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Trust-Based Beacon Node Localization Algorithm for Underwater Networks by Exploiting Nature Inspired Meta-Heuristic Strategies

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Abstract: Conventional underwater technologies were not able to provide authentication and proper visualization of unexplored ocean areas to accommodate a wide range of applications. The aforesaid technologies face several challenges including decentralization, beacon node localization (for identification of nodes), authentication of Internet of Underwater Things (IoUTs) objects and unreliable beacon node communication between purpose oriented IoT-enabled networks. Recently, new technologies such as blockchain (BC) and the IoUTs have been used to reduce the issues but there are still some research gaps; for example, unreliable beacon messages for node acquisition have significant impacts on node identification and localization and many constrained node resources, etc. Further, the uncertainty of acoustic communication and the environment itself become problems when designing a trust-based framework for the IoUTs. In this research, a trust-based hybrid BC-enabled beacon node localization (THBNL) framework is proposed to employ a secure strategy for beacon node localization (BNL) to mine the underwater localized nodes via the hybrid blockchain enabled beacon node localization (HB^{2}NL) algorithm. This framework helps to merge two disciplines; it is hybrid because it follows the nature and bio inspired meta heuristics algorithms for scheduling the beacon nodes. The performance of the proposed approach is also evaluated for different factors such as node losses, packet delivery ratios, residual and energy consumption and waiting time analysis, etc. These findings show that the work done so far has been successful in achieving the required goals while remaining within the system parameters.

Keywords: data packet forwarding; blockchain-based beacon communication; node localization; end-to-end delay; energy consumption; hybrid technique; firefly strategy; foraging behavior

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1. Introduction

IoT-enabled wireless communication devices and related technologies have significantly contributed to the advancement of human life. There is an exponentially increasing number of smart sensors probing every aspect of the individual's life, work and entertainment. The advent of increasingly miscellaneous wireless applications triggers an outpouring in underwater data traffic [1]. Further, as part of the Internet of Things (IoTs) [2], Underwater Acoustic Sensor Networks (UASNs), which are typically self-organized heterogeneous wireless networks coping with IoT, namely, the Internet of Underwater Things (IoUTs), have emerged as a hotspot for research projects utilizing diverse sensors in the marine exploration and aquatic environment monitoring application domains. Basically, as a subcategory of the IoTs, a term first used in 1985 [3] and the IoUTs, first discussed in 2012, [4] are defined as "the network of smart interconnected underwater objects" while the meaning of IoT "the infrastructure of the information society". Essentially, the IoUTs includes underwater sensors, autonomous underwater/surface vehicles, base/master stations, buoys and ships, and has become an important part of the evolution of smart oceans in smart cities. This is not limited to the several attempts and references in [5,6] to emphasize the importance of IoUTs, as most underwater areas remain unexplored (only 5% of underwater volume has been explored). To the best understanding of underwater, Figure 1 presents the scenario of the underwater environment. In any underwater scenario taken from [2], the process of localization is important. Basically, localization is a key activity that detects a target's location underwater for different reasons such as data classification, tracking nodes underwater, and coordinating the movement of node groups. This is because the sensor data is meaningful only when sensing nodes are localized [7]. In underwater communication scenarios, the nodes that have ther 'location information' called '*beacon or anchor node*' that generate "*beacon message*" to broadcast to other nodes for communication. The beacon node is a communication gateway capable of building an underwater network and pursuing the localization process [8,9]. The process of localization enables underwater communication, sensing and control of the whole network's topology. All existing techniques based on base station localization, but some or few research papers discussed the idea of localization through 'beacon node'. There is dire need to understand the difference between base station and 'Beacon Node Localization (BNL)', which is quite interesting. This BNL has enough potential to expand the horizons of research. The beacon node is responsible for the formation of underwater networks lis same as the base station. Several important decisions are based on BNL; for example, computation complexity, distance of neighboring node, network strength, receiving signal strength, angle of arrival and its difference, time difference of arrival and reliability analysis, etc. [10].

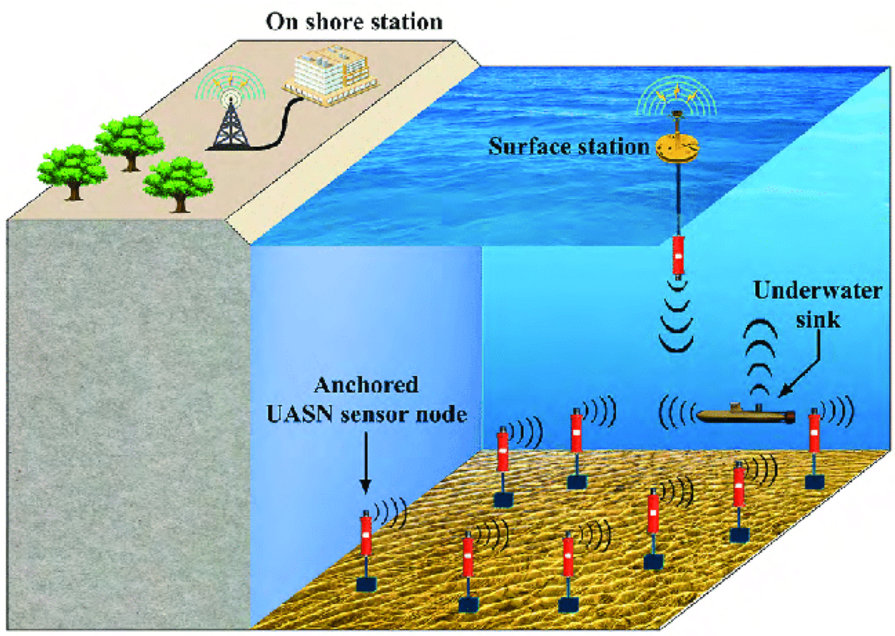

Figure 1. Underwater acoustic sensor network: a scenario [2].

Most importantly, the beacon node is fully responsible for localization based on the previously mentioned parameters. Effective strategies and reliable shield embedded beacon nodes ensure localized sensor nodes at various places with minimum margin of cost and maximum location-oriented indication of neighboring node list (that need to be localized). The efficient localized nodes and its reliability challenges are another crucial issue in underwater scenarios. Most of the localized nodes cannot be considered secured after localization due to unreliability factors, data handling, estimation errors, blindly selected localized nodes, unexpected changes in underwater environment, dynamic uncontrolled network topology, node behavior regarding joining/leaving the network boundaries, etc. [11]. Recently, BC-based distributed, decentralized, peer-to-peer networks have evolved to enable the safe and cost-effective storage of underwater IoT data without depending on any intermediate trusted authority, while maintaining anonymity [12]. BC can support decentralization for capturing IoUTs communication processes as well as secure processing and exchanges data with other organizations. Decentralized access control and distributed trust are required for almost all IoUTs applications. Indeed, even with the bulk of the research found on BC-based localization in WSNs, the same development of BC in the undersea sector has yet to begin. Present underwater communication emphasizes the adoption of BC localization algorithm that can calculate and secure the unknown node's location, authentic accuracy and improve its efficiency, particularly when the environment is unmanned and hostile. In this research, a trust-based hybrid beacon node localization (THBNL) communication framework is proposed for underwater problems regarding BNL. Further, this framework consists of a hybrid blockchain enabled beacon node localization (HB^2NL) algorithm which provides smooth communication towards the destination through verified beacon nodes (VBN). VBN are those nodes that can be localized through blockchain and have the capacity to localized other nodes.

Contributions

The following are the potential contributions of the proposed framework:

- THBNL is a BC enabled framework that considers the acquisition of BNL features (e.g., localization accuracy, node losses and Packet Delivery Ratio (PDR)) and determines the verified and trusted beacon nodes. THBNL relaxes the parameter assumptions; thus, it can emulate realistic situations in UASN for safe localization through HB^2NL algorithm.
- THBNL focuses on the heterogeneity of the verified localized beacon nodes that challenges the algorithm design of HB^2NL. It achieves the localization accuracy in beacon node level identification for different acoustic environments (e.g., deep and shallow water). Moreover, the THBNL framework is extremely flexible and can easily be extended by supporting more selection features for better efficiency (where needed).
- The effectiveness of the HB^2NL algorithm is validated via different load measurements (e.g., base load, interruptible load, uninterruptable load and on average load) of acoustic communication data traffic. Finally, we compare the accuracy of HB^2NL algorithm with localization accuracy, node losses, PDR, survival nodes, residual energy and number of delivered/received packets.
- Scheduling and scalability are addressed for selecting verified beacon nodes (VBN) by meta-heuristic bio/nature inspired techniques by Levy Firefly Algorithm (LFA) and Birds Foraging Algorithm (BFA), respectively. Moreover, for the purpose of scheduling, we introduce the notion of 'beacon node coordination'. This aids the scheduler in selecting the verified beacon nodes (which are localized) and neighboring nodes without any localization interruptions.
- To achieve the system objectives and incorporate the cost reduction mechanism (CRM), we will schedule BNL as a '*knapsack problem*' with a knapsack capacity (small items with largest values), which is solved using 'dynamic programming' [13]. This helps the CRM to draw inferences regarding newly encountered nodes and schedule them correctly.
- The beacon node mechanism inside HB^2NL selects a group of validator nodes as VBN using the (*TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) to rank BC nodes. TOPSIS, a multi-criteria decision analysis method, estimates the shortest geometric distance from the ideal best value and the longest geometric distance from the ideal worst value) TOPSIS/multi-criteria analysis method. Through

this criterion, the beacon node with the greatest trust value is chosen as a validator node for the localization process of a block in BC and responsible for smooth data forwarding.

