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Bat and Grey Wolf Algorithms to Optimize Complex Network Reliability

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Abstract. This paper use two contemporary optimization algorithms inspired by nature to optimize the reliability of complex networks. The first one is the Bat (BA) algorithm that simulates the behavior of bats to echo-locate prey and barriers while the second simulates the command hierarchy and style of hunting mode of gray wolves which is called Grey wolf optimization (GWO) algorithm. To find out the best reliability with the lowest cost, we used five different cost functions whose are logarithm, exponential, exponential with feasibility factor, power and tan functions with these two algorithms, and we got different results. A comparison was made between the results of two algorithms, in addition to discussing the results obtained using five cost functions with two algorithms.

INTRODUCTION

The issue of optimizing the reliability of complex networks is one of the contemporary issues, which developed in conjunction with the development of methodologies for solutions in the era of the development of modern engineering technology. The improvement of modal optimization techniques to the workable purpose of attaining the topmost reliability below different physical and pecuniary constraints, has kept studying of clinical improvement [1-3,16,20]. The mission of reliability optimization requires the conceptualization of selection variables, constraints, and single or more than one capability that describe the general overall performance of an engineering design trouble for any product, and a try and discover the overall values of choice variables that yield preferred targets. Whether expressed in mathematical terms or not, each product design problem has schematic objectives that need to be changed to meet some appropriate requirement.

Researchers working in the broader discipline of mathematical programming are constantly creating and developing new algorithms to solve larger and more difficult problems, and to do so more efficiently than before [1,3,19,18,22]. Yang is one of those researchers who managed in 2010 to simulate the behavior of bats to locate prey/food and barriers, and came up with the bat algorithm (BA) [1-3]. The second algorithm that turned into used in this study is the grey wolf set of rules (GWO), it's miles one of the new meta-optimization algorithms provided via Mirjalili in 2014. This algorithm is inspired by the use of social hierarchy and the way gray wolves search for their prey [3-6]. We used those two algorithms with five cost functions (logarithm, exponential, exponential-feasibility, power and tan) to optimization complex networks reliability at the lowest possible cost and we got the best reliability and the lowest cost. The results of these two algorithms with five cost functions were excellent, as will be seen later.

NETWORKS RELIABILITY

To calculation the reliability of any complex network we want to convert it to an easier network, as if we turn it into a network whose components are related in a series or parallel manner. The reliability of a series and parallel networks with m components are respectively:

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$$R_N = \prod_{i=1}^{m} R_i \tag{1}$$

$$R_N = 1 - \prod_{i=1}^{m}(1 - R_i) \tag{2}$$

Here R_N represents to the reliability network and R_i is the reliability of the component i [6,8,11,17,23,24]. From equations (1) and (2) we will compare the reliability of each complex network with p minimum paths that is given via:

$$R_N = 1 - \prod_{k=1}^{p}\left(1 - \prod_{j=\alpha}^{\omega} R_j\right) \tag{3}$$

Here α is the index of first component and ω is the index of last component of a minimal path k. now, the reliability of a complex network in Fig. 1 below can be calculated by equation (3).

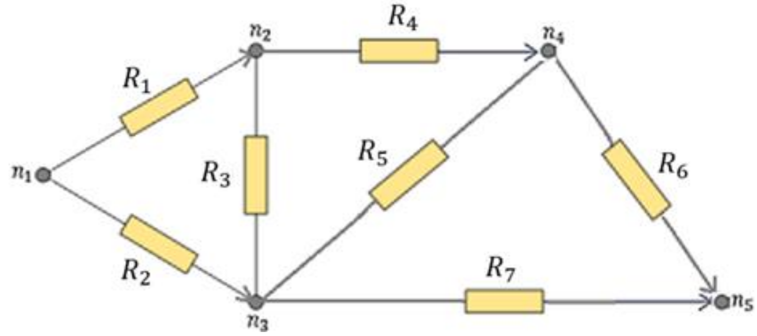

FIGURE 1. Complex network

The sets:

$$P_1 = \{R_2R_7\}, P_2 = \{R_1R_3R_7\}, P_3 = \{R_1R_4R_6\}, P_4 = \{R_2R_5R_6\}, P_5 = \{R_2R_3R_4R_6\}, P_6 = \{R_1R_3R_5R_6\},$$

$$P_7 = \{R_1R_4R_5R_7\} \text{ and } P_8 = \{R_2R_3R_4R_5R_7\}$$

Are represent all minimum paths of a network in Fig. 1 [9]. So, the network reliability is given by:

