How to Cite:
Abd Alsharify, F. H.., & Hassan, Z. A. H. (2022). Optimization of complex system reliability: Bat algorithm based approach. *International Journal of Health Sciences*, *6*(S1), 14226–14232.
https://doi.org/10.53730/ijhs.v6nS1.8637

Optimization of complex system reliability: Bat algorithm based approach

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***Abstract*---**The issue of optimizing the reliability of complex networks is one of the contemporary issues, which has evolved with the development of methodologies for solutions with the development of modern engineering technology. Algorithms that mimic nature are among the most powerful algorithms used in optimization . In this study, the bat algorithm was presented to obtain the best reliability for a complex network that was selected at the lowest possible cost using three different cost functions, the logarithmic, the exponential and the tangent functions. Where we got different results according to the cost function used and the comparison was made between those results and we were found that the result of the logarithmic function is the best.

***Keywords*---**complex system reliability, modern engineering technology, logarithmic function.

1. Introduction

Reliability theory was established in particular, on probability theory and statistics, for a systematic and accurate analysis of functional problems in products in order for the product to be reliable, and reliability aims to analyze and evaluate the product's ability to perform its required functions in a specific time. As technology evolves and advances, the complexity of modern engineering systems increases and at the same time consumer expectations of high functionality, high performance and high reliability increase, resulting in increased challenges and opportunities. Then, although the problems of improving network reliability have been studied and analyzed, the ever-increasing

Manuscript submitted: 18 March 2022, Manuscript revised: 9 April 2022, Accepted for publication: 27 May 2022

number of new problems presents the general field of research with interesting problems that need to be solved. One of the most important goals of complex network design is to have high reliability at the lowest possible cost. The goals are often prioritized by decision makers, choosing the most important goal as an objective function and restricting the rest of the goals to acceptable limits [1-3].
Algorithms are often based on an evolutionary approach that designs an evolutionary method, or algorithms that explore phenomena of swarm intelligence. The algorithm that was used to find the best reliability he provided based on the set of solutions that explore the phenomena of swarm intelligence introduced by Yang in 2010, is called the bat algorithm. He incorporated exploration-phase balancing as well as exploit-phase balancing methods for modern swarm-based algorithms by modeling the behavior of prey-seeking bats and by exploring the phenomenon of echolocation capabilities [4,5].

2. Reliability Network

In our research, we will study the complex network shown in Figure 1. In order to find the reliability of complex network we must find all minimal paths (a minimal path is a path from which no component can be removed without disconnecting the link between the start node and the end node)
Let $P_1, P_2, \cdots, P_m$ be the complete list of all minimal paths for any complex network. Then the reliability network is given by:

$$R_N = 1 - \prod_{k=1}^{m}\left(1 - \prod_{R_j \in P_k} R_j\right) \qquad \cdots (1)$$

Now, we find the reliability of complex network in Figure (1) by using equation (1).

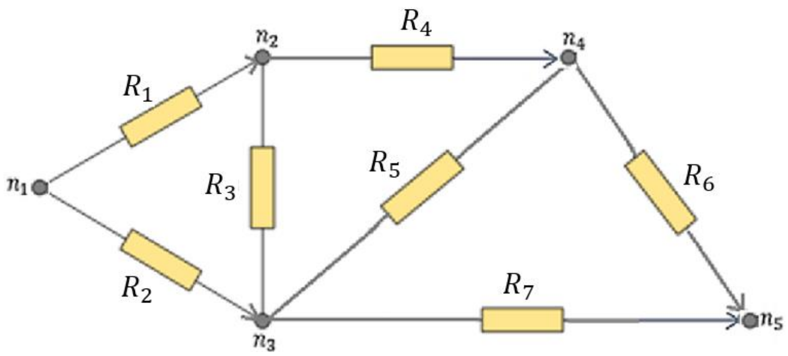

Figure 1. Complex network

The sets $P_1 = \{R_2R_7\}, P_2 = \{R_1R_3R_7\}, P_3 = \{R_1R_4R_6\}, P_4 = \{R_2R_5R_6\}$,
$P_5 = \{R_2R_3R_4R_6\}, P_6 = \{R_1R_3R_5R_6\}$, and $P_7 = \{R_1R_4R_5R_7\}$ are represent all minimal paths of complex network in Figure (1) [1,2].
So, the reliability of this complex network giving by:

$$R_N = 1 - (1 - R_2R_7)(1 - R_1R_3R_7)(1 - R_1R_4R_6)(1 - R_2R_5R_6)(1 - R_2R_3R_4R_6)$$
$$(1 - R_1R_3R_5R_6)(1 - R_1R_4R_5R_7)$$
$$R_N = R_1R_2 + R_6R_7 + R_2R_3R_4 + R_4R_5R_7 + R_1R_3R_5R_7 + R_2R_3R_5R_6$$

$$+R_1R_2R_3R_4R_5R_6 + 2R_1R_2R_3R_4R_5R_7 + R_1R_2R_3R_4R_6R_7 + 2R_1R_2R_3R_5R_6R_7$$
$$+R_1R_2R_4R_5R_6R_7 + R_1R_3R_4R_5R_6R_7 + 2R_2R_3R_4R_5R_6R_7 - R_1R_2R_3R_4$$
$$-R_1R_2R_6R_7 - R_4R_5R_6R_7 - R_1R_2R_3R_5R_6 - R_1R_2R_3R_5R_7$$
$$-R_1R_2R_4R_5R_7 - R_2R_3R_4R_5R_6 - R_2R_3R_4R_5R_7 - R_1R_3R_5R_6R_7$$
$$-R_2R_3R_4R_6R_7 - R_1R_3R_4R_5R_7 - R_2R_3R_5R_6R_7 - 3R_1R_2R_3R_4R_5R_6R_7 \cdots (2)$$

3. Bat Algorithm (BA)

The Bat algorithm is a set of guidelines proposed by Yang in 2010 that simulates the behavior of bats and how they use echolocation ultrasound in order to detect and locate prey and echo obstacles in hunting [4,5], as shown in Figure (2)

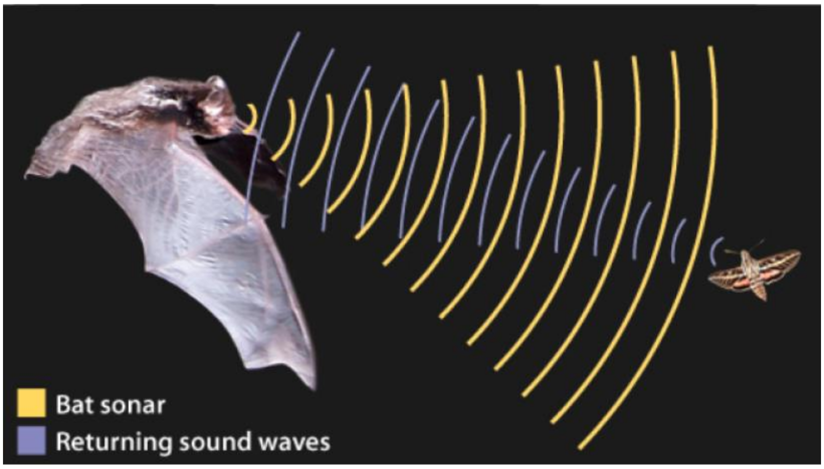

Figure 2: Sonar and Echolocation

To develop the basic concept of this algorithm, Yang proposed the following basic hypotheses:
(1) To sense the distance between bats and prey, all bats use echolocation, it also distinguishes between prey and rear barriers.
(2) Bats fly randomly with speed s_i in position p_i, fixed frequency f_{min}, wavelength $\boldsymbol{\lambda}$, and loudness A_0 to search for prey. They can vary the rate of pulse emission $r \in [0,1]$ depending on the distance of prey.
(3) Suppose the loudness varies from a small constant value A_{min} to the highest value A_0 even though the loudness varies for deferent reasons. It is necessary to specify how to update the bat position p_i and speed s_i.

The format of the update method for speed s_i^t and position p_i^t in step t is given by:

$$f_i = f_{min} + (f_{max} - f_{min})\beta$$
$$s_i^t = s_i^{t-1} + (p_i^t - p^*)f_i$$
$$p_i^t = p_i^{t-1} + s_i^t$$

here $\beta \in [0,1]$ is a random vector while p^* was signal to the modern global best solution that's positioned after evaluating all the solutions.
The nearest neighborhood to the best solution generates the optimal solution. The format of the update will be as follows:

$$p_n = p_o + \varepsilon A^t$$

here p_n is the new solution, p_o is the best old solution, $A^t \in (A_{min}, A_0)$ represents to the average of the loudness of all bats at time t, and $\varepsilon \in [-1, 1]$ is directions and lengths that are randomly generated. When the bats are closer to their prey the number of pulses emitted increases, the loudness can be adjusted to an appropriate value as follows:

$$A_i^{t+1} = \alpha + A_i^t, \; r_i^{t+1} = r_i^{t=0}(1 - e^{\gamma t})$$

The simple steps within the BA algorithm manner are presented in the flowchart shown in Figure (3) [4,5].

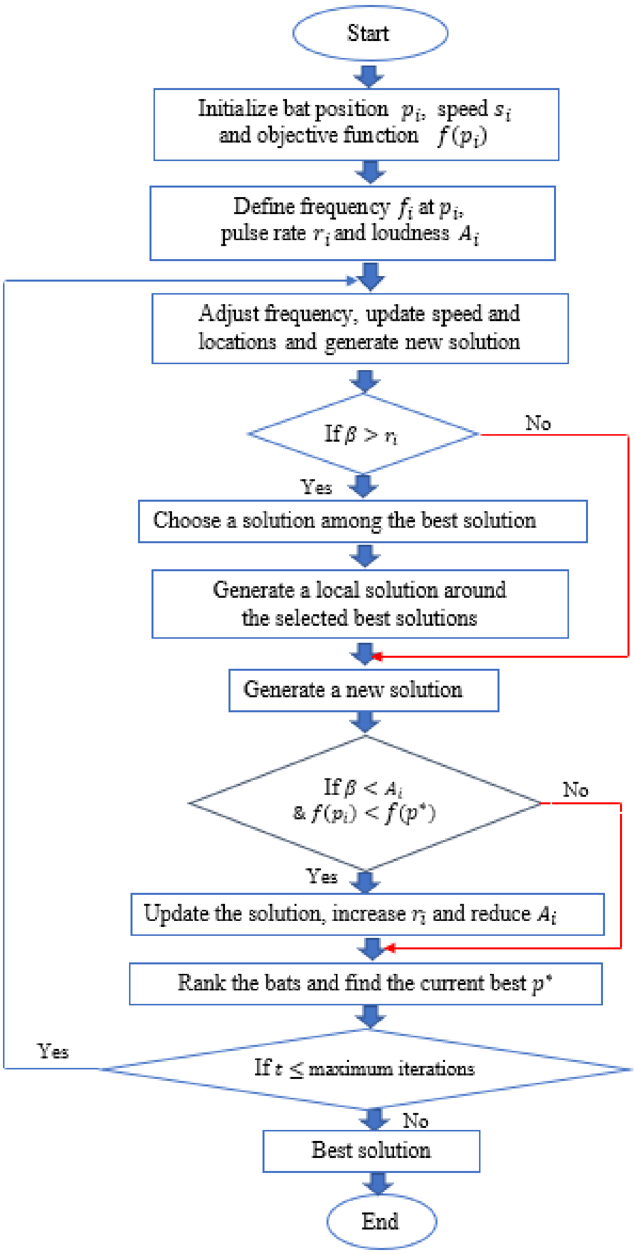

Figure 3: Flowchart of BA algorithm

Note: We used these two algorithms by 100 from iterations to find out the best reliability of a complex network in Figure 1.

4. The Models of Cost Function

Producers are interested in changing their product designs in order to reduce production costs by changing higher quality materials, reducing reprocessing costs, or other factors. Of course, the cost is directly proportional to the value of the reliability of the product, so reducing the cost should not significantly affect the value of the reliability of this product, for this reason and when designing the product, producers aspire to obtain a product with the highest value for reliability at the lowest possible cost [6,7]. Assume that C_i and R_i are the cost function and the reliability of $i-$th component, C_N is the value of total cost, R_N is the reliability network, a_i and b_i are constants such that $a_i, b_i \in (0,1)$. Then the three models of cost functions are [6]:

1. Logarithmic function: $f_1(R_i): C_i(R_i) = -a_i \ln(1-R_i)$
2. Exponential function: $f_2(R_i): C_i(R_i) = a_i e^{b_i/(1-R_i)}$
3. Tan function $f_3(R_i): C_i(R_i) = a_i(\tan 2R_i/\pi)^{b_i}$

5. Reliability Optimization

It is natural that the reliability of any product device is equal to one when it is manufactured, but it begins to decrease gradually with the increase in operating time and this results from the decreasing reliability of the device's components over time [8]. For this reason and to be close for reality, we required the reliability of each component to be within the range $0.45 \leq R_i \leq 0.95$. Our goal is to maximize the reliability network R_N represented in equation (2) at the lowest possible cost C_N. So, the mathematical formulation of the nonlinear multi-objective optimization problem takes the form:

Minimize $\left(C_N(R_i), -R_N(R_i)\right)$
Subject to: $0.45 \leq R_i \leq 0.95$
$R_N \geq R_G$
$0 < C_i \leq 2$
$C_N \leq C_G$

We choose the objective of network reliability $R_G = 0.95$ and the objective of total cost $C_G = 7$.

For consistency, we transform the maximize R_N problem into equivalent minimize $-R_N$ problem [9].

6. Computational Results of Bat Algorithm

To find out the best reliability of a complex network, we used BA by number of iterations (IN) = 500 with the aforementioned three cost functions. The results were rounded to three decimal places and listed in table (1)

A Summary Table of R_i, C_i, R_N and C_N by BA with all Cost Functions

i	Logarithmic function		Exponential function		Tan function	
	R_i	C_i	R_i	C_i	R_i	C_i
1	0.921	0.440	0.878	0.644	0.858	0.575
2	0.940	0.440	0.908	1.606	0.925	0.563
3	0.742	0.180	0.614	0.187	0.684	0.103
4	0.775	0.244	0.600	0.256	0.802	0.729
5	0.546	0.120	0.668	0.296	0.700	0.317
6	0.930	0.515	0.903	0.833	0.900	0.126
7	0.949	0.448	0.940	1.528	0.931	0.266
N	0.992	2.387	0.982	5.350	0.986	2.679

From table (1) we have the following notes:

(1) Best network reliability R_N was greater than 0.98 by using Bat algorithm with all cost functions which is a very acceptable value.

(2) $0.982 \leq R_N \leq 0.992$, here, the difference between largest and lowest value is 0.01 which has two indications, first one is that the value of R_N is not much affected by the cost function, and the second is that we are on the right path to convergence values.

(3) Best cost is $C_N = 2.387$, this value was done by using logarithm cost function, while the highest cost $C_N = 5.350$ when use an exponential cost function. The difference between higher and lower total costs is due to two reasons, the first is the difference in formulas of cost functions, and the second is random selection of values for constants a_i and b_i.

7. Conclusions

The results of the bat algorithm with the three cost functions, despite the difference between their values, showed that it can be relied upon to improve the reliability of complex networks at a low cost. It turned out that the best value for reliability and the lowest cost was by using the bat algorithm with the logarithmic function.

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