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Original Article

Optimal Healthcare Resource Allocation in Covid Scenario Using Firefly Algorithm

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Abstract - *Coronavirus pandemic is spreading exponentially across the world, and so is the surge in requirement of the intensive care unit (ICU) of hospitals. Proper management of healthcare resources and providing proper hospital beds, supplies, and healthcare services to patients are needed to cope with this disease. Fare rationing of scarce ICU resources should be allowed by critical care triage. This is one of the scenarios where emerging computing technologies contribute in an indispensable way. This paper presents a bio-inspired firefly algorithm for smart healthcare resource allocation in the COVID era. The firefly optimization results show a reduction in average waiting time and improvement in resource utilization compared to the random allocation technique.*

Keywords - *Coronavirus, Covid-19, Firefly, Fog Computing, Healthcare.*

1. Introduction

Coronavirus, declared a pandemic by WHO, is widespread in almost the whole world. The rapid outbreak of coronavirus disease scared people and made them feel helpless. Researchers, scientists, doctors. Healthcare workers and technologists are trying their best to deal with this virus.

Efficient management of healthcare resources like ambulances, ICU beds, ventilators, etc., is required to prevent the further spread of the virus and provide better and excellent healthcare services to patients. The provisioning of healthcare resources must be aligned according to a varying load of patients because of COVID-19. This is where emerging and advanced computational technologies play a vital role.

The smart healthcare concept has been abstracted from the "Smart Planet" concept, with which IBM is acquainted.[1] It is an intelligent, interconnected, and instrumented infrastructure that uses sensor networks to transmit and receive information through IoT. Information processing is accomplished with advanced computing technologies like cloud and fog computing. Smart healthcare is a healthcare service to implements an intelligent medical ecosystem by using advanced technologies such as IoT, sensors, wearable devices, and computing technologies to connect people with medical and healthcare institutions.[2], [3], [4], [5], [6] It ensures that people get timely services and the allocation of healthcare resources is expedited. The evolution of various advanced computing and communication technologies integrated with emergent smart devices, advanced sensors, data analysis methods, healthcare social networks, and social media sites provided opportunities for implementing an intelligent and sustainable smart healthcare service system. [7] [8]

In most IoT applications, such as smart healthcare systems, fast response time and mobility support are needed. [9] Also, it is not obligatory to forward data every time to remote cloud data centers for processing. Conclusions can be implied in the vicinity of edge networks without transmitting data to the cloud. In today's world, issues linked with network bandwidth, latency, security, and reliability cannot only be addressed by the cloud model.[9] To overcome these challenges of conventional cloud computing, CISCO introduced the idea of fog computing in 2012. [10]

Fog computing, an extension of cloud computing, is used extensively in smart healthcare systems to provide storage and computation services in the proximity of networks. [11] Fog computing is a distributed computing environment that acts as a midway layer between IoT devices and cloud data centers. In a fog computing environment, traditional networking components such as gateway, routers, Base Stations (BS), etc., can be deployed near the edge of the network to be used as fog nodes.[9] These fog nodes provide computing, networking, storage, and processing facility in the proximity of the end-user and perform efficiently to overcome service latency, energy consumption, and network traffic complexity. [12]

A bio-inspired algorithm may be used at the fog node for healthcare resource provisioning.[12] Firefly algorithm is a bio-inspired metaheuristic algorithm that can tackle various optimization problems.[13] In this paper, the healthcare system is represented by a fog environment, and a bio-inspired algorithm is employed to address and contribute toward healthcare resource provisioning.

This paper elaborated on each component required for a smart healthcare system. Section 1 gives an introduction to smart healthcare. Section 2 presents a literature review on fog computing and firefly algorithms in the smart healthcare system. The smart healthcare model in the COVID-19 Scenario is described in section 3, and the experimental findings are presented in section 4. The conclusion is summarized in Section 5.

2. Literature Review

The continuously increasing demand and less resource capacity hassled the healthcare system during COVID-19. All health officials and policymakers worldwide face a common problem of allocating scarce healthcare resources such as hospital beds, oxygen cylinders, and ventilators. The imbalance between demand and supply for healthcare resources raised the question of how scarce healthcare resources could be allocated efficiently and fairly [14] to patients during COVID-19?

