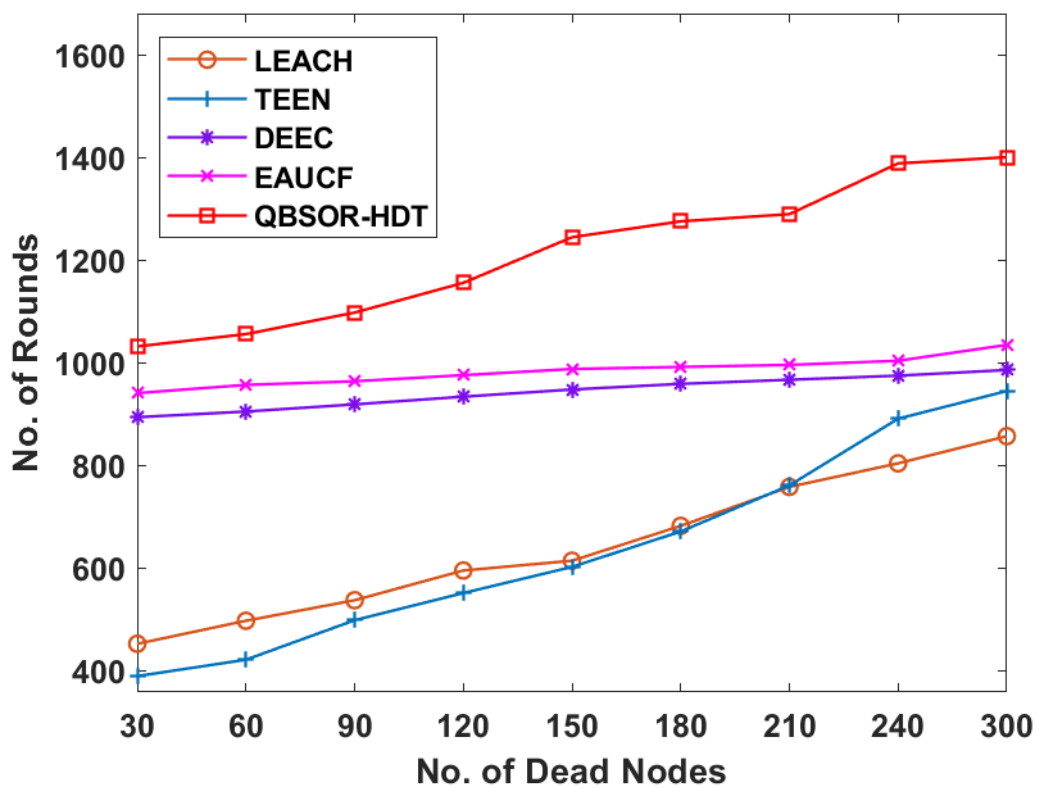**Fig. 7.** No. of dead nodes for several rounds: Scenario 2



**Fig. 8.** No. of dead nodes for several rounds: Scenario 3

As the adjacent nodes in WSN forward the similar data and FND does not show a greater impact of overall network performance. However, the quality of sensing data has been limited. If the LND reaches, the complete WSN is referred as dead. Hence, attained FND, HND, and LND of QBSOR-HDT model on 3 scenarios are depicted in Table 1. The simulation outcome of dead nodes in 3 scenarios isdemonstrated in Figs. 6-8correspondingly. From the figure, it is evident that FND of QBSOR-HDT does not incur previously when compared with traditional methods.

## 4. Conclusion

This paper has developed an effective QBSOR-HDT protocol for WSN. The QBSOR-HDT protocol determines the optimal routes to BS by deriving a fitness function comprising RE, distance to BS, and ND. Followed by, the QBSOR-HDT protocol determines the route to BS and then data transmission process has begun in a hybrid way, i.e., the data is transmitted at periodic time duration and reactive way. In addition, a thresholding mechanism is applied for reactive data transmission. A detailed set of simulations were performed under varying scenarios. The experimental results portrayed that the QBSOR-HDT protocol has maximized the energy efficiency and lifetime of WSN. As a part of future extension, the proficiency of the QBSOR-HDT protocol can be improvised using clustering and data aggregation approaches.

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