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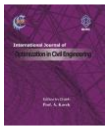

A HYBRID CHARGED SYSTEM SEARCH - FIREFLY ALGORITHM FOR OPTIMIZATION OF WATER DISTRIBUTION NETWORKS

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ABSTRACT

Water distribution networks are one of the important and costly infrastructures of cities and many meta-heuristic algorithms in standard or hybrid forms were used for optimizing water distribution networks. These algorithms require a large amount of computational cost. Therefore, the converging speed of algorithms toward the optimization goal is as important as the goal itself. In this paper, a new method is developed by linking the charged system search algorithm and firefly algorithm for optimizing water distribution networks. For evaluating the proposed method, some popular benchmark examples are considered. Simulation results demonstrate the efficiency of the proposed algorithm compared to others.

Keywords: water distribution system; optimal design; charged system search; firefly algorithm.

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1. INTRODUCTION

Importance of Water Distribution Networks (WDN) is increased by growing population and it should be redesigned and reconstructed after a specified period. Changing WDN is costly and therefore its optimization can play a crucial role in reducing the construction costs. WDN is a complex combination system of pipes, reservoirs, pumps and etc.; and changing in one of the components can affect the whole system. To illustrate that how components are connected to each other, a layout graph can be a good choice. Trial-and-error method is a normal and popular way to design a WDN. However, optimization can assist designer to reduce the cost and the time of designing procedure. In addition, optimization can help the

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designer to choose the best combination of pipes, nodes, and pumps among millions of possible combinations. The designer should consider some constrains in choosing the connectivity among the nodes. Often for many WDNs, designer can only choose specific diameters for pipes. Although most of the researchers worked on cost optimization of WDNs, dealing with other aspects of design, such as uncertainty is also important.

There are many equations governing the design procedure of a WDN. Most of them such as conservation of mass and energy equations have nonlinear nature. Researchers of all around the world have been dealing with the optimization of WDNs using different approached and algorithms. There are different tools for optimal designing of this type of structures and one of the tools that gains a huge popularity among experts is meta-heuristics. A huge part of equations that were being solved by a large group of trial-and-error methods are being solved by meta-heuristic algorithms as well, these days. These algorithms are fast and their efficiency is a today's challenging subject. There are many algorithms for this purpose and of course, they have their own advantages like speed or efficiency, simplicity in modeling or powerful performance base. Although, these algorithms are powerful, they can be improved as well. When the problem is complex, there are some major points like speed and efficienct searching properties that can affect the final results.

One of the first works in optimizing WDNs belongs to Alperovits and Shamir [1]. Subsequent studies are under the inspiration of this research and they tried to improve different features of the optimal design process. (Quindry *et al.* [2], Fujiwara *et al.* [3], Lancy *et al.* [4], Kesseler *et al.* [5], Fujiwara *et al.* [6]). Walski *et al.* in 1987 [7] introduced a procedure using the structured messy genetic algorithm for designing WDN problems. Su *et al.* in 1987 [8] presented a framework for a model to be used in optimization of WDNs. The model had some weak points and one of them was commercially unavailable diameter results that had to be round of. Fujiwara *et al.* in 1990 [9] discussed a heuristic method for minimizing the cost of WDNs and design it under given conditions. Former meta-heuristic algorithms were being used for optimization of WDNs were GA (Genetic Algorithm) used by Simpson *et al.* [10], PSO (Particle Swarm Optimization) developed by Suribabu *et al.* [11] and Tabu search used by Cunha *et al.* [12] and ACO (Ant Colony Optimization) applied by Maier *et al.* [13]. Supervised Charged System Search (CSS) is used for optimization of WDNs by Kaveh *et al.* [14]. Also, other CSS-based methods is presented by Sheikholeslami *et al.* [15]. Firefly algorithm with harmony search (FAHS) as a new hybrid method is also developed by Tahershamsi *et al.* [16] that are used for optimizing WDSs. The new algorithm, Tug of War, which used for optimal design and analysis of WDNs, is presented by Kaveh *et al.* [17]. In these studies, they reach near optimal solution, however their convergence speed was not low and in some cases, distance between the worst and best answer was quite wide.

While finding optimal or near-optimal solutions for real size problems is so important, requiring a high computational costs of optimization methods decreases the critical role of these methods for practical application [18]. However, the efficiency of meta-heuristic algorithms is being challenged around the world with different problems. One of the topics for this purpose is comparing the results and speed of these algorithms by applying them to benchmark problems. Comparing the hybrid form of algorithms with standard ones can be a good measure of improvements. This paper develops a new hybrid method using Charged System Search and Firefly algorithm for solving WDN problems.

2. HYBRIDIZING CHARGED SYSTEM SEARCH AND FIREFLY ALGORITHM

The hybrid of Charged System Search (CSS) and Firefly algorithm (FA) includes characteristics of both algorithms. Following sub-sections present a brief explanation of each algorithm.

2.1 Charged system search

Results of using meta-heuristic algorithms in engineering problems indicate that charge system search (CSS) algorithm works good enough for engineering problems [15]. Although it is a population-based algorithm, it has a memory to keep so-far best answers then it can use them to improve final results of optimization. As a brief explanation to show how it works, CSS can be described as follow:

- Initial positions for Charged Particles (CPs) are determined by random numbers.
- The location of CPs are evaluated as a fitness function for the problem.
- CPs are added in a memory so-called CM.
- The new location for CPs are determined as follows:

$$X_{j,new} = k_a.rand_{j1}\frac{F_j}{m_j}.\Delta t^2 + k_v.rand_{j2}V_{j,old}\Delta t + X_{j,old} \quad (1)$$

$$V_{j,new} = \frac{X_{j,new} - X_{j,old}}{\Delta t} \quad (2)$$

- After going to the next iteration, position for each CP changes and then continues from second step.
- Stopping criteria depends on problem situation [15].

2.2 Firefly algorithm

Firefly algorithm is one of the meta-heuristic algorithms that is based on light intensity differences [19]. The brighter firefly (best answer according to cost or fir function) is more attractive and helps other fireflies to move toward the best answer in the solution space. Firefly attraction is due to its brightness of firefly indicates how much the place of firefly is better according to fitness function. All of the fireflies have their own brightness and attraction due to the cost function and brighter ones attract less bright ones to themselves in combination with some random numbers to change positions of all of the fireflies. All of the fireflies are unisex and the attraction is not influenced by the sex of a firefly. The movement for a firefly that is attracted by other firefly can be formulated as:

$$\Delta x_i = \beta_0 e^{-\gamma r_{i,j}^2}(x_i - x_j) + \alpha\varepsilon_i \quad (3)$$

where r_{ij} is the distance between firefly i and firefly j, β_0 is the attractiveness at $r = 0$, the distance between any two fireflies i and j at x_i and $x_j$is the Cartesian distance , respectively and γ is a coefficient for light absorption to control the light intensity [19].

2.3 The proposed hybrid CSS-FFA

Standard CSS is one of the powerful algorithms that was used for solving different problems in its standard and hybrid forms. The results of CSS show the efficiency and good speed of the algorithm for solving different problems. Clearly, there are some weaknesses in CSS as well similar to any other algorithm and it can be upgraded. Weakness of CSS algorithm is its convergence speed. Mostly this algorithm searches the space and find the near optimum answer quickly but this takes time to reach the final optimum point. The FA is very quick in getting around the answer but it takes much time to get exactly to the specified answer. Using Firefly algorithm speeds up the convergence toward the best answer area and when the firefly algorithm slows down, the CSS algorithm increases its action while FA slowly gives the solution area to CSS algorithm to go on its way toward optimization goal.

This hybrid algorithm considers CPs of CSS algorithm as fireflies in FA. First of all, the process starts with creating random CPs and then when the algorithm goes for finding forces and velocities as described in the CSS algorithm. Then, these CPs are used by the FA (as fireflies) and the attraction of fireflies is calculated by using the values offitness function and after that the fireflies change their positions; as

$$x_{new} = x_{new-css} + k_d.\Delta x_{firefly} \tag{4}$$

$$x_{j,new} = k_a.(rand_{j,1}.\frac{F_j}{m_j}.\Delta t^2) + k_v.(rand_{j,2}.V_{j,old}.\Delta t) + k_d.\Delta x_{firefly} + x_{j,old} \tag{5}$$

Flowchart for the proposed algorithm is presented in Fig. 1.

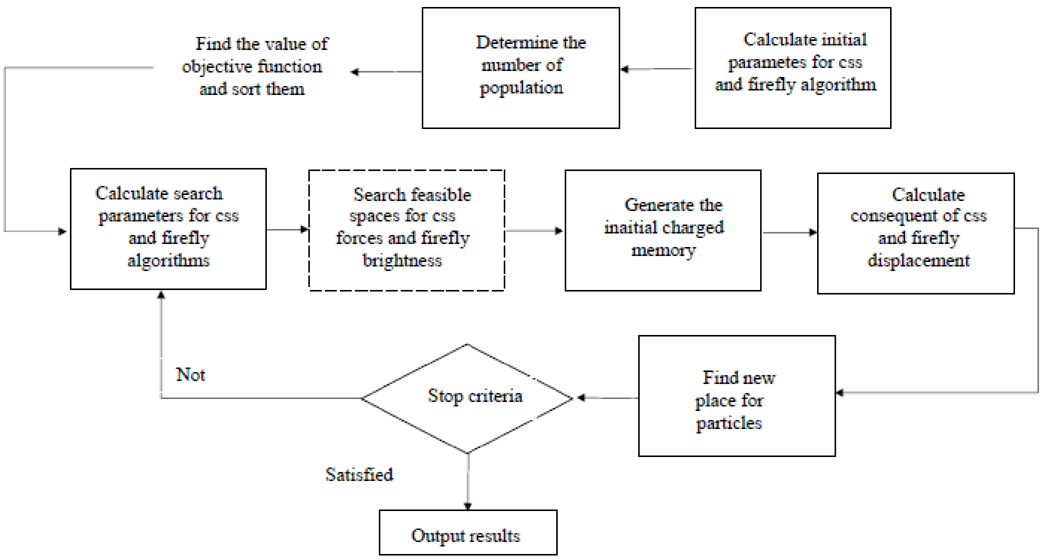

Figure 1. Flowchart for the hybrid CSS and FA

3. OPTIMIZATION OF WATER DISTRIBUTION NETWORKS USING CSS-FA

There are different ways to optimize water supply networks. Minimizing the cost of a WDN construction by determining optimum size of pipes, minimizing energy consumption and maximizing pump efficiency by finding optimum location of pumps are some familiar ones. These problems are restrained by specified pressure head for nodes and sometimes specified velocity in pipe flow that can guarantee service and safe flow with specified node demand. In this study, the hybird CSS-FA algorithm is used for optimization of water supply networks in order to minimize cost by changing pipe size. The equations for optimization and fundamentals of fluid mechanics can be written as:

Minimize:

$$f_{\cos t} = \sum_{i=1}^{np} C_{(D_i)}.L_i \qquad (6)$$

Subject to:

$$\begin{cases} \sum Q_{in} - \sum Q_{out} = \sum Q_e \\ H_j \geq H_j^{\min} \end{cases} \qquad (7)$$

in which, $C_{(Di)}$ is the cost for unit length of diameter D for pipe i and L_i is the length of pipe i and np is number of pipes used in the network. Continuity Equation is presented in Eq. (7) shows that the amount of water is being carried into network should be consumed in nodal demands.

There are different formulas for calculating head loss and the Hazen-Williams formula is one of the best known formulas regularly used for head loss calculation. The formula used in this study is Hazen-Williams formula as presented in Eq. (8):

$$h_f = \omega \frac{L}{C^{\alpha} D^{\beta}} Q^{\alpha} \qquad (8)$$

where, in metric system $\omega = 10.6668$, $\alpha = 1.85$, $\beta = 4.87$, Q is the pipe flow (m^3/s), C is the Hazen-Williams roughness coefficient which ranges from 150 for smooth walled pipes to as low as 80 for old, corroded cast iron pipes, D is diameter of pipe (m), and L is pipe length (m), [15]. Grater value for ω increases head loss and network needs larger diameter to deliver that amount of water because these can violate requirements for minimum pressure. Therefore, higher value for ω requires a more costly WDN design.

The algorithm initiates the design process by selecting initail values for calculating design variables. Then, the algorithm checks the pressure head and velocity at each node and pipe and calculates the cost of the network. After that algorithm compares the answers and finds new positiond, and the next iteration continues until the stopping criteria come true and the best answer comes out.

In order to control the constraints, a penalty approach is utilized. If constraints do not exceed allowable limits, the penalty is zero. otherwise, the amount of penalty is obtained by dividing the violation of allowable limit to the limit itself. After analyzing a model, the pressure of each node is obtained and these values are compared to the allowable limits to calculate the penalty functions as follows:

$$\begin{cases} H_j^{\min} \le H_j \rightarrow \Delta_j = 0 \\ H_j^{\min} > H_j \rightarrow \Delta_j = \dfrac{H_j^{\min} - H_j}{H_j} \end{cases} \quad j = 1, 2, ..., np \tag{9}$$

In this method, the objective function is redefined by introducing the cost function as:

$$F_{\cos t} = f_{\cos t} \cdot \left(1 + \varepsilon_1 \left(\sum \Delta_j\right)^{\varepsilon_2}\right) \tag{10}$$

The penalty function method has certain drawbacks; for example penalty parameters are dependent of problems and proper parameter tuning is necessery to converge a feasible domain. When the penalty parameters are large, penalty functions tend to be ill-conditioned near the boundary of the feasible domain and this may result in a local optimal solution or an infeasible solution. In this case, repeated trial-and-error are suggested by changing the penalty parameter until satisfactory results are obtained. Here, the constant parameters are selected considering the exploration and exploitation rate of the search domain. ε_1 is set to unity and ε_2 is selected in a way that it decreases the penalties and the variables values, as well. Thus, in the first steps of the search process, ε_2 is set to 0.5 and ultimately increased to 1.05.

4. SIMULATION AND HYBRID METHOD

The hybrid CSS-FA algorithm is coupled with the water distribution network analyze software, EPANET 2. After analyzing model by EPANET 2, the pressure for each node and velocity of flow in each pipe are resulted then the values are compared to constraint limits. EPANET 2 software is provided by the Environmental Protection Agency of United States that is a dynamic link library (DLL) of functions that allows developers to customize software for user's specific needs. The software usage process implemented in MATLAB and optimization runs were carried out on a computer with and Intel Core$_2$due, 2.66GHz processor and 4 GB RAM. A brief description of the steps that are taken for optimization of network is given below:

(1) Generate *N* CPs for starting analysis in MATLAB with random numbers. Each of CPs is a possible combination of pipelines that indicates network to be solved.

(2) Compute the network cost for each population and sort them for the processes mentioned in the CSS algorithm.
(3) Update the input file of the problem to be solved. In this type of optimization only pipe diameters are changed.
(4) Analyze network using EPANET 2 for determining node pressures and pipe flow velocities.
(5) Generate penalty function and use it in determining the cost function.

5. DESIGN EXAMPLES

There are different benchmark examples for checking the efficiency of algorithms in a water distribution network. In this study, 4 famous benchmark problems are optimized and the results compared with previous studies. The first design example is two-loop network proposed by Alperovits and Shamir [1]. The first network is a simple example of how a WDN looks like and how optimization process is done. The second example chosen to compare is the Hanoi water network proposed by Fujiwara and Khang in 1990 [9] which is made of 34 pipes and 32 nodes and a 100 m fixed head reservoir. Minimum head pressure for every node is 30 m and Hazen-Williams coefficient for all of the pipes is 130. Double Hanoi network is third design example, first proposed by Cisty in 2010 [20], which is made of two Hanoi networks with those constrains for head pressure and pipe properties. The last example presented in this study is GoYang network [21], a network for a city in Korea, which is made of 22 nodes and 30 pipes with a pump.

5.1 Example 1: A two-loop network

One of the most famous benchmark problems presented by Alperovits and Shamir [1] is the two-loop network. The network has 7 nodes and 8 pipes that are being fed by a reservoir with 210m fixed head. All pipes have fixed length of 1000 m and Hazen-wiliams coefficient of 130. Base demand and elevation of nodes are presented in Table 1. Diameters of pipes used in the network are {1, 2, 3, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22 and 24} that cost {2, 5, 8, 11, 16, 23, 32, 50, 60, 90, 130, 170, 300 and 550}.

Table 1: Nodal demands and elevations for two-loop network

Node No.	Elevation (m)	Demand (m^3/h)
1 (Reservoir)	210	-
2	150	100
3	160	100
4	155	120
5	150	270
6	165	330
7	160	200

Results show that algorithm reaches the best solution answer with a great speed. The performance of this algorithm is compared with other algorithms in Table 2.

Table 2: Comparison of presented algorithm for two-loop network

Pipe No.	Savic & Walters [22]	Abede & Slomatine [23]	Cunha & Sousa [24]	Present work
1	20	18	18	18
2	10	14	10	10
3	16	14	16	16
4	1	1	4	4
5	14	14	16	16
6	10	1	10	10
7	10	14	10	10
8	1	12	1	1
Cost ($)	420,000	424,000	419,000	419,000

5.2. Example 2: Hanoi network

The Hanoi arrangement, formerly studied by Fujiwara and Kang [9] in Vietnam is shown in Fig. 2. The cost of available pipe sizes that are determined for consumption in this network are {12, 16, 20, 24, 30, 40; in inches} that cost {45.73, 70.40, 98.38, 129.30, 180.80, 278.30; in dollar/meter}. The characteristics for pipes and nodes are presented in Table 3. The water required in this network is much higher than the accustomed demands for other ones so for satisfying these demands, the maximum velocity limitation is set to 7 m/s. The pressure limit for nodes are minimum 30 meters and length of pipes are shown in Table 4.

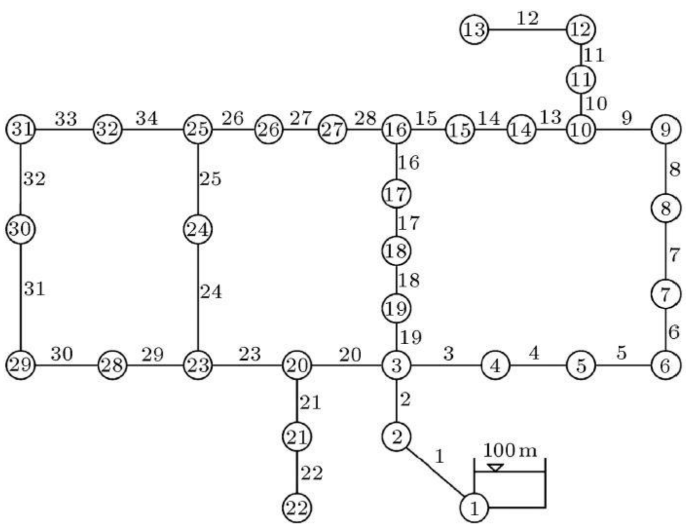

Figure 2. Hanoi network plan layout

Table 3: System data for Hanoi network

Pipe No.	Length (m)	Diameter (answer)	Node No.	Demand (m^3/h)
1	100	40	1(Reservoir)	-
2	1350	40	2	890
3	900	40	3	850
4	1150	40	4	130
5	1450	40	5	725
6	450	40	6	1005
7	850	40	7	1350
8	850	40	8	550
9	800	40	9	525
10	950	30	10	525
11	1200	24	11	500
12	3500	24	12	560
13	800	20	13	940
14	500	16	14	615
15	550	12	15	280
16	2730	12	16	310
17	1750	16	17	865
18	800	24	18	1345
19	400	20	19	60
20	2200	40	20	1275
21	1500	20	21	930
22	500	12	22	485
23	2650	40	23	1045
24	1230	30	24	820
25	1300	30	25	170
26	850	20	26	900
27	300	12	27	370
28	750	12	28	290
29	500	16	29	360
30	2000	12	30	360
31	1600	12	31	105
32	150	16	32	805
33	860	16		
34	950	24		

Table 4: Nodal Pressure head for Hanoi network

Node No.	Nodal pressure (m)
1 (Reservoir)	0
2	97.14
3	61.67
4	56.92
5	51.03
6	44.82
7	43.37
8	41.63
9	40.24
10	39.22
11	37.66
12	34.23
13	30.03
14	35.56
15	33
16	31.4
17	33.46
18	49.94
19	55.1
20	50.6
21	41.25
22	36.09
23	44.5
24	39.02
25	35.53
26	31.8
27	30.89
28	42.38
29	31.14
30	31.16
31	31.39
32	33.5

Table 5: Comparison of presented algorithm for Hanoi network

Method	Best Cost ($\$10^6$)	Average Cost	Worst cost ($\$10^6$)	No. Iteration
BLIP [25]	6.363	6.429	N/A	N/A
MSATS [25]	6.352	6.538	N/A	N/A
SSSA [25]	6.273	6.688	N/A	N/A
SCE [26]	6.220	N/A	N/A	26,402
BB-BC [27]	6.224	6.292	N/A	30,000
HBA [28]	6.232	N/A	N/A	259,000
MGA [29]	6.190	N/A	N/A	18,000
IFA-HS [16]	6.224	N/A	N/A	15,200
ACO [30]	6.134	N/A	N/A	85,600
GENOME [31]	6.081	N/A	N/A	50,000
TS [12]	6.081	N/A	N/A	40,200
CS [32]	6.081	6.195	6.224	52.890
CSHS [32]	6.081	6.107	6.160	31.800
Standard-CSs	6.081	6.251	6.292	16,440
Present work	6.081	6.217	6.278	14,600

BLIP: Binary Linear Integer Programming
MSATS: Mixed Simulated Annealing and Tabu Search
SSSA: Scatter Search Simulated Annealing
SCE: Shutted Complex Evolution
BB-BC: Big Bang Big Church
HBA: Heuristic-Based Approach
MGA: Modified Genetic Algorithm
IFA-HS: Firefly Algorithm – Harmony search
ACO: Ant Colony Optimization
Particle Swarm Optimization
GENOME: Genetic Algorithm Pipe Network Optimization
TS: Tabu Search
CS: Cuckoo search
CSHS: Cuckoo Search Harmony Search

Results of minimum cost design and number of evaluation for this network is presented in Table 5. The algorithm presented in this study achieved the best solution answer for this network, equals 6.081×10^6 by 14,600 iterations. It means convergence speed of this algorithm in comparing to other algorithms in achieving minimum solution answer is good. As shown in Table 5, best convergence speed is belong to the new hybrid method. The results of other algorithms in optimizing the network is compared with the proposed algorithm and presented in Table 5. Constrain and nodal head pressure is presented in Fig. 3. The speeds of the algorithm id good enough and it is shown in Fig. 4 that the best costs for the new algorithm can be obtained in lower iterations compared to the standard CSS. The new algorithm reached 6.8113 (12% away from best reached answer) after 300 iterations (6000 analysis).

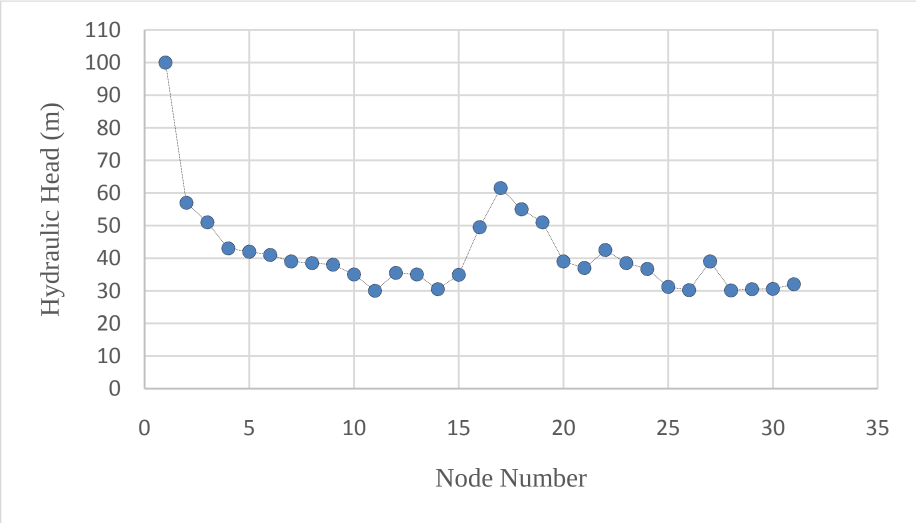

Figure 3. Nodal heads for Hanoi network

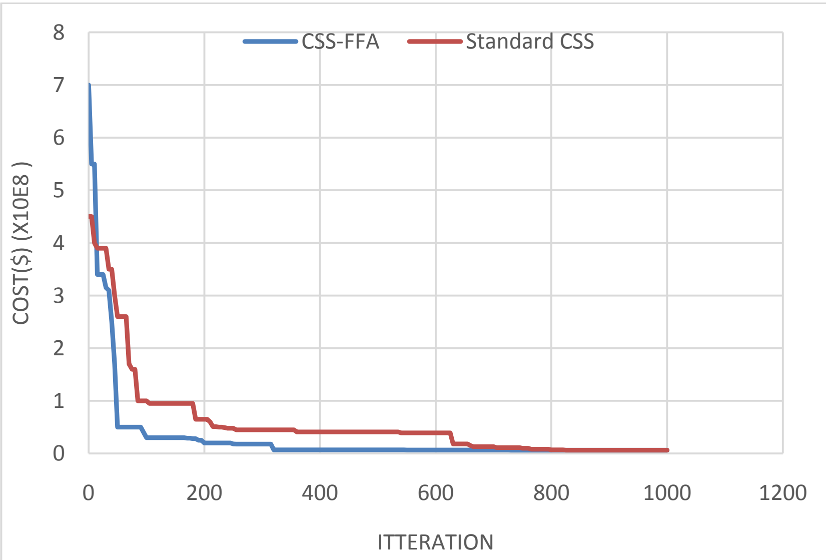

Figure 4. Comparison converging in standard CSS and hybrid CSS-FA

All meta-heuristic algorithms have some coefficients that should be determined before solving the problem in order to get to specified area of solution space which the best answer located there. To specify these coefficient parametric analysis is performed. Controlling parameters are k_a, k_v and k_d. Specified values for parametric analysis for these three coefficients are {0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1} and this parametric analysis is performed two times. The number of runs for this parametric analysis is 2×7×7×7×5000=3,430,000 runs. Results for this parametric analysis is presented in Fig. 5.

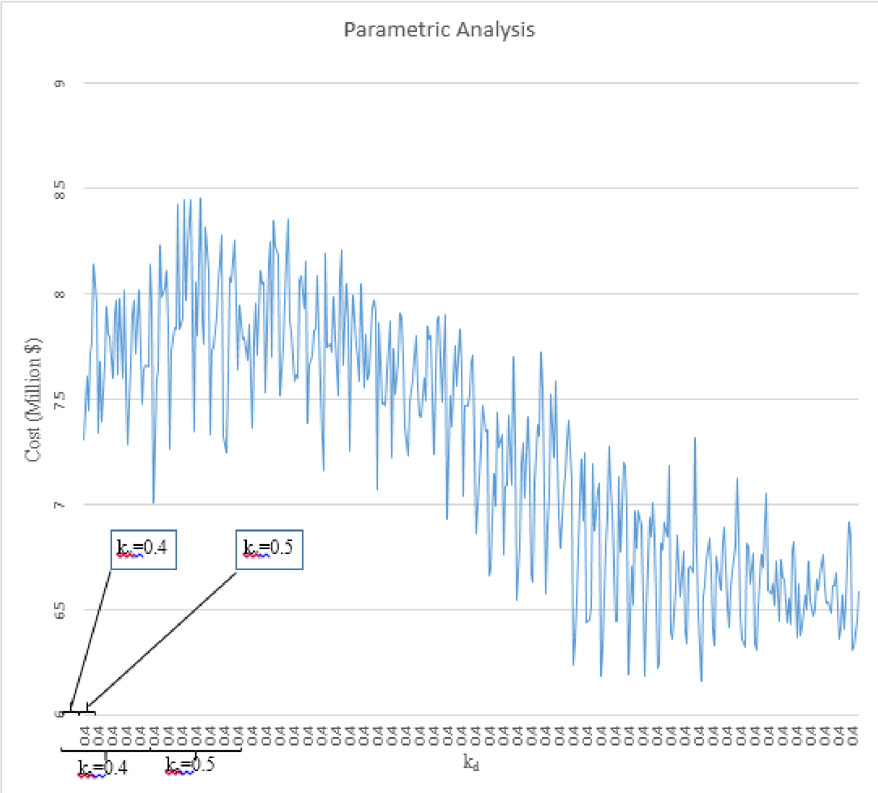

Figure 5. Results for parametric analysis for hybrid CSS-FA

After analyzing results for this parametric analysis, selected values for parameters k_a, k_v and k_d for initial convergence are 0.8, 0.6 and 0.5. As said before, by getting toward the best solution answer, k_a, k_v increase and the parameter k_d decreases. The speed of FA is good in getting toward area and the efficiency of CSS algorithm is better than FA. This means when algorithm needs big changes in input values, the FA performs much better but when it needs smaller changes, the CSS algorithm finds better answers for the problem.

5.3 Example 3: double hanoi network

Double Hanoi network is combination of two mirrored Hanoi network and all of nodal demands, pipe length and other properties of reservoir and network are the same as Ref. [20]. The pipe which connects the reservoir to the network is shortened from 100 to 28.9m. There are 67 pipes in whole network and the solution space for this network is equal to $6^{67}=1.37\times10^{52}$. Nodal and pipe numbers and layout for Double Hanoi network are shown in Fig. 6. As the optimal result for Hanoi network is specified, the optimal solution for Double Hanoi network is calculated as follows:

$$C_{DH} = 2C_H - 2l_{pipe1} \times c_{pipe1} + 28.9c_{pipe1} \tag{11}$$

where C_{DH} is the optimal solution for Double Hanoi network in feasible solution space and l_{pipe1} is length for pipe 1 and c_{pipe1} is cost for pipe 1 (in optimal design, the diameter for the pipe is 40in).

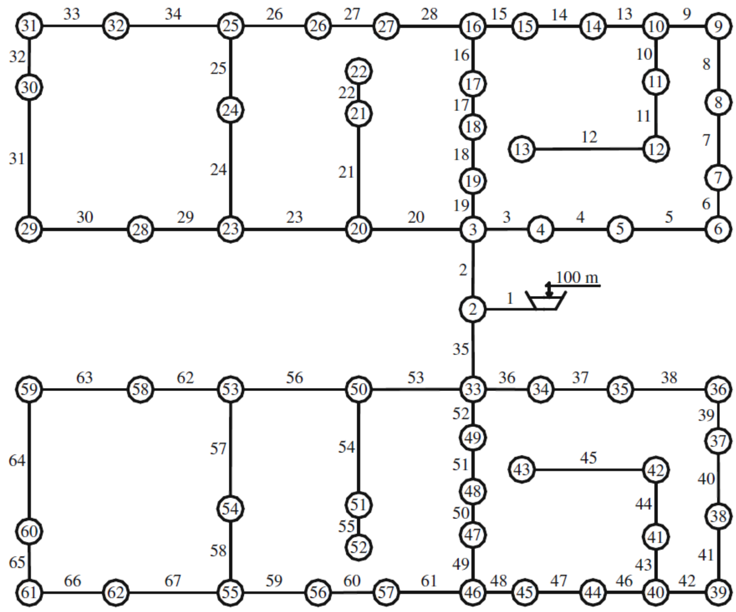

Figure 6. Double Hanoi network layout [20]

As the best answer for Hanoi network is 6.081×10^6, by stated relationship between these two networks, the best answer for this network should be 12.114×10^6. Best results for this network is obtained by the new method, CHSH and BB-BC as presented in Table 6.

Table 6: Comparison of presented algorithm in Double Hanoi network

Method	Hanoi Cost ($\$10^6$)	Double Hanoi Cost ($\$10^6$)	Global error (%)	No. Iteration
OptiDesigner [33]	6.115	12.795	5.62	N/A
GA [33]	6.081	12.600	4.01	N/A
HS [34]	6.081	12.404	2.39	N/A
BB-BC [27]	6.224	12.647	4.39	N/A
CS [32]	6.081	12.871	6.24	N/A
CSHS [32]	6.081	12.346	1.91	N/A
Standard-CSS	6.081	12.118	0.04	100,000
Present work	6.081	12.121	0.06	31,000

The hybrid CSS-FA found 12.121×10^6 after 30,900 evaluations and as stated before this is the best answer obtained. The worst answer obtained by the new method is 12,600,624 and the average of answers from 100 different runs is 12,251,163. The results show that the new algorithm can escape of local optimums in different runs.

5.4 Example 4: GoYang water distribution network

The last benchmark problem which is selected to evaluate the hybrid algorithm is GoYang network which is presented by kim *et al.* [21] in South Korea. The network has 22 nodes that 30 pipes connect them and fed by a 71 m fixed head reservoir and a 4.52kW power pump. GoYang network layout is presented in Fig. 7. The cost of commercially available pipe sizes {80, 100, 125, 150, 200, 250, 300, 350}; in mm is {37,890; 38,933; 40,563; 42,554; 47,624; 54,125; 62,109; 71,524}; in won/meter, respectively. The Hazen-Williams coefficient for this network is 100. The solution space for this problem is $8^{30} = 1.24\times10^{27}$ possible designs. Nodal head constrain is 15m above the ground level.

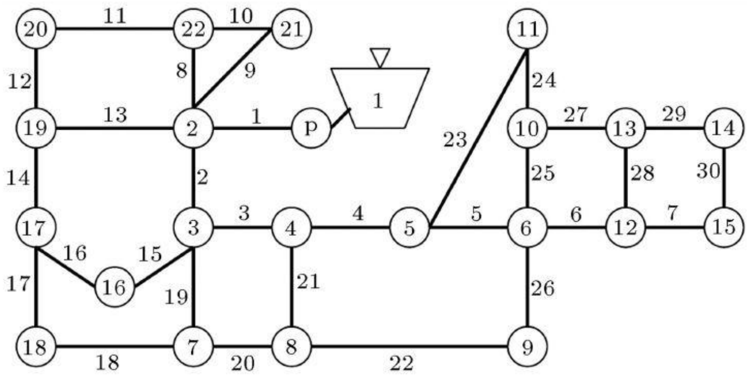

Figure 7. GoYang Network layout [21]

GoYang network is simpler than other benchmark problems solved in presented work but this simplicity makes competition with other algorithms difficult. The best solution for GoYang networks is also obtained by the present work. The performance comparison of the algorithm is presented in Table 7. The converge history of the algorithm for this example is presented in Fig. 8.

Table 7: Comparison of presented algorithm in GoYang Network

	Algorithm	Cost (won)
Geem et al. [34]	HS	177,135,800
Kim et al. [21]	NLP	177,136,000
Tahershamsi et al. [16]	IFA-HS	177,010,359
Present work	CSS-FA	177,010,359

NLP: Nonlinear Programing
HS: Harmony Search
IFA-HS: Firefly and Harmony Search

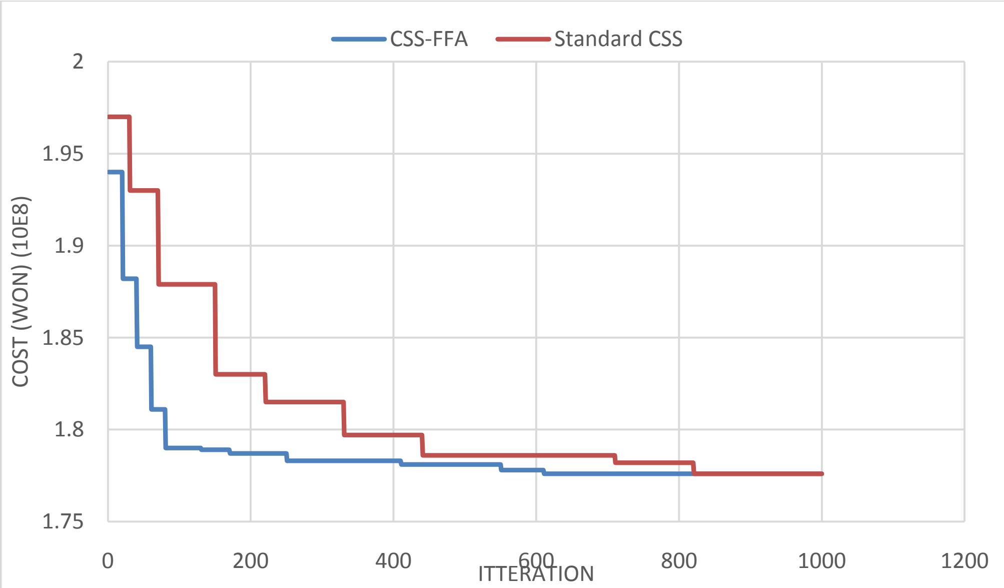

Figure 8. Comparison of Converging Standard CSS and hybrid CSS-FA

6. CONCLUSION

Standard CSS algorithm is one of the efficient algorithms that is presented for optimization and different design examples. The results carried out by using standard CSS algorithm for optimization purposes are nearly the best answer reached for each example but the speed of converging to the best answer can be improved. To fulfill this aim, another algorithm (FA) is used in hybrid form with the CSS algorithm. The final mehod is the result of hybridizing the standard CSS and FA. The FA makes the standard CSS algorithm works faster than its original variant.

The efficiency for the new hybrid algorithm is compared to other algorithms using 4 famous WDN design examples and in all of these examples the result of the hybrid algorithm are compared to the other methos. Results indicate that both of the algorithms (the standard CSS and hybrid CSS-FA algorithms) reach the best solution answers.

There are three important parameters for the proposed algorithm to be determined. In order to tune these parameters, a sensitivity analysis is performed. For the second design example, 3,430,000 runs are performed and best parameter values are chosen for the proposed algorithm.

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