Several ethical guidelines and considerations were discussed to develop an allocation protocol for providing scarce healthcare resources.[15] In the COVID-19 pandemic, some recommendations were made to manage healthcare resources, including prioritizing health workers and avoiding allocating resources on a first-come, first-serve basis.[14] There should be a fair allocation of scarce resources with the greatest benefits to the individual with the fewest existing resources during public health emergencies.[15] A random method for resource allocation was considered better than the first-come, first method as it maximized the fairness of resources by preceding all values. Still, it became difficult to operationalize if patients did not arrive simultaneously.[15] So, there was a need for an efficient resource allocation strategy to curb the indefinite demand for resources in the COVID environment. During a public health emergency, a conceptual framework for the distribution of ventilators was presented.[16] Decision-makers could set ethically justified priorities for allocating resources during a pandemic when resources are scarce, but some grounds of priority could be discriminatory and inappropriate.[17] This framework satisfied population-level requirements, but the individual patient requirement issue was not considered. A hybrid model consisting of forecasting demand, discrete event simulation to capture the patient pathway uncertainties, and an optimization model for estimation of healthcare resources was also developed.[18]

A single-objective approach using meta-modeling optimization was provided to reduce the waiting time of patients in the emergency department (ED) and the optimal allocation of healthcare resources.[19] Three models to estimate the inpatient demand for every population area, minimize the patient total travel distance to the hospital and allocate the additional resources whenever available were developed to determine the optimal allocation of medical resources. [20] A simulation and metamodels-based optimization tool using a genetic algorithm were presented for near-optimal resource allocations. This tool made real-time decisions for optimal resource allocation within the stipulated period.[21] A proactive approach to identifying the locations having a shortage of resources and allocating healthcare resources in specified locations to minimize the shortfalls of scarce resources during the COVID-19 pandemic was presented. [22] Although a maximum resource allocation (MRA) method was presented for effective allocation and efficient delivery of healthcare resources, this work did not consider waiting time as a prime factor which is an important parameter to be considered in pandemics like COVID-19. [23]

This section also presents the contribution of fog computing in smart healthcare and the firefly optimization techniques in a smart system.

2.1. Contribution of Fog Computing and IoT in Smart Healthcare

Extensive research has been conducted to improve and strengthen the currently existing healthcare system with the amalgamation of various computing technologies. IoT could provide an integrated healthcare system to fight with COVID-19 pandemic. Several applications and merits of IoT in healthcare management during COVID-19 were studied and discussed.[24] IoT was used to interconnect available healthcare resources and patients with a critical diseases.[25] An IoT-based solution was established to monitor and control the patient health parameters like blood sugar, HB, and BP and other programs such as safe motherhood in rural areas.[26] An IoT-based healthcare system for smart cities that connected all the available healthcare resources for home care/ telemonitoring and diagnosing patients with chronic illness was proposed. [27] A demo was proposed to develop, deploy, and manage healthcare applications in a hybrid cloud/fog environment.[28] A hierarchical framework for healthcare monitoring, an intelligent warning model, and a health assessment model was proposed for a fog-assisted environment.[29]

To preserve the privacy of end-users,' the author proposed using fog nodes as middleware between the cloud and end-user. This prevented information attacks by confining the details within trusted devices.[30] In the clinical environment, successful deployment of e-Health smart gateways (UT-GATE) and Early Warning Score (EWS) introduced local data processing, storage, and faster decisions at the fog layer.[31] To examine the benefit of fog computing in e-health applications in terms of data security, deployment, communication protocols, and infrastructure development, a taxonomy of fog computing for e-health was suggested.[32] An IoT-based smart platform for patients' initial screening for COVID-19 disease was developed so that patients should not come into contact with hospital staff, and the spreading of germs to each other was being prevented. [33]

2.2. Firefly Optimization Technique in Smart Systems

An investigative work by authors showed that Firefly Algorithm (FA) was used to solve various issues in the healthcare and biomedical field.[34] The authors proposed an automated approach to predict possible hospital readmission by using deep learning models and firefly optimization techniques to classify the data.[35] Firefly algorithm was used to optimize healthcare applications, and this was useful in providing optimized solutions for engineering problems.[36] A reliable firefly and Feed Forward Back Propagation Neural Network (NN) method were developed to improve parking efficiency and reduce space search time.[37] To enhance the performance of smart cities, address the smart mobility issues, and reduce greenhouse gas emissions (smart environment), a public and smart urban transportation tool (PRT) was implemented using discrete FA.[38] To provide efficient residential energy management to reduce electricity bills, an objective function formed on Firefly Algorithm and Harmony Search Algorithm (HSA) was proposed, categorizing and scheduling home appliances more optimally.[39]

In this spirit, a fog-enabled smart healthcare model in which healthcare resources are optimally allocated using the firefly optimization algorithm is being presented in this paper.