$$R_N = 1 - (1 - R_2R_7)(1 - R_1R_3R_7)(1 - R_1R_4R_6)\,(1 - R_2R_5R_6)\,(1 - R_2R_3R_4R_6)(1 - R_1R_3R_5R_6)$$

$$(1 - R_1R_4R_5R_7)(1 - R_2R_3R_4R_5R_7) \tag{4}$$

Note: When the $i-$th component succeeds, then $R_i = 1$ and when it fails, then $R_i = 0\ \forall\ i = 1, \cdots, 7$, these leads to $R_i^n = R_i$ [7,9,11].
By use the note above, equation (4) becomes as the following polynomial:

$$R_N = R_1R_2 + R_6R_7 + R_2R_3R_4 + R_4R_5R_7 + R_1R_3R_5R_7 + R_2R_3R_5R_6 + R_1R_2R_3R_4R_5R_6 + 2R_1R_2R_3R_4R_5R_7$$

$$+R_1R_2R_3R_4R_6R_7 + 2R_1R_2R_3R_5R_6R_7 + R_1R_2R_4R_5R_6R_7 + R_1R_3R_4R_5R_6R_7 + 2R_2R_3R_4R_5R_6R_7$$

$$-R_1R_2R_3R_4 - R_1R_2R_6R_7 - R_4R_5R_6R_7 - R_1R_2R_3R_5R_6 - R_1R_2R_3R_5R_7 - R_1R_2R_4R_5R_7$$

$$-R_2R_3R_4R_5R_6 - R_2R_3R_4R_5R_7 - R_1R_3R_5R_6R_7 - R_2R_3R_4R_6R_7 - R_1R_3R_4R_5R_7$$

$$-R_2R_3R_5R_6R_7 - 3R_1R_2R_3R_4R_5R_6R_7 \quad (5)$$

BAT ALGORITHM

Bat algorithm is a set of guidelines suggested by Yang in 2010 that simulates the behavior of bats for echolocation in hunting. 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 v_i in position x_i, fixed frequency f_{min}, wavelength λ, and loudness A_0 to search for food or 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 different reasons. It is necessary to specify how to update the bat position x_i and speed v_i.

The format of the update method for speed v_i^t and position x_i^t in step t is given by [1-3]:

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (6)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x^*)f_i \quad (7)$$

$$x_i^t = x_i^{t-1} + v_i^t \quad (8)$$

Here $\beta \in [0,1]$ is a random vector while x^* 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:

$$x_n = x_o + \varepsilon A^t \quad (9)$$

Here x_n is the new solution, x_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 [1-3]. 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:

$$A_i^{t+1} = \alpha + A_i^t,\ r_i^{t+1} = r_i^{t=0}(1 - e^{\gamma t}) \quad (10)$$

The simple steps within the BA algorithm manner are presented in the flowchart shown in Fig. 2.

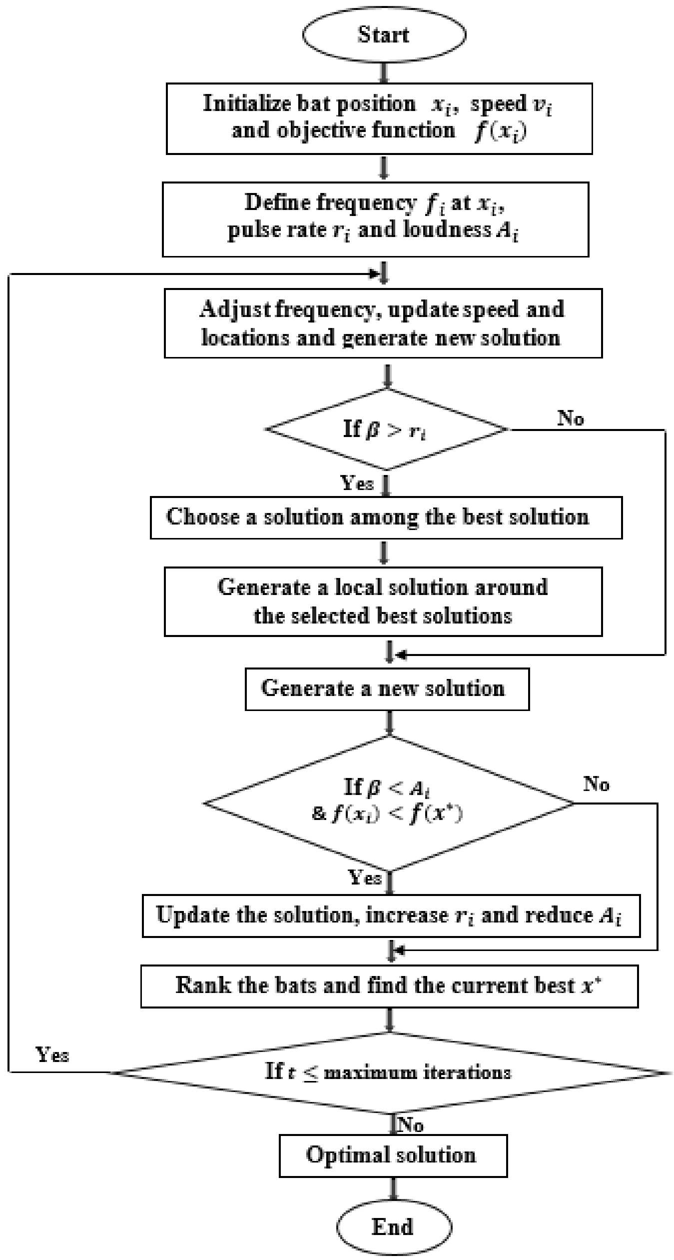

FIGURE 2. Flowchart of BA algorithm

GREY WOLF (GWO) ALGORITHM

Grey wolf algorithm is one of modern meta-optimization algorithm, which turned into delivered by Mirjalili in 2014 and advanced by Gholizadeh in 2015 to clear up an optimization hassle of double-layer networks. GWO set of rules is inspired with the resource of social hierarchy and the smart hunting method of grey wolves. Mirjalili described the behavior of gray wolves in search of prey as follows [3-6]:

$$\overrightarrow{B} = \left| \overrightarrow{C} . \overrightarrow{X_p}(t) - \overrightarrow{X}(t) \right| \tag{11}$$

$$\overrightarrow{X}(t+1) = \overrightarrow{X_p}(t) - \overrightarrow{A}.\overrightarrow{B} \tag{12}$$

Here t is an iteration number, $\overrightarrow{X_p}$ is a vector of the prey's positions, $\overrightarrow{X}$ is a vector of the grey wolf's positions, $\overrightarrow{B}$ is a calculated vector used to specify a new position of the grey wolf, while $\overrightarrow{A}$ and $\overrightarrow{C}$ are coefficient vectors can be found from an equation below

$$\overrightarrow{A} = 2\overrightarrow{a}.\overrightarrow{r_1},\ \overrightarrow{C} = 2\overrightarrow{r_2} \tag{13}$$

Here $\overrightarrow{a}$ is a vector set to decrease linearly from 2 to 0 over the iterations, $\overrightarrow{r_1}$ and $\overrightarrow{r_2}$ are random vectors in $[0,1]$. To express the hunting process of gray wolves, suppose that α (a filter for the best solution), β and δ have knowledge of the likely location of prey. Thus, the three best solutions achieved so far are saved and this forces the rest of the wolves to update their positions to achieve the best place in the decision space. This hunting behavior can be simulated by [3-6]:

$$\overrightarrow{B_\alpha} = \left|\overrightarrow{C_1}.\overrightarrow{X_\alpha} - \overrightarrow{X}\right|, \overrightarrow{B_\beta} = \left|\overrightarrow{C_2}.\overrightarrow{X_\beta} - \overrightarrow{X}\right|, \overrightarrow{B_\delta} = \left|\overrightarrow{C_3}.\overrightarrow{X_\delta} - \overrightarrow{X}\right| \tag{14}$$

$$\overrightarrow{X_1} = \overrightarrow{X_\alpha} - A_1.(\overrightarrow{B_\alpha}), \overrightarrow{X_2} = \overrightarrow{X_\beta} - A_2.(\overrightarrow{B_\beta}), \overrightarrow{X_3} = \overrightarrow{X_\delta} - A_3.(\overrightarrow{B_\delta}) \tag{15}$$

The simple steps within GWO algorithm manner are presented in the flowchart shown in Fig. 3.

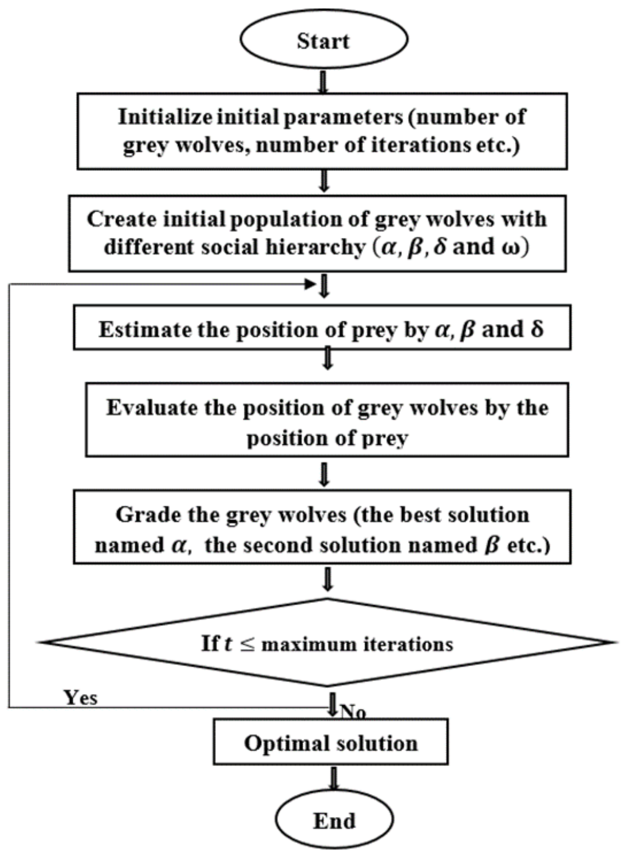

FIGURE 3. Flowchart of GWO algorithm

Note: We used these two algorithms by 500 from iterations to find out the optimal reliability of a complex network in Fig. 1.

THE MODELS OF COST FUNCTIONS

Manufacturers change their product designs for the lowest possible cost by changing higher quality materials or reducing reprocessing costs, administrative fees, or other factors. Naturally, the cost will increase as the assigned reliability approaches the most achievable reliability. This is the value of reliability that is handled asymmetrically with an increase in cost but it is never actually reached. Cost increases because custom reliability is based on the minimum or present value of reliability. The reliability of the components should not depend on lower values than they really were. Depending on the optimization, the reliability of the component may not be needed from its current value, but it will not decrease [10,12,13].

Assume that $C_i(R_i)$ is the cost function of a component i, R_i is the reliability of a component i, C_N is the value of total cost , R_N is the reliability network, a_i, b_i are constants such that $a_i, b_i \in (0,1)$ and $F_i \in (0,1)$ is the feasibility factor of a cost function for the component i. Then the five models of five cost functions are [12-15,21]:

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. Exponential function with feasibility factor $f_3(R_i)$: $C_i(R_i) = e^{(1-F_i)(R_i - R_{i,min})(R_{i,max} - R_i)}$
4. Power function $f_4(R_i)$: $C_i(R_i) = a_i {R_i}^{b_i}$
5. Tan function $f_5(R_i)$: $C_i(R_i) = a_i(\tan 2R_i/\pi)^{b_i}$

USE BA AND GWO ALGORITHMS TO REACH THE OPTIMAL SOLUTION

The results of the two algorithms were calculated using MATLAB R2020a in COM. with a device (Intel(R) Core (TM) i7-7500U CPU @ 2.70GHz 2.90 GHz RAM 12 GB VGA 920M 4GB). The results of BA algorithm with cost functions fixed in Table 1. We note that the best reliability when using BA algorithm with f_2 and f_5, while the lowest cost was when using the tan as a cost function.

TABLE 1. Summary table for optimal values of R_i, C_i, R_N and C_N by BA algorithm

i	$f_1(R_i)$		$f_2(R_i)$		$f_3(R_i)$		$f_4(R_i)$		$f_5(R_i)$	
	R_i	C_i	R_i	C_i	R_i	C_i	R_i	C_i	R_i	C_i
1	0.991	2.843	0.956	0.026	0.562	1	0.802	0.018	0.992	0.018
2	0.997	3.578	0.966	0.034	0.865	1.007	0.860	0.019	0.980	0.018
3	0.561	0.494	0.654	0.012	0.741	1.040	0.738	0.011	0.902	0.012
4	0.898	1.373	0.945	0.024	0.813	1.008	0.682	0.019	0.932	0.019
5	0.770	0.884	0.826	0.018	0.982	1.002	0.613	0.016	0.864	0.016
6	0.519	0.439	0.979	0.029	0.992	1	0.995	0.011	0.989	0.011
7	0.861	1.186	0.995	0.254	0.993	1	0.996	0.013	0.998	0.013
N	0.998	10.797	0.999	0.397	0.997	7.057	0.998	0.107	0.999	0.107

While, the results of GWO algorithm listed in Table 2 which tell us that the reliability of the complex network was equal to 0.999 when using the GWO algorithm with f_1, f_2, f_4 and f_5, and it was equal to 0.997 with f_3 while the lest total cost C_N is in power function.

TABLE 2. Summary table for optimal values of R_i, C_i, R_N and C_N by GWO algorithm

i	$f_1(R_i)$		$f_2(R_i)$		$f_3(R_i)$		$f_4(R_i)$		$f_5(R_i)$	
	R_i	C_i	R_i	C_i	R_i	C_i	R_i	C_i	R_i	C_i
1	0.998	4.017	0.983	0.037	0.562	1	0.995	0.019	0.998	0.121
2	0.998	3.924	0.986	0.046	0.865	1.007	0.995	0.014	0.998	0.143
3	0.657	0.644	0.950	0.016	0.741	1.036	0.995	0.015	0.547	0.093
4	0.544	0.472	0.950	0.023	0.813	1.008	0.995	0.014	0.547	0.093

$\boldsymbol{f_1(R_i)}$	$\boldsymbol{f_2(R_i)}$	$\boldsymbol{f_3(R_i)}$	$\boldsymbol{f_4(R_i)}$	$\boldsymbol{f_5(R_i)}$	$\boldsymbol{f_1(R_i)}$	$\boldsymbol{f_2(R_i)}$	$\boldsymbol{f_3(R_i)}$	$\boldsymbol{f_4(R_i)}$	$\boldsymbol{f_5(R_i)}$	$\boldsymbol{f_1(R_i)}$
$\boldsymbol{R_i}$	$\boldsymbol{C_i}$	$\boldsymbol{R_i}$	$\boldsymbol{C_i}$	$\boldsymbol{R_i}$	$\boldsymbol{R_i}$	$\boldsymbol{C_i}$	$\boldsymbol{R_i}$	$\boldsymbol{C_i}$	$\boldsymbol{R_i}$	$\boldsymbol{R_i}$
5	0.623	0.585	0.950	0.026	0.983	1.002	0.995	0.011	0.547	0.116
6	0.589	0.534	0.983	0.039	0.992	1	0.995	0.015	0.998	0.165
7	0.764	0.869	0.986	0.025	0.992	1	0.995	0.020	0.998	0.100
N	0.999	11.045	0.999	0.212	0.997	7.053	0.999	0.108	0.999	0.831

DISCUSS THE RESULTS

As shown in Table 3, the least reliability of the network was 0.997 and the highest cost was 11.045, while the highest reliability was 0.999 and the lowest cost was 0.107. The values in Tables 1 and 2 show us that the reliability of the complex network R_N was greater than 0.99 by using two algorithms with all five cost functions. These values for network reliability considered as an excellent value. Through Tables 1 and 2, there is an interesting note that when using f_3 with two algorithms, C_i is equal to or very slightly greater than one for all i, and this means that the values of $R_i - R_{i,min}$ and $R_{i,max} - R_i$ terms are either zero or very close to zero, and we understand from this that $R_i, R_{i,min}$ and $R_{i,max}$ are almost equal values $\forall\ i = 1, \cdots, 7$.

TABLE 3. Summary table for optimal values of R_N and C_N by BA and GWO algorithms

Cost Functions	**BA**		**GWO**	
	$\boldsymbol{R_N}$	$\boldsymbol{C_N}$	$\boldsymbol{R_N}$	$\boldsymbol{C_N}$
$f_1(R_i)$	0.998	10.797	0.999	11.045
$f_2(R_i)$	0.999	0.397	0.999	0.212
$f_3(R_i)$	0.997	7.057	0.997	7.053
$f_4(R_i)$	0.998	0.107	0.999	0.108
$f_5(R_i)$	0.999	0.107	0.999	0.831

CONCLUSION

The results of two algorithms BA and GWO (despite their differences) has been shown that, they can be relied upon to optimization complex networks reliability at a low cost. The optimal reliability value at the lowest cost is by using the bat algorithm BA with tan function. Also, we obtained optimal reliability when using the GWO algorithm with the power function and with a very small difference to the value of the cost function as shown in Table 3.

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