The remaining sections of the paper deal with related work, problem description and proposed framework in Sections 2–4, while meta-heuristics analysis and simulation results are discussed in Sections 5–7. Section 8 deals with the conclusion.

2. Related Work

The use of BC and other issues of underwater networking have mostly been investigated separately. Crossovers between these two fields have only recently become apparent. Numerous important studies provide an in-depth examination of the undersea networks and BC research scene. We categorized these works into (i) pure overviews of BC in all possible disciplines; (ii) reviews of surveys of underwater networks techniques in updated modern lines; (iii) reviews of antique and recent localization techniques; (iv) works have enabling BC driven underwater networks at the intersection between the underwater wireless network and BC. We summarize underwater localization techniques in Table 1 and its associated state-of-the-art algorithms in Table 2, while the below section lists the most representative publications in each class. A growing number of survey papers that represent advancement in Terrestrial Wireless Sensor Network (TWSNs) enable to monitor, detect and track various environmental phenomena and events. These kinds of functionalities of TWSN extend the research to underwater applications to give rise to a network of underwater acoustic sensors nodes (UASN) [14–16]. The authors present the use of medium access control (MAC) protocol due to its potentially large impact on overall network performance in [13]. Unlike TWSN, this survey highlights the current state-of-the-art of MAC protocol because minimum delay and maximum throughput are major concerns of underwater networks [14]. The authors found different applications for offshore exploration and ocean monitoring. Different kinds of routing techniques are covered in this survey [15]. The authors highlight the characteristics of UWSNs for its dynamic structure, narrow bandwidth, high latency and rapid energy consumption. These open issues motivates the idea of design such routing protocol in this domain and propose a route decision maker strategy framework [16]. The authors discussed the security criteria, different malicious attacks, accurate communication channel and ground-based counterparts that require the deployment of efficient and reliable security mechanisms [17]. The authors also classified underwater deployment methods into the following categories depending on the sensor node's mobility: (i) static deployment; (ii) self-adjustment; (iii) movement aided. The mobility of nodes and their various practical parameters such as computing complexity, energy consumption, and deployment objectives are thoroughly examined [14–17]. The authors put forward the role of recent technologies in underwater networks. The next generation UWSN are coped with different technology which make flexible, robust and adaptive programmable support resource sharing features and are easy to manage and resolve [18]. For this, software defined n etworks (SDN) is easily merged with cognitive acoustics, software-defined radio, network function virilization, the software's network resources and internet of underwater things (IoUTs) [19]. More recently, the authors claimed that no more than 5% of the volume of the oceans has been observed by humans. Therefore, there is still dire need for networking solutions towards efficient reliable underwater data collection. As a result, an overview of undersea development in a wide variety of areas and its possible applicability to network traffic control systems [20]. Additionally, their analysis identifies some unresolved research concerns that merit further investigation. There are different kinds of localization algorithms of UWSN are classified in three categories such as: stationary, mobile and hybrid localization algorithms [21]. Domingo et al. introduce techniques, applications and guidelines for applying to review the UWSNs surveys. Their study simply classifies the underwater domain in three categories: energy-based, data-based and geographic information-based protocols. Meanwhile, the advantages and disadvantages of different routing issues are analyzed in detail with future directions that will enable the researcher to conduct future study more effectively [22,23]. The currently available list of various routing protocols and its taxonomy, comparison and discussion are presented in [24]. The design applications are discussed in [25], different modes of underwater communications in [26], a comprehensive list of localization optimization algorithms in [27]. Moreover the BC oriented scheme for sybil attack of UWSN, bio-inspired algorithms in [28] and a dynamic trust-based evolution of hidden Markov models cooperate, and opportunistic routing protocols and there design guideline are listed in [26–28].

Table 1. Summary of existing articles, transaction and magazine papers, and books related to WSN and UASNs with their addressed scope of followings where IoT stands for Internet of Things (IoTs), BC stands for BC, Hybrid stand fpr combination of two fields for same problem of interest, NL stands for node localization and RP stand for routing path. The symbol '✓' indicates the publication in the scope of the domain and '✗' indicates a publication that does not directly cover the area but from which readers may retrieve some related insights. Publications related to both BC and IoT enabled UASNs are shaded along with Our Scope which is marked with *.

Ref.	**One Sentence Summery**	**Scope**									
		WSN					**UASN**				
		IoT	**BC**	**Hybrid**	**NL**	**RP**	**IoUTs**	**BC**	**Hybrid**	**NL**	**RP**
[14]	A review of TDoA based self-localization	✓	✗	✗	✓	✓	✗	✗	✗	✓	✓
[15]	A localization Tracking in WSNs	✓	✗	✗	✓	✓	✗	✗	✗	✓	✓
[16]	A detailed approach of topological localization	✓	✗	✗	✓	✓	✗	✗	✗	✓	✓
[16]	A grey Wolf Optimization based localization	✓	✗	✗	✓	✓	✗	✗	✗	✓	✓
[17]	A New kernelized approach to WSN localization	✓	✗	✗	✓	✓	✗	✗	✗	✓	✓
[18]	A comprehensive overview of localization algorithm	✓	✗	✗	✓	✓	✗	✗	✗	✓	✓
[19]	An overview of self-learning localization	✓	✗	✗	✓	✓	✗	✗	✗	✓	✓
[20]	A lightweight localization scheme for localization	✓	✗	✗	✓	✓	✗	✗	✗	✓	✓
[21]	An introduction of secure localization scheme based on trust assessment for WSNs	✓	✓	✓	✓	✓	✗	✗	✗	✓	✓
[22]	A survey of Localization Optimization in WSNs Using Meta-Heuristics	✓	✓	✗	✓	✓	✗	✗	✗	✓	✓
[23]	A Hybrid localization for underwater	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓
[24]	A survey of localization algorithm in underwater	✓	✗	✗	✓	✓	✓	✓	✗	✓	✓
[25]	A Source localization in inhomogeneous underwater	✓	✗	✗	✓	✓	✓	✗	✗	✓	✓
[26]	Game theory based hybrid localization	✓	✗	✓	✓	✓	✓	✗	✓	✓	✓
[27]	An overview of Anchor node-based range free cooperative IoT-underwater localization	✓	✗	✗	✓	✓	✓	✗	✗	✓	✓
***Our Scope**	**An introduction of BC enabled localization for IoUTs**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 2. Nomenclature of algorithm symbols and equations notations.

Symbols	Description
N_B	Populations of Beacon nodes
N_d	Domination/elimination rounds
N_r	Population response
N_c	Firefly catching rounds
F_{Pop}^{B}	Fitness of population of Beacon node
ϕ_i	Bacterium vector direction (randomly)
θ_i	Bacterium's Platest position
KS_{D_e}	Knapsack Dynamic equation
Loc_B	Localization of B
Loc_{B_v}	Localization of VBN
Loc_B^{negh}	Localization of Beacon inside neighboring nodes
E_{cost}^{negh}	Cost of neighboring Beacon nodes
$B_n^{Trust}ON$	Beacon's Node trust value is ON
BC_{Min}^{Date}	Blockchain Miners against data transection
F_{Pop}^{B}	Fitness of population of Beacon node
F_f	Fitness function
Pop	Population set
Std	Standard deviation
θ_i	Bacteria's latest position
N_B	Populations of Beacon nodes
N_d	Domination/elimination rounds
N_r	Population response
N_c	Firefly catching rounds
N_s	Stochastic rounds
KS_{D_e}	Knapsack Dynamic equation

The above findings are the indicators of the necessity to devise novel mechanisms of trust and reputation assessment gives the idea of blockchain-enabled UASNs. The next section formally defines the specific problem of localization and its solution:

- There is no technique at present which is a hybrid, jointly considering BC and the IoUTs as a BC-enabled Internet of Underwater Things (BIoUTs) for the trusted BNL problem with meta-heuristic techniques;
- There is no such job found that provides trust and reputation assessment in wireless underwater networks for secure BNL using BC;
- Better relationship management (in terms of data exchange) among node participants requires the absence of third parties. There is none of any idea has been found which enables BC at beacon level, i.e., the beacon nodes-oriented communication of the BNL problem;
- To ensure privacy and security of data transferred across hierarchical sensor beacon nodes without incurring excessive computing costs and requiring centralized control;
- There is no such work that facilitates the entire cycle of routing communication process of underwater among participants for trust and reputation assessment in solving the BNL problem by BC;

- There is no approach in the literature that applies BC at the beacon level to the BNL problem to assure localization while dealing with its dynamic, multi-level and heterogeneous character.

It has been noted during the literature analysis, the proposed localization techniques are lacking the concept of inducing BC at this level such that it accounts for communication overhead, localization accuracy and preservation cost. Most of the localization methods and algorithms which were described earlier, such as [14–17] and [19–21], which are implement localization at sink levels; however, [10,12,13,17,19,20,23,27,28] produce high localization accuracy while [8,9,14,15,18,22,24] have noticeable communication transparency. Furthermore, [12,15,23] ignore the high energy consumption ratio. In case of error estimation, [2,4,6–8,10,11,13–17,20–23,25] did not investigate their impact. However, [10–12,14–16,19,21,22,27] are good for maintaining energy and prolong the network lifetime. Moreover, [2–6,10,12–17,19,22,23] are proven to be delay-oriented techniques. It is interesting to note that none the localization techniques/algorithms were previously tested with BC. Therefore, our proposed THBNL framework in this research reduces the cost, delay and energy, and improves the localization accuracy while maintaining the communication overhead and network lifetime. The proposed framework will solve the BNL problem without using any extra resources while establishing coordination among verified beacon nodes to minimize CRM constraints.

3. Problem Description

The issues of the insecure and non-trusted underwater environment [2] discourage localization of nodes, data sharing and forwarding for underwater communication. Previous techniques used central authorities to determined node positions. The central authorities (e.g., base and master station) [14–16] are not capable of ensuring cross-validation of node positions and their selection due to the absence of an authentication mechanism. Moreover, several collateral problems occur when an unknown object is detected as a known object (such as location information privacy and reporting). The whole communication is exposed and disturb with bogus routing, as well as data gathering communication situations. Conventional underwater methodologies were not able to provide authentication and proper visualization of unexplored ocean areas in order to accommodate a wide range of underwater applications. For independent secure communication in terms of centralized authority, the use of BC underwater has been revolutionized in terms of localization, as well as end-to-end. The beacon nodes are used for localization with its trust value which is subsequently shared with adjacent nodes via BC technology to successfully perform the localization process.

The solutions of waiting time (with different base loads), number of received packets and PDR are discussed in Section 7. Its preliminary results are also discussed.

The solution of the identification of the surviving nodes and its impact is discussed in Section 7.

The solutions of the number of rounds for energy exhausted, energy consumption for received packets and residual energy are discussed in Section 7.

The simulation of the number of alive and dead nodes are also discussed in Section 7 respectively.

4. The Proposed Framework

Bio-inspired meta-heuristic techniques are used for its simplicity, adaptability and ergodicity [29,30]. To begin, most of these algorithms are rather straightforward to implement in comparison to those in other programming languages. Second, they are adaptable in the sense that they may be used to address a wide variety of issues. Finally, some of the strategies can deal with ergodicity due to their capacity to readily escape local minima [30]. For this reason, these approaches should be used rather than meta-heuristics based on assumptions such as proportionality. On the other hand, meta-heuristic processes make few or no assumptions. The author in [31] described the argumentation of local and global search. Local search is more important to the BFA than global search is to genetic algorithms (GA) [32]. Both methods are lauded for their superiority; nevertheless, they are not without faults. In GA, there are problems with convergence which necessitate several iterations and a vast search space.

THBNL is a concept that utilizes both the Levy Firefly Algorithm (LFA) and the Birds Foraging Algorithm (BFA) to get around these limitations. However, the proposed approach is based on a private BC enabled localization scheme with a following extended range free algorithm which is quite different from the existing approaches of UWSNs. Further, in our research, the extended range free BC enabled algorithm copes with meta-hermitic nature, and the bio-inspired technique is employed for the secluding and scalability of the verified beacon node localization (VBNL). By contrast, all currently used localization strategies are tested without the usage of BC. In fact, current underwater solutions, such as decentralized key management for security concerns, have leveraged the BC model to address underwater difficulties. The main objective of this proposed framework is to solve the problem of BNL with minimum CRM. Which helps to make decisions about VBNL enabled with BC.

In our scenario, targeted objective beacon nodes are based on fitness function constraints which are given in Equation (5a). Our second main objective: a reliable communication-oriented hybrid framework that considers the localized environment which is handled in real-time scheduling. The proposed system for efficient scheduling of BC based beacon nodes minimizes the UID_n and U_n. The first layer of the model shows the overall scenario. The data of beacon nodes and their associated terminology is processed empirically in the second layer. In the third layer, the prescription study about the selection of 'Verified Beacon Nodes' is processed. The results obtained from third layer are again sent to second layer where B^{negh} makes decisions depending on the outcome of completing the whole reference. The second and fourth layer jointly consider the separation of relative 'Verified Beacon Nodes' and the optimization of validators to achieve useful results that help to improve the operational planning of selected 'Verified Beacon Nodes'. Moreover, the separation and minimization of UID_n are formulated in Equation (1):

$$Q_1 = \min\left(UID_n^B - UID_n\right) \tag{1}$$

where UID_n^B is the total un-identified beacon nodes that are calculated using Equation (2):

$$E_{cost}^{total} = \sum_{B=1}^{\hat{B}} B^{Rel} - U_n \times \text{Ɣ} \times UID_n^B \tag{2}$$

where E_{cost}^{total} represents the aggregated total cost of the network during the process of selecting of reliable beacon nodes (B^{Rel}) which are separate out and 'U_n' represents the aggregated value of total unknown nodes inside the network. Meanwhile, Ɣ = 1, 0 for selected and unselecting of $\hat{B}$ (verified trusted beacon nodes) from 'B' beacon nodes. The objective function of B_{unit}^{negh} has a reciprocal function with E_{cost}^{negh}; this relationship is mathematically represented as follows in Equation (3) as described in [32]:

$$B_{unit}^{negh} \propto \frac{1}{E_{cost}^{negh}} \tag{3}$$

where B_{unit}^{negh} is calculated as:

$$B_{unit}^{negh} = \begin{cases} 1, & if\ B_n^{\boldsymbol{Trust}} on \\ 0, & if B_n^{\boldsymbol{Trust}}\ off \end{cases} . \tag{4}$$

Trust values of beacon nodes are 'on' when the union of reliable beacon and neighboring nodes is considered. Mathematically: $B^{Rel}\ U\ B_{negh}^{Rel} \times \left(List_B + List_B^{negh}\right) List_B\ \geq B^{Rel}$ which means only a selected list of beacon nodes were formulated with it and $List_B^{negh} \leq B_{negh}^{rel}$, respectively. Specifically, only those nodes that are in the list of $List_B$ are not proceeded by mutation relation and further the constraints of Q_1 as defined as the fitness function 'F_f' represented in Equation (5). This feature aids in the discovery of the best explanation from 'F_f': choose the fitness criteria via list F_{pop}^B to avoid the unnecessary selection and saturation of beacon nodes:

$$F_f = \min\left(F_{pop}^B\right). \tag{5}$$

Meanwhile, F_{pop}^B is calculated using Equation (5a) which is taken from [33,34].

$$F_{pop}^B = \begin{cases} B_{negh}^{leg} \leq BC_{beac}^{negh} \leq B_{l1} \; if \;\; \hat{I}_N = 0 \\ B_{l2} \leq E\left(B_{negh}^{leg}\right) < B_{l3} \; if \;\; \hat{I}_N = 1 \end{cases} \tag{5a}$$

$$B_{l1} = Sum\left(BC_{beac} \times BC_{beac}^{negh}\right) - std\left(E\left(BC_{beac}^{negh}\right)\right) \tag{5b}$$

$$B_{l2} = std.\, E\left(BC_{beac}^{negh}\right) + \eta \times \min\left(E\left(BC_{beac}^{negh}\right)\right) \tag{5c}$$

$$B_{l3} = \text{ mean } \left(E\left(BC_{beac}^{negh}\right)\right. \tag{5d}$$

$$Loc_B = \frac{Loc_B^{negh}(B_{l1}) - \min\left(List_{Loc_B}^{\text{int}}\right)(B_{l2})}{\max Loc_B^{negh}(B_{l3}) - \min\left(List_{Loc_B}^{\text{int}}\right)(B_{l2})} \tag{5e}$$

The value of 'η' is determined by keeping the cost of BC enabled neighboring nodes minimal with the help of by-products of the BC beacon node and its neighboring nodes. The under observed scenario of taking η = 2 and Loc_B is considered as per set $\forall \, l \; \varepsilon \; \{2, 3, 4, \ldots\}$.

The variable of "η" is initialized by "2". This is because of the first beacon node must be selected and considered as the beacon node to start the process therefore η = 2 for the localized blockchain and the limited criteria Bl_1, Bl_2 and Bl_3, respectively. The limitation of the total beacon limit (Bl_1) and its related standard deviation (std deviation) (Bl_2), with its mean value of (Bl_3), can be calculated using (5b), (5c) and (5d), respectively. Therefore, the distribution of localization can be done using Equation (5e), where Loc_B (localization of beacon nodes) is calculated from Equation (2).

4.1. Verified Beacon Nodes Selection

Our second objective is the selection of the verified beacon node. The Loc_B is already calculated from Equation (5e) and F_{pop}^B is represented in Equation (5a). It can be mathematical defined as:

$$Q_2 = \min(B_{Honest}^{Ff} - Loc_{U_n}^{UID_n^B}). \tag{6}$$

The beacon selection in optimized by following objective Q_2 will be used as a constraint for Q_1 where:

$$E\left(B_{Honest}^{F_f}\right) = \sum_{B=1}^{B_{Honest}} \left(E\left(BC_{cost}^{negh}\right)\right) \tag{7}$$

where $E(BC_{cost}^{negh})$ is calculated using Equation (8):

$$E(BC_{cost}^{negh}) = \sum_{B=1}^{B_H} \left(BC_{Min} \times BC_{Min}^{Data}\right) \times \text{Ɣ}. \tag{8}$$

4.2. Cost Reduction of B_H

Ensuring verified selection is one of our goals that will be achieved through B_v with the help of other constraints which is automatically accomplished by Equation (1). Formally

$$Q_3 = \text{Min}\ (Cost\ (B_v)) \tag{9}$$

$$C_{B_H} = \frac{\text{Max}\left(B_v^{F_f}\right)^2}{(avg(Loc_{B_v})^2)} \tag{10}$$

where $\left(B_v^{F_f}\right)^2 = \left\{B_{v1}^{F_f},\ B_{v2}^{F_f},\ B_{v3}^{F_f}, \ldots\right\}$ represents the verified beacon node with its fitness function using Equation (7).

4.3. User Comfort Maximization

In a localization process, the major concern is to achieve maximum output with minimum cost as far as ensuring the B_v using Equation (9). We concentrate on optimizing user comfort, which may be described statistically in Equation (11). Now, the BC enables nodes have a large neighboring set with minimum cost. As per Equation (3), the inversely proportional relation exists that clearly requests the addition/removal of the number of nodes according to the requirements of experiment. Only by validator collaboration nodes can comfort and the number of nodes against user interruptions be attained. In a real-time scenario, it can be represented as taken from [35]:

$$Q_4 = Max(comfort\ BC_{\min} + B_v) \tag{11}$$

That Q_4 is a constraint that is involved with Q_1–Q_3, respectively, is describe further as:

$$Comfort\ BC_{\min} = \begin{cases} 1,\ if\ \hat{I} \\ 0,\ otherwise \end{cases} \tag{12}$$

Consequently, it is an inverse relation against selection of a greater number of $\text{BC}_{\min}$ and 'Verified Beacon Nodes' mathematically:

$$Comfort \propto \frac{1}{\sum_{B=1}^{\hat{B}} (B_H \times BC_{\text{Min}})} \tag{13}$$

where B is a beacon node and $\hat{B}$ is a trusted beacon node.

$$B_H = \left| (B + B_{unit}^{negh}) \times (\hat{B} + \hat{B}_{unit}^{negh}) \right| \tag{14}$$

4.4. Model Transformation

This section summarizes all constraints with multiple objective methods from Equations (1), (6), (9) and (11), respectively. However, qualitative items (such as user comfort) are neglected during the transformation analysis. It has highly significant during scheduling and re-selecting of B_v on demand. Further, to make it simpler, two objective constraints Q_1 and Q_3 are considered:

$$\lambda \times (Q_1) + (Q_2) + (1 - \lambda) \times Q_3\ . \tag{15}$$

Equation (15) is derived from Equations (5a) and (12), where the highest priority is given to objective constraints that separate out the identified unlocalized and localized nodes (Q_1 from Equation (1)), 'VBN' selection (Q_2 from Equation (6)) and cost reduction of 'VBN' (Q_3 from Equation (9)), which is accomplished using the linear Equation (5a) where $\lambda = 1$ to achieve objective Q_4.

5. Meta Heuristic Strategies for Node Scheduling

In practice, the intermediate nodes connect the beacon node to the sonobuoys, allowing nodes to be dispatched to meet communication and localization needs. It is worth mentioning that the beacon nodes are only the source which makes the network topology of underwater networks.. The role of beacon nodes localization is just to ensure the correct and reliable indication of the position of the various nodes that will take important roles in communication scenarios (usually with a routing path).

5.1. Nature-Inspired Meta-Heuristic Mechanism for BNL Node Scheduling

The LFA [36] is nature-inspired stochastic swarm intelligence, meta-heuristics, and population-based multi-agent algorithm. Swarm intelligence [31] is a technology inspired by nature that is mostly used to address production and scheduling challenges. It is called 'swarm intelligence' because it depicts the self-organization behavior of diverse flocks of birds, bees, insects and other animals such as fish. Many species such as birds and insects were kept in a restricted space where their natural and social behavior for solving problems and overcoming obstacles was observed and incorporated as algorithms [26].

The self-organized behavior of fireflies is the motivation behind the firefly algorithm. All the flies in the LFA are attracted to one other, and their attraction is proportional to their brightness; as the distance between the fireflies grows, the brightness decreases. The fitness of each firefly in the swarm improves because of their brightness behaviors and interactions with other brighter firefly swarms, allowing 'Levy flights' to refine their search method and schedule the next firefly in a row. Based on the above facts, the LFA can help in the scheduling of BNL (in the same way which schedules the flies according to their brightness) and striking a better balance between exploration and exploitation of the search space. This aids in the selection of system constraints and their convergence without harming the stability and accuracy of the possible solutions, as compared to other stochastic behaviors. As previously established, the basic goal function of generating cost is represented by a quadratic function. As a result, BNL costs may be more efficiently planned by using the LFA to tackle the BNL problem in the underwater environment for IoUTs. The proposed conceptual combined model for the BNL problem is shown in Figure 2.

5.2. Bio-Inspired Optimal Mechanism for VBNL

Passino [24] presented a meta-heuristic optimization approach. Its functioning architecture is built on weak foraging methods. The algorithm's statistical behavior of bacteria foraging is basically towards an optimal solution that encourages us to use the BFA for B_v scheduling optimization $J_i\ [j,k,l]$. The step of the BFA to address the problem is discussed in this part. In reality, the BFA begins with a randomly generated population as 'Np' (usually 100 times from its original value), in which every object is treated like a bacterium. It begins by calculating each bacterium's fitness, K_i. Finally, regarding F_f from the updated F_{pop^B}, the desired result is achived. In addition, the best solution 'θ' to search the space for optimization issues is generated using an evolutionary meta-heuristic method. The BFA is built around the fitness and random selection 'i' of bacterium as its basic structural component. The BFA is a global metaheuristic method inspired by the genetic processes of live beings and based on evolutionary programming to solve the problem described in the preceding section. In comparison to mathematical methods, the BFA uses fewer processing resources, fewer limitations, and uses fewer parameters to solve optimization issues taken from [34] and described in Equations (16) and (17), respectively.

$$J_i\ [j,k,l] = \sum_{B=1}^{\hat{B}} (100 \times \left(\theta(i,b+1) - \left(\theta(i,b)^2\right)^2\right) + \left(\theta(i,b) - 1)^2\right) \tag{16}$$

where θi is calculated using Equation (17):

$$\theta_i\,[j,k,l] = \theta_i\,[j-1,k,l] + C\frac{\Delta_i}{\sqrt{\Delta_i^{\tau}\Delta_i}}. \quad (17)$$

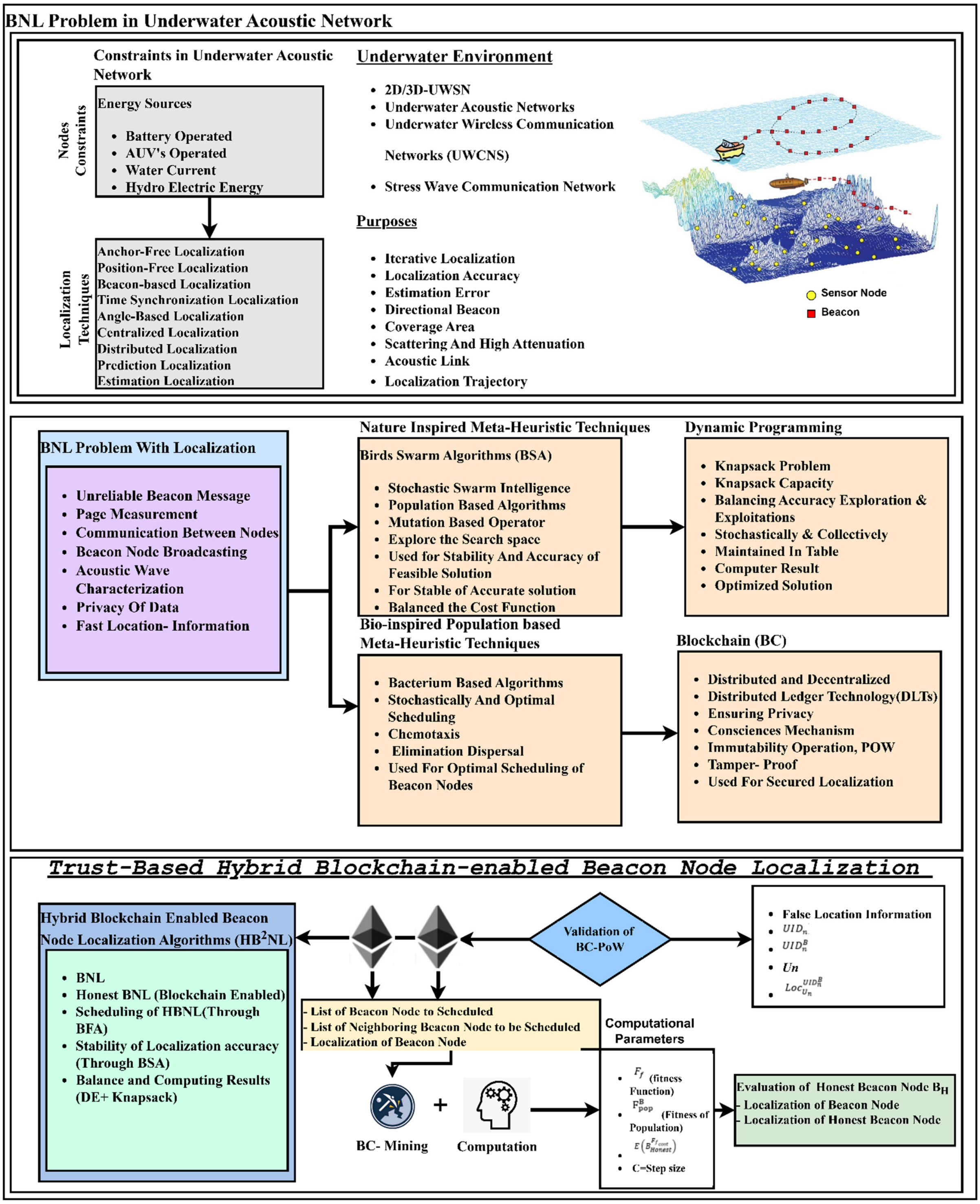

Figure 2. Combine System Model for BNL in UASNs.

The selection of a trusted and 'Verified Beacon' node that is further unable to localize their neighboring nodes is solved through the 'Knapsack Problem'. To solve the knapsack problem, dynamic programming is adapted [12]. The basic function of dynamic programming is to divide the whole problem into sub problems and maintain its record in a table with the following Equation (18). In our works, small items having the largest value (as one selected B_v has a set of verified neighboring nodes) are calculate using Equation (19) and maintain the table B $[\hat{i}, \hat{j}]$. That strategy will reduce the cost of selected B_v saved in table VBN $[\hat{i}, \hat{j}]$. Finally, the optimized solution is selected using Equation (20) as used in [37].

$$KS_{De}^{1,2} = \left[B\left[i'-1, j'\right]\right],\ value\ \left(i'-1\right) + B(i'-1, i'j - List_B(i'-1) \tag{18}$$

$$T\ \left[\,i', j'\right] = \begin{cases} \max(KS_{De}), if\ B_N^{Trust} ON \\ \min(KS_{De}), if\ B_N^{Trust} OFF \end{cases} \tag{19}$$

$$HB\ \left[i', j'\right] = \begin{cases} 1,\ if T[i', j'] = KS_{De} \\ 0, if\ otherwise \end{cases} \tag{20}$$

The complete conceptual architecture of model BNL system is described in Algorithm 1. It is assumed that, in the BNL problem, the beacon nodes usually contact with most neighboring nodes to become part of the communication scenario from the localization purposes [38–40]. The combined system model and working of HB^2NL is presented in Figure 3 and data forwarding process is presented in Algorithm 2.

Algorithm 1: VBN Selection and Scheduling in BNL

Initialization $(F_{PoP}^{B}, N_B, N_D, N_r, N_C, N_S\, B_{Verified}^{F_f})$
Evaluate the fitness criteria and saturation of beacon nodes using Equation (5) to (5e).
Analyze the criteria of VBN using Equations (6) and (7).
$K_{last} \leftarrow K_i$
For i = 1→N_B **do**
for j = 1→N_d **do**
for k = 1→N_r **do**
for l = 1→N_c **do**
for m=1→N_s **do**
Plunge Beacon and find $\theta_i\,[j,k,l]$ for F_{PoP}^{B} update fitness $J_i\,[j,k,l]$
IF $B_{unit}^{negh} > 0$ **then**
$K_{last} \leftarrow K_i$
else if B_n^{Trust} on $\leftarrow E(BC_{cost}^{negh} = \sum_{B=1}^{B_n}(BC_{M,N} \times BC_{min}^{data})$
Calculate the cost for CRM using Equation (15).
Update $\theta_i\,[j,k,l]$ according to the current position of B_H
Re-calculate F_{PoP}^{B} using Equation (5)
else if
Aggregate the negh. cost using std. Deviation
Plunge Beacon and planned in that direction.
end for
end for
end for
end for
Calculate maximization using Equation (11) and update the CRM function
End for
End IF
Elimination-dispersal step using Equation (20) BFA and LFA.
Start: BFA for maximum in iteration and LFA for maximum Scheduling
End: BFA and LFA
$BC_{Min}^{Data} \leftarrow$ Transaction
Sch (B) $\leftarrow$ **best**
This process continues until all blockchain enabled IoUTs nodes are scheduled and localized.

Algorithm 2: HB^{2}NL Forward (pkt)

Input: Casual (0, 1), initializes and evaluate the Equation (16)
Output: **P_{hgh}, P_{low}, P_{th}, *RREQ pkt*** forwarding probability, Threshold to forwards ***RREQ pkt, TBN***
START
If *Pkt.BID* previously received | | **P.Fwd(Pkt)** == Weak **then**
Discard **(Pkt);**
End If
If $L_{oc}B$ = Source-Zone **then**
Else if $L_{oc}BH < L_{oc}B$ (Pkt.$L_{oc}B$ **then**
Pkt.$L_{oc}B$=$L_{oc}HB$
Transmission(pkt)
Else if Discard (Pkt)
End if
IF $L_{oc}HB \leq \boldsymbol{B_n^{Trust}ON}$ **($\boldsymbol{B_n^{Trust}ON}$) then**
Pkt.src.RREQ = $\boldsymbol{Loc_B^{negh}}$BC-Validators /* The RREQ is still in BC-Minors */
Else if $L_{oc}D \geq$ BC-Validators
For updating values of BC-validators in Table
$KS_{De}^{1,2} = \left[T\left[i' - 1, j'\right]\right], value\left(i' - 1\right) + T(i' - 1, i'j - List_B\left(i' - 1\right)$
$T\,[\,i', j'] = \begin{cases} \max(KS_{De}), if\ B_N^{Trust} ON \\ \min(KS_{De}), if\ B_N^{Trust}\ OFF \end{cases}$
$S\left[i', j'\right] = \begin{cases} 1, if T\left[i', j'\right] = KS_{De} \\ 0, if\ otherwise \end{cases}$
Plunge BC-Validators and calculate the cost of $\boldsymbol{E\left(B_{Verified}^{F_{f_{cost}}}\right)}$ with fitness functions
End For/IF
if $L_{oc}BC$ == 2(max(KS_{De})+min(KS_{De}), $if\ B_N^{Trust}/2$) **then**
Pkt.src.RREP = List B and List Negh.Pkt.src.RREQ = TBN (Destination)
else if Pkt.src.RREQ | | $L_{oc}BC < \infty$ **then**
$P_{th} = P_{hgh}$
else if $P_{th} = P_{low}$
else if P_{th} = Beacon (pkt)
end if
The RREQ have left the VBN and not arrive the destination zone
if casual [0, 1) $\leq P_{th}$ **then**
Pkt.L_{oc}B = L_{oc}HB
Broadcasting **(pkt)**
else
Discard **(pkt)**
end
END

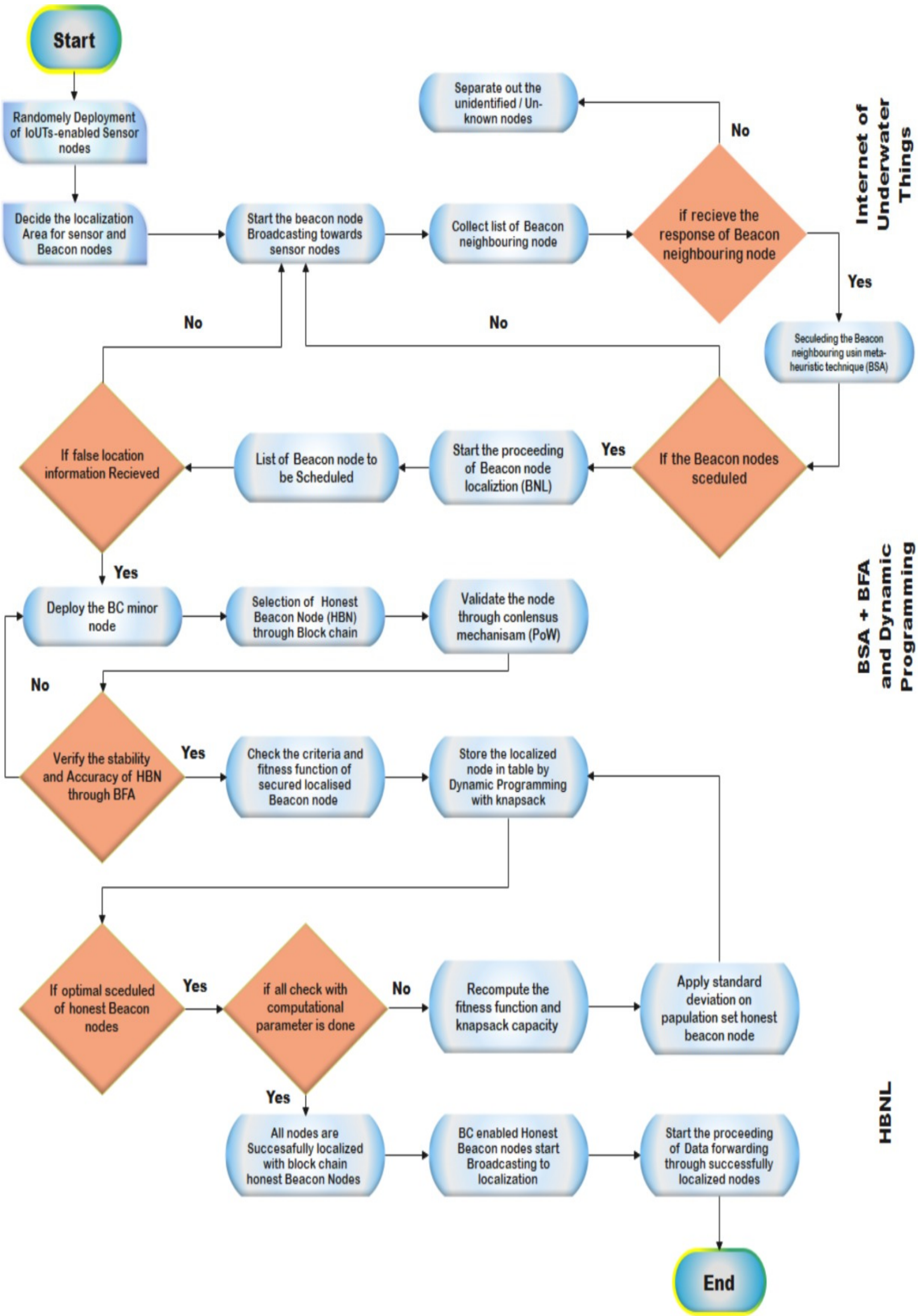

Figure 3. Layout and working flow of HB2NL algorithm.

6. Description of Algorithms

This section describes the line by line working of Algorithms 1 and 2. The first algorithm is used for selection and scheduling of the beacon nodes as VBN with reference to the evaluation of fitness criteria from populations of beacon nodes (N_B). Meanwhile, after evaluation with several domination/elimination rounds (N_d), another loop is used for calculating the population response 'N_r' for VBN. This process is continued until the firefly catching rounds (Nc) are successfully performed. The fireflies considered as underwater nodes that are used for simulation purposes. The several stochastic rounds '*Ns*' applied as meta-heuristics techniques usually follow these rounds by the home of swarm intelligence mechanisms. The plunging of the beacon nodes starts with rounds for continuously updating the fitness of the population of beacon node $F^B{}_{PoP.}$ To calculate the cost for *CRM* using update $\theta_i\ [j,k,l]$ according to the current position of B_v and, if needed, re-calculate F^B_{PoP} using Equation (5) (line 6–12). All other neighboring nodes are aggregated, and beacon nodes are plunged in that direction. In the final step, we calculate maximization using Equation (11) and update the *CRM* function from line 20, and call the optimal BFA and LFA for beacon node maximum scheduling, as shown in lines (23–28). These nodes have scheduled output and are prepared for transactions with blockchain. In such instances, only the best nodes that can optimize and send data to the destination are rescheduled.

The HB^{2}NL algorithm is especially used for the data packets forwarding process with several conditions and checks for localization of nodes. The data packets forwarding process only ends when the nodes are localized. In the same way, the localized nodes must be scheduled before data forwarding; therefore, the scheduling process is first undertaken as described in detail in Algorithm 1 and then the process of communication for underwater nodes in undertaken, as described in Algorithm 2. First of all, the *RREQ pkt* forwarding probability mechanism is used with Casual Flag values of either 0 and 1 for VBN and the totaling of beacon nodes. If any malware-vulnerable beacon node ID is received, it is directly discarded form lines 1–3. It is because these localized nodes can neither be scheduled nor localization oriented. Location is estimated from neighboring beacon nodes as counted from lines 4–9 and its trust ratio for blockchain enabled beacon nodes is estimated from lines 10–12. The blockchain minors' nodes are estimated using 'Knapsack Theory' by (small items with large weights) from Equations (19)–(20) in lines 14–16, respectively. After that, the plunging process of beacon nodes starts and all nodes are localized accordingly following the optimal mechanism of the LFA and the BFA, as shown in lines 20–30. In a special case, if the data packet is from the destination zone, its localized value is calculated accordingly (lines 30–33); otherwise, we broadcast the data packet through (lines 34–36). All the notations that are used in algorithms are listed in the Table 2.

7. Simulation Environment

The sensor and relay nodes are deployed uniformly with dimensions of 2000 m $\times$ 2000 m $\times$ 2000 m as shown in Figure 4. The connectivity of any ad hoc network is highly dependent on the mobility model it follows. As per the previous study mentioned in [41–43], the random way mobility model is widely used to simulate the performance of any mobile ad hoc network such as [44–46], fixing the source and sink nodes at the bottom and surface of the water, respectively, with coordinates (80, 90,100) and (10, 20, 30). To calculate the value of energy consumption, we use the 'Tx' Power 'Rx' Power and 0.007 W, respectively. Each node initially has an energy of 1000 joules which is enough for medium and large-scale networks. The source node will send the data with 58 bytes per two seconds. This mobility model is selected with randomly selected speed and destination from a uniform distribution (f-max speed). After successfully reaching the destination, every node selects the new destination and speed. To build the high mobility scenario, the pause time is set to 0. Phgh = 1.0 and Plow = 0.3, which all are experiment values. Table 3 summarizes the simulation parameters' value.

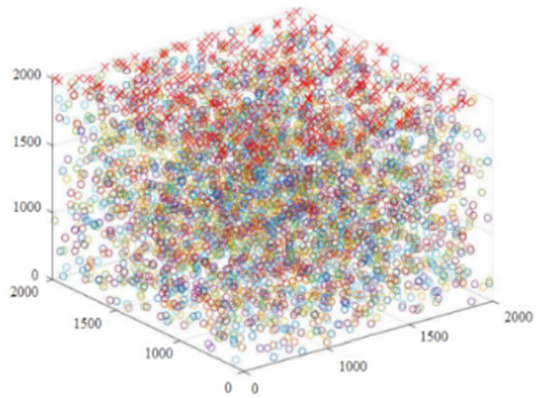

Figure 4. Nodes Deployment in dimension of 2000*2000*2000.

Table 3. Simulation Parameters and their Values.

Simulation Parameter	Value
Network Simulator	NS-3 (v3.35)
Topology Size	2000 m × 2000 m × 2000 m
Initial Energy	100 J
Acoustic Network Speed	1500 m/s
Number of Nodes	700 (including Sinks)
Transmission range	200 m
Data packet size	50 B
Beacon message size	54 B
Bandwidth	2Mbps
Traffic Type	CBR
Packet Size	512 bytes
Previous Hash	16 bytes
Block Header/Block Size	80/8 bytes
Link Type of Queue	Queue Drop Trail

8. Simulation Results

The suggested scheme's performance is validated in this section using simulation data and the results are discussed thereafter. To validate the preliminary results, we take the following parameters: localization accuracy, node losses, end-to-end delay, energy tax and beacon-based broadcasting error. Our preliminary results concern the evolving of a bunch of 300 nodes until it reaches 550 according to the simulation scenario environment. Inside the evaluation: the number of rounds for energy exhausted, number of received packets, surviving nodes, packet delivery ratio, number of successfully received packets with increased the quality of nodes, energy consumption, residual energy, alive/surviving and dead nodes during broadcasting and localization scenario when localization accuracy is set against different base loads. For smooth simulation purposes and understanding the behavior under study technique, these parameters are grouped into two categories.

In Figure 5, the x-axis shows the number of nodes that as used in the experiment while the y-axis shows energy exhausted rounds. Figure 5 represents the energy exhausted during the mining of BC nodes to get VBN against LFA and the BFA output. These VBN nodes are also called verified beacon nodes (VBN). Further, the data forwarding is smooth as the number of nodes is increased. Moreover, the relationship between BNL and VBNL selection that used further beacon-based broadcasting is interlinked. This pattern with increasing number of nodes from 500 to 520 can be observed in Figure 5 and it reached

540 with increasing trend. Our findings show that the increasing trends of the number of nodes do not sufficiently impact the energy exhausted. Figure 6 represents the behavior of number of received packets vs. number of rounds that are being recorded. The x-axis shows that the total number of received packets for VBNL is maximum. It also recorded the pattern when the rounds are increased and the packets recounts also rapidly increased; therefore, a directly proportional relation exists between these two variations. The impacts of alive nodes and dead nodes are shown in Figures 7 and 8, respectively. Similarly, the PDR is represented in Figure 9. From Figure 10, it can be observed that one third of the total number of nodes (almost 270) has survived during simulation, for example, if 1200 rounds are applied, only 400 nodes survived rest of the simulation. The energy consumption and residual energy have been analyzed in Figures 11 and 12, respectively. The energy is measured in joules (j) for beacon broadcasting and data forwarding processes with respect to 900, 1000 and 1100 rounds as depicted in Figure 13. In order to evaluate the performance of the system, we take different network loads and record the waiting time values when a BC functioning are onboard. It is interesting to know that, regarding the different loads the node losses and localization accuracy is not much disturbed while E2E delay has a slight impact on the overall performance of the proposed scheme. In Figure 13, the waiting time was recorded as 5 and 5.5 h while the additional waiting time of 1 h to its previous value for localization accuracy, E2E delay, and node loses are observed.

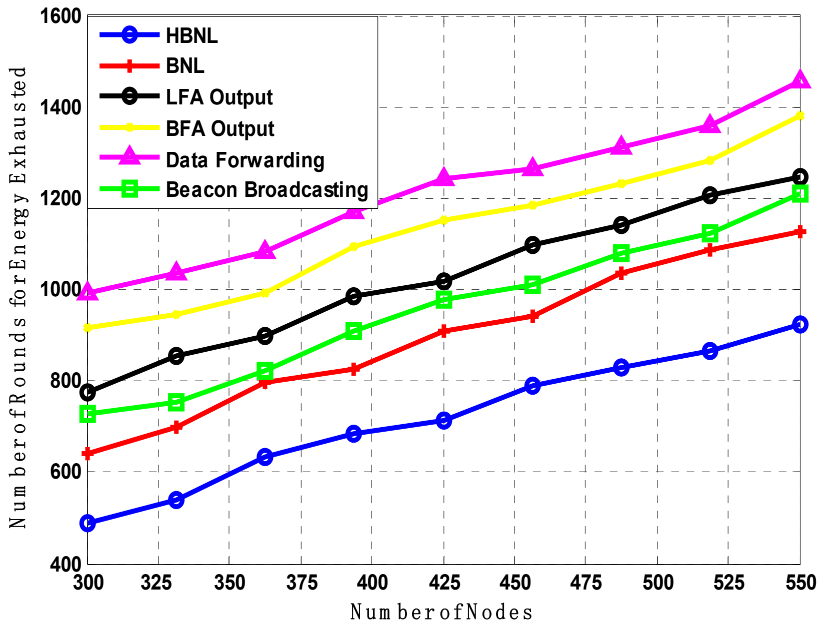

Figure 5. Evaluation of Energy Exhausted.

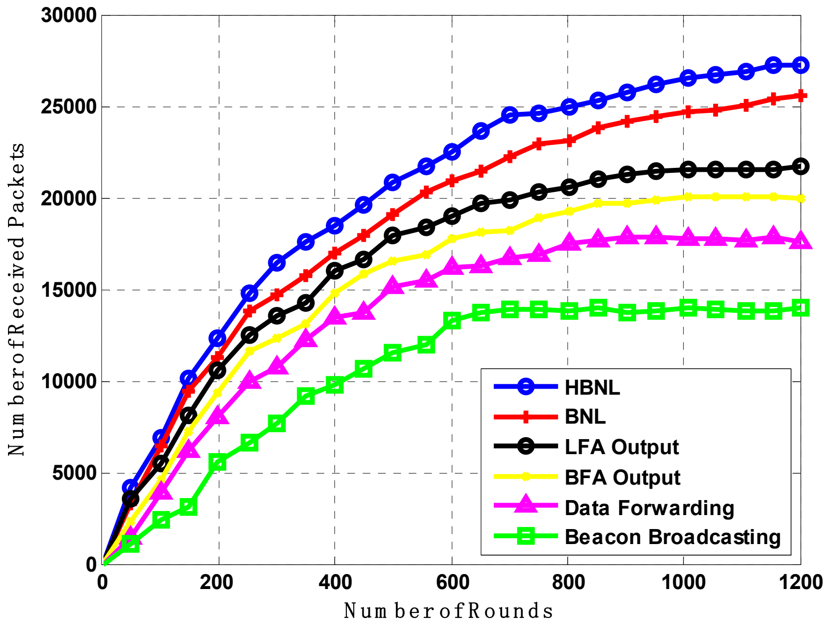

Figure 6. Number of received packets.

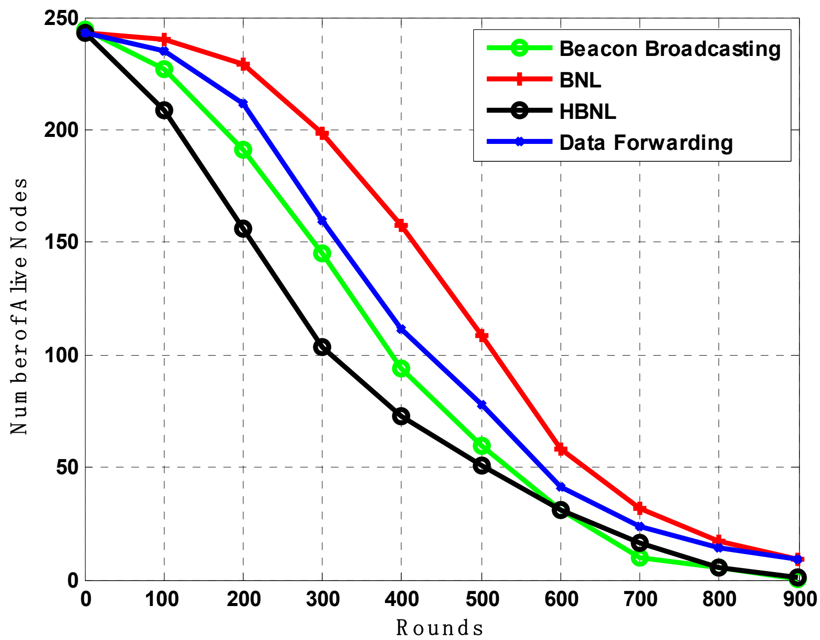

Figure 7. Analysis of alive nodes.

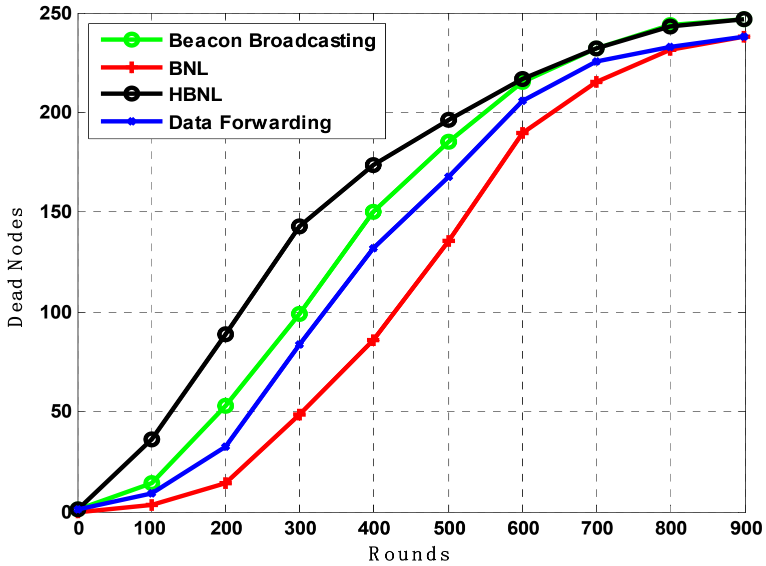

Figure 8. Analysis of dead nodes.

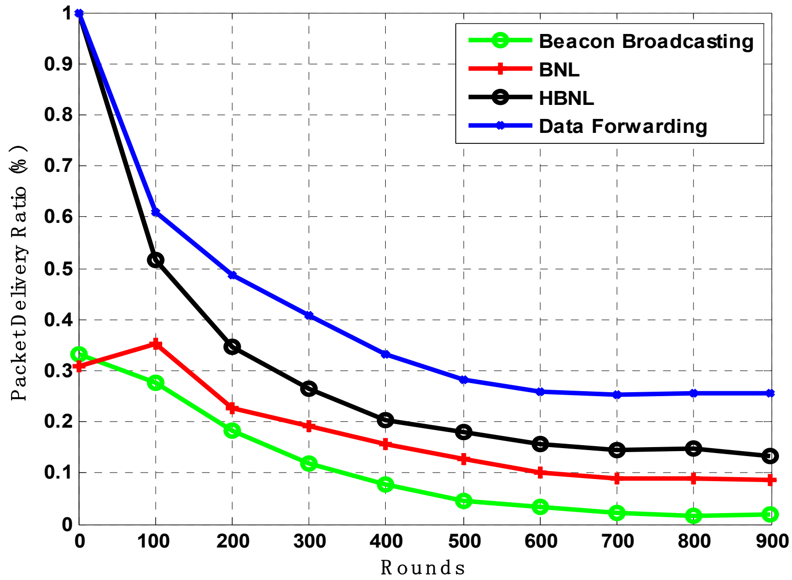

Figure 9. Analysis of PDR.

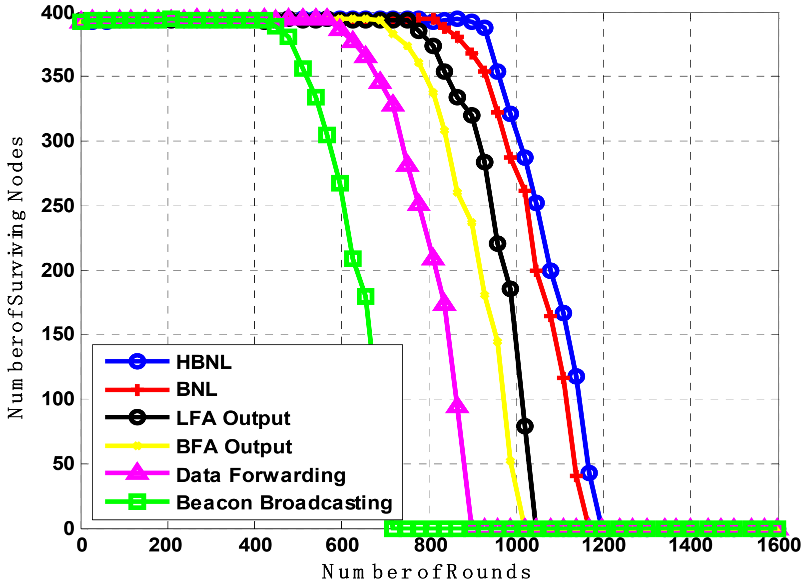

Figure 10. Analysis of surviving nodes.

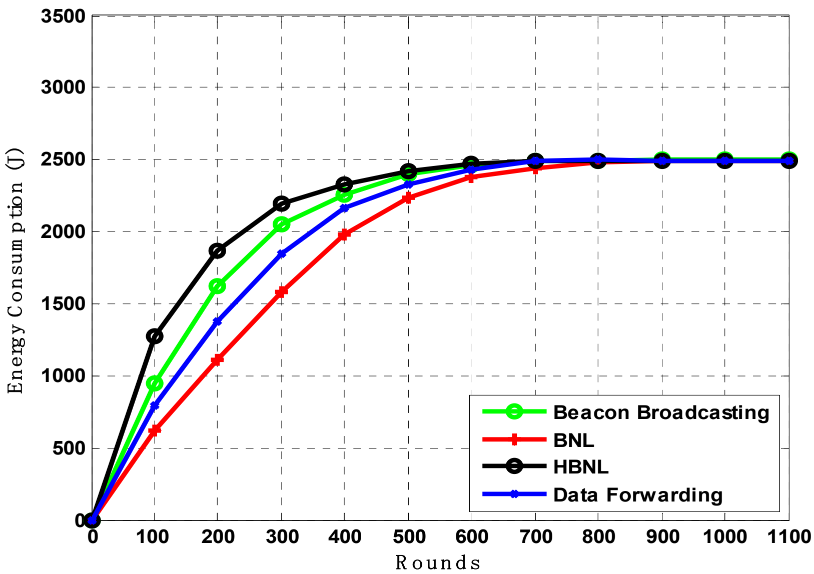

Figure 11. Energy consumption.

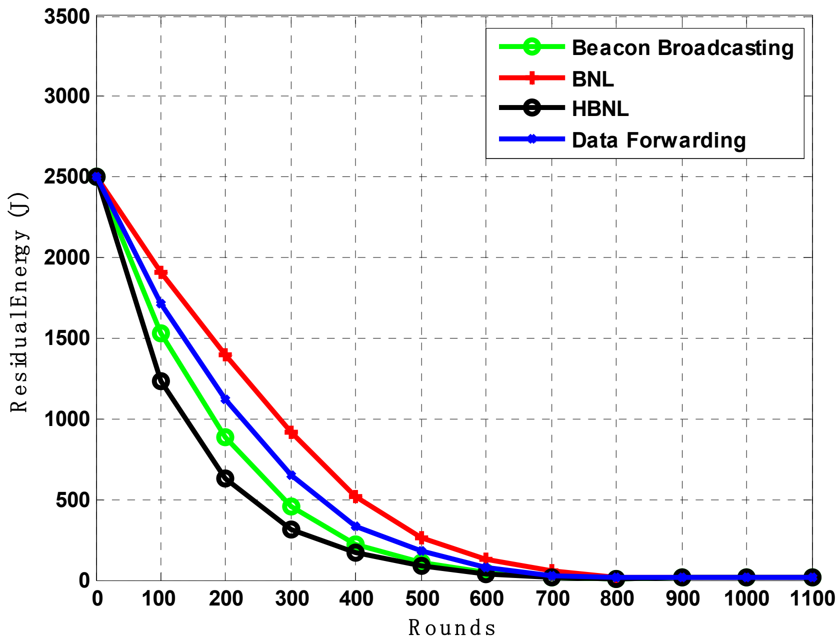

Figure 12. Residual energy.

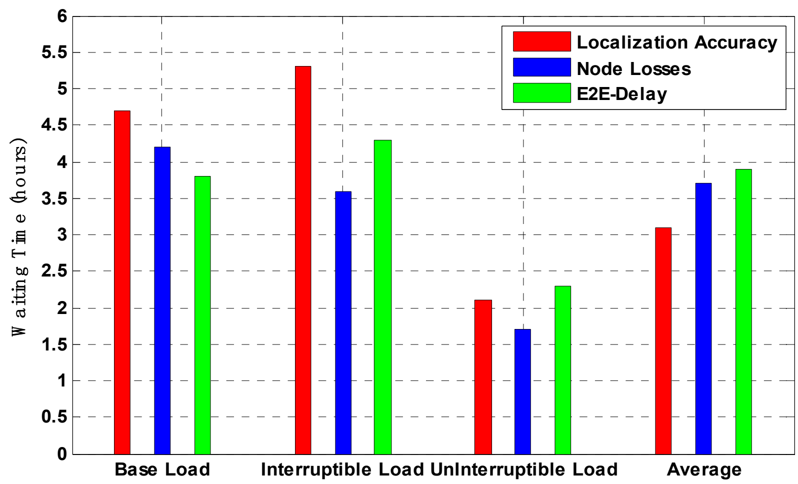

Figure 13. Analysis of waiting time.

9. Conclusions

The purpose of this study is to provide a comprehensive view and provide authentication of nodes on state-of-the-art BC learning practices in underwater areas. The major problem that was addressed is localization problems including decentralization, and beacon node localization for the identification of nodes, as well as the authentication of Internet of Underwater Things (IoUTs) objects and unreliable beacon nodes. According to our study, the overall value of energy expended for 400 nodes is 1400 rounds, while the value for 550 nodes is not much more, calculated as 1450 rounds. Similarly, the suggested technique may accomplish the 25,000 and 28,000 packets received for 600 and 1200 cycles, respectively. The dead nodes/alive nodes ratios are also satisfactory for 200 nodes that have reached the value of 900 rounds respectively. The ratio of PDR is achieved at about 0.9% for 800 rounds and it remained the same for the surviving nodes for beacon-based broadcasting. The value of residual energy is the same for all parameters at 2800 J. The waiting time analyses for base load, interruptible load and uninterruptable loads are 3.5 h, 5 h and 2 h, respectively, for measuring the localization error, but the average value is 3 h for all evaluated terms in different base loads, which is satisfactory performance for the large-scale networks. The proposed hybrid algorithm and regulating method for accessible energy sources would enable customers to reduce localization errors by reducing costs and minimizing reliance on surrounding nodes. For future work, we intend to experiment on the IoUTs inside the seabed against different parameters.

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