3. Smart Healthcare Model

Smart healthcare uses emerging computing technologies to reduce medical procedure cost and risk, improve the utilization efficiency of medical resources, and provide the facility of personalized healthcare and medical treatments, online assistance of patients, e-medicine, and self-service medical care. [40]

Fog-enabled smart healthcare systems integrate smart devices with intelligent software agents to efficiently deliver automated and intelligent healthcare services. This helps hospitals in decision making, efficient resource utilization, fair resource allocation, and quality and performance analysis.[8] Because computations are being performed between cloud and network edge, in comparison with cloud computing, fog computing is more scalable and adaptable, also reduces delay and network traffic, and improve energy efficiency. Hence, fog computing offers a more advantageous solution for the smart healthcare system.

A smart healthcare system encompasses the integration of components and services being offered.

3.1. Smart Healthcare Components

Smart healthcare systems can be prospected by integrating IoT services, emerging computing technologies, and smart edge devices like smartphones. The smart healthcare system is composed of the following components:

- Smartphones, smart vehicles, or other smart devices equipped with internet facilities to send a request for healthcare services and get a response in acknowledgment.
- Fog nodes to perform local request processing and computations. It is also connected to the cloud so that requests that cannot be processed at the fog layer will be forwarded towards the cloud.
- A collection of software components is termed an API so that patients can send requests for healthcare services, and API can process that request with defined optimized algorithms and can perform required actions.
- A database is required to store the status of healthcare resources and data being generated after processing the requests at the fog or cloud layer. This data is stored for future use, such as data analysis and data presentation.

3.2. Smart Healthcare Services

These are the services provided by the smart healthcare system for ease of work.

- Searching for nearby hospitals providing isolation beds, corona testing facilities, ventilator beds, and oxygen beds to corona patients.
- Searching for available resources in the hospital.
- Booking and confirmation of Ambulance.
- Booking and confirmation of isolation bed in the hospital.
- Booking and confirmation of corona testing in hospital.
- E-Receipt of the corona test report.
- Monitoring the patient's health condition while being in the ambulance so that doctors can provide virtual medical assistance and give advice so that patients receive timely treatment.

3.3. COVID-19 Scenario

A smart healthcare model in the COVID-19 Scenario is shown in figure 1. The steps followed to process the requests successfully are listed below:

1. Hospitals update the availability of the resources at the fog node. Hospitals frequently send data regarding available resources like ICU beds, ventilators, ambulances, etc., to fog nodes. Data generated by hospitals is being stored at the fog node's database so that timely and appropriate decisions can be made whenever the patient is submitting any request for COVID hospital.
2. Patients send search requests for the best available hospital through laptops, mobile, or any wearable device while being at home or traveling.

3.a. The fog node responds to the end-user directly, giving availability of resources.

3.b.1 If a fog node is overloaded, the request can be offloaded to other fog nodes.

3.b.2 Two fog nodes can also communicate for data and resource sharing.

3.c.1 If no fog node is available to process the end-user

request, then such request is being transferred to cloud datacenter.
3.c.2. The request is processed at a fog node or cloud data center using an efficient resource scheduling algorithm to allocate ICU beds in the best available hospital. After processing the request at the cloud, the datacenter response is transferred to the fog node.

4. Allocation of Healthcare Resources

There is a need to introduce an optimization algorithm capable of allocating healthcare resources efficiently to treat corona patients well in time. The foremost aim of the proposed work is to reduce the waiting time for patients and ensure fair and efficient allocation of healthcare resources.

A bio-inspired firefly algorithm is used at the fog node for healthcare resource provisioning. There are a variety of bio-inspired intelligent metaheuristic algorithms, but the firefly algorithm is used because of its uncomplicated nature and effectiveness in solving the problems.

4.1. Firefly Algorithm

In 2008, Xin-She yang introduced the Firefly algorithm, which is inspired by the flashing behavior of fireflies.[41] There are three steps by which the mating process of fireflies takes place.

a. Fireflies are unisex and attracted to each other irrespective of their gender.
b. The attraction of fireflies towards each other is directly proportional to their brightness and inversely proportional to their distance apart. Fireflies will always move toward a brighter firefly; if no firefly is found, the firefly will move randomly.

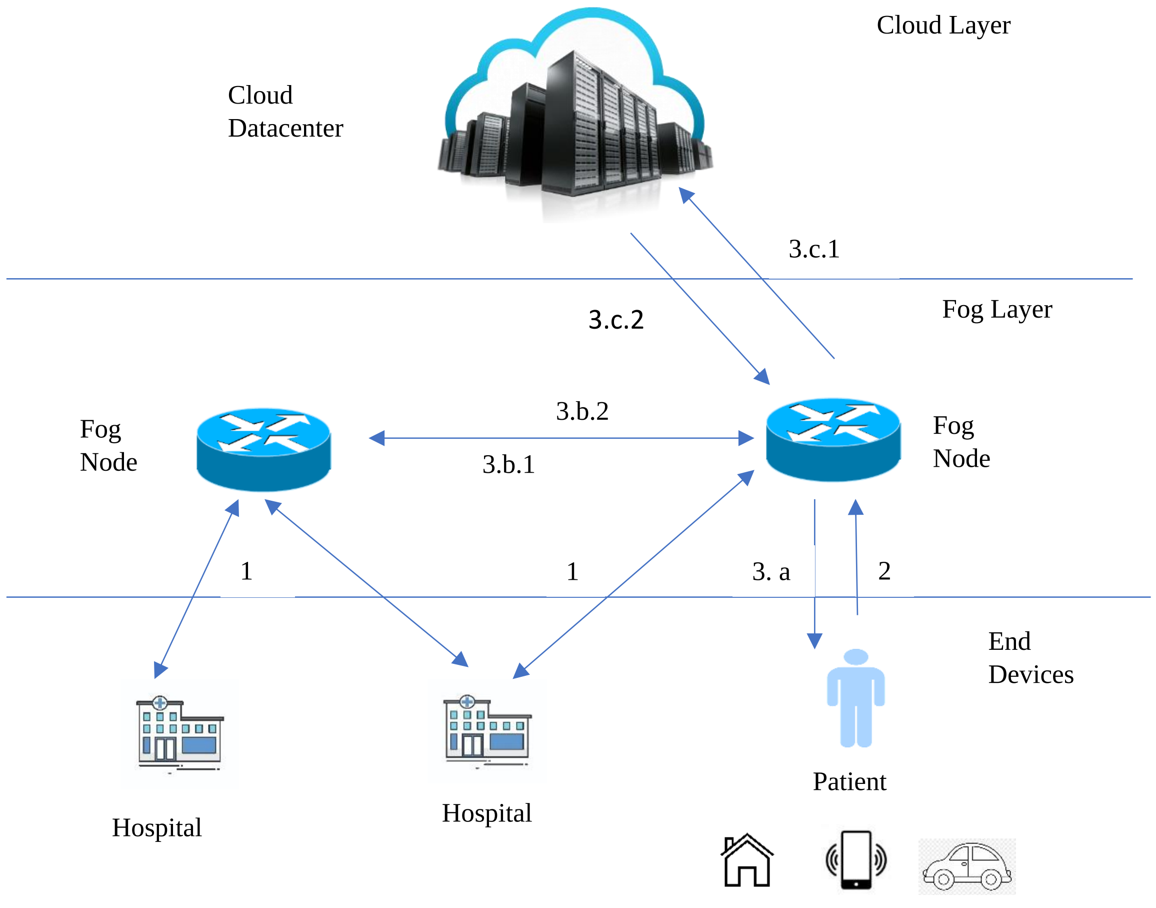

Fig. 1 Smart Healthcare System

c. An objective function determines the brightness of every firefly.

It is observed that attractiveness, randomization, and absorption are the three main parameters to be considered for the execution of the Firefly Algorithm (FA). FA uses attractiveness between brighter fireflies to find an optimized result. Because of this property, it converges quickly towards the global maximal optimal solution. Randomization parameters and global communication among fireflies prevent FA from getting stuck in local optima. The steps followed by the firefly algorithm to achieve the best possible solution are depicted in figure .

4.2. FA Based Allocation of Healthcare Resources

The Fireflies are analogous to patients, and their assignments refer to the allocation of available resources, i.e., hospital beds and oxygen cylinders and ventilators. Every corona patient admitted to the hospital will be treated as a firefly. Each firefly's fitness value or brightness is to be updated at the local fog server so that corona patients of that particular area get notification about the best possible options of hospitals in nearby areas. A patient admitted to a hospital with the maximum number of available beds, and oxygen cylinders and ventilators will be treated as brighter fireflies. So brighter fireflies, i.e., patients not admitted to any hospital or patients waiting for a bed in an occupied hospital, will get attracted to the brighter firefly, i.e., towards the hospital, which has the maximum available resources. This attractiveness also depends upon the distance between two fireflies, i.e., the patient will try to get the bed in the nearby hospital.

This algorithm successfully notifies the best available options to corona patients. It offloads an over-occupied hospital to a nearby less occupied hospital so that corona patients can be treated well in time. If any patient does not find any option, then the patient can choose a hospital randomly.

4.2.1. Initial Population Generation

Patients are likely to go to a nearby hospital with the availability of beds. Initially, Fireflies are initialized based on the number of patients, and subsequently, each firefly is assigned with admitted patient and hospital resources combination.

4.2.2. Brightness Calculation

The fitness of all the fireflies is directly related to brightness or intensity, and the number of available resources determines the fireflies' brightness.

$$brightness\ (I)\ \alpha\ No. of\ Available\ Resources \quad (1)$$

A patient admitted to a hospital with a maximum number of available beds, and an oxygen cylinder and ventilator will be treated as a brighter firefly.

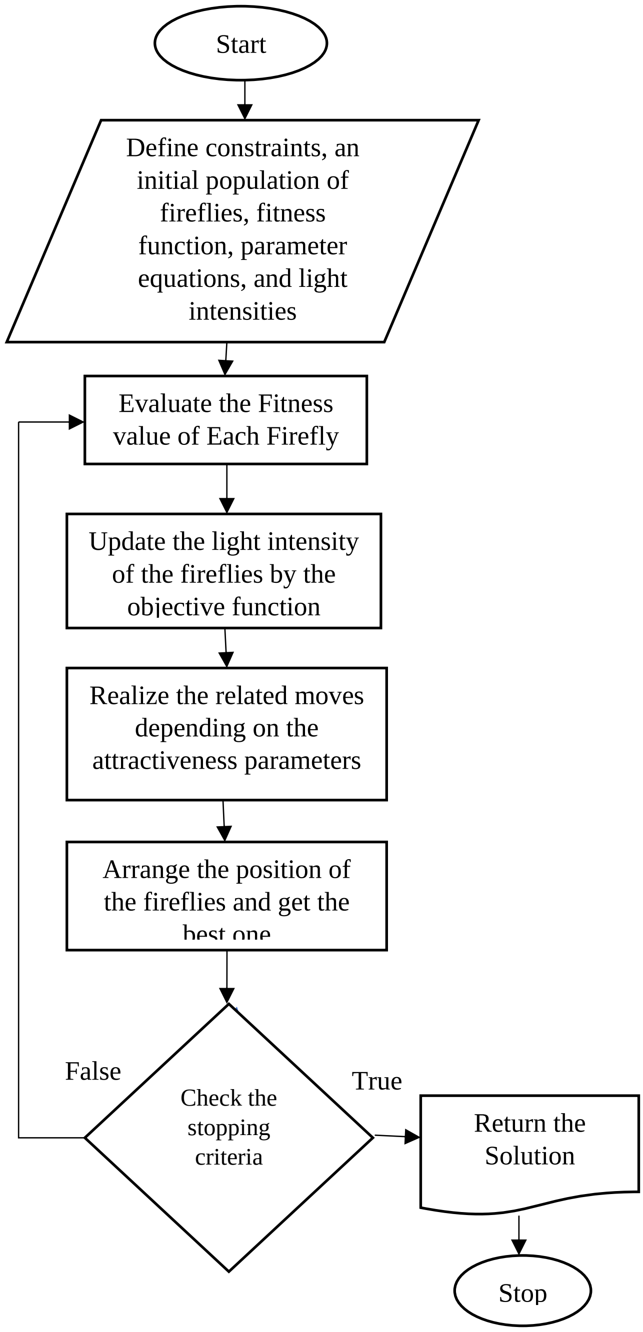

Fig. 2 Flowchart of firefly algorithm technique [42]

Suppose there are n fireflies, then the fitness value for each firefly is calculated using the following equation.

$$F(y_i) = \sum_{i=1}^{n} I_i \quad (2)$$

4.1.3. Movement Towards attractive firefly

The brightness of each of the fireflies is evaluated and compared with another. At every iteration, the best firefly is identified, and the firefly moves toward a new position, i.e., in the direction of a brighter firefly. The less bright will be attracted to the brighter fireflies.

$if(l_j > l_i)\ then$:
Move i^th^ firefly towards j^th^ firefly (3)

The Movement of the i^{th} firefly at position y_i moving to a brighter j^{th} firefly at position y_j is given as:

$$y_i(t+1) = y_i(t) + \beta e^{-yr^2}(y_i - y_j) + \alpha\varepsilon_i \quad (4)$$

Where β is the attractiveness value, attractiveness is inversely proportional to distance and directly proportional to the number of available beds. The nearby hospital with many available resources would be much more attractive. βe^{-yr2} is the attractiveness value between two fireflies, yi, and y_j. Attractiveness(β_0) varies with distance r, where r is the distance between two fireflies. The distance *r* between the *i^th^* and *j^th^* fireflies is given by:

$$r_{ij} = \sqrt{\sum(y_i - y_j)^2} \quad (5)$$

$\alpha\varepsilon_i$ is the randomization parameter; if β_0 =0, then the firefly moves randomly based on the equation given:

$$y_i(t+1) = y_i(t) + \alpha\varepsilon_i \quad (6)$$

The attractiveness of a firefly in a new position is compared to the attractiveness of a firefly in an old position. If attractiveness at the new position is higher than attractiveness value at the old position, then the firefly moves towards a new position. Otherwise, it will not change its position and will remain at its current position. If no brighter firefly is found, then the Movement of the firefly will be random. After reaching the termination criterion, it gives the best possible solution.

Corona patients will be notified about nearby less occupied hospitals so that patients can be treated well in time. If any patient does not find the best option, he will choose the hospital randomly according to his choice.

5. Results

For the allocation of healthcare resources, the Firefly optimization algorithm is used, and the simulated results are compared with Random Allocation (RA) method. Both algorithms evaluate and compare the average waiting time, the number of successfully processed tasks at fog nodes, and resource utilization. PureEdgeSim [43] simulator is used for simulation purposes. The analytical research method is adopted in this paper to analyze the COVID scenario, and for simulation purposes, the dataset is taken from covid19india.org [44]. The spread trend of uniform scale mode is observed. The total number of corona cases is divided into two scenarios: low and high, depending on the corona cases per day. The low set ranges from 10 to 100, where an increase in per day cases is low, i.e., 10 average new cases are coming per day. The high set ranges from 100 to 1000, where an increase in per day cases is high, i.e., 100 average new cases are coming per day. Here, edge devices will be treated as corona patients, which can generate any number of requests to fog nodes, i.e., a patient can check for the availability of beds, book for the test slot can, request for an oxygen cylinder, etc. 16 VMs available at fog servers are being treated as hospitals and cores as beds equipped with oxygen cylinders and ventilators. Every hospital has a different number of beds ranging from 32 to 128.

5.1. Average Waiting Time

Average waiting time is the time to get notification about the best available hospital for patients. If the number of cases increases, the waiting time for notification about the best available hospital also increases. As shown in figure 3.1 and figure 3.2, when the number of cases is low average waiting time of random allocation is a little better than the firefly algorithm. Still, the average waiting time for the random allocation algorithm increases drastically as corona patients are more than 600. The average waiting time is calculated using equation 7.

$$Average\ waiting\ time = \sum_{i=0}^{n}(response\ arrival\ time - request\ generation\ time)\ /n \quad (7)$$

When the firefly algorithm is compared with the random allocation method, the average waiting time for the low range scenario is 15.66% higher, as shown in figure 3.1. Initially, when all resources are free, and the number of cases is less, resources are easily available and can be allocated without any optimization. But, when the number of cases increases, optimized allocation becomes necessary so that hospitals, where all beds are already occupied, are not included in search space; hence, waiting time is reduced. Therefore, as shown in figure 3.2, the high range scenario average waiting time of the firefly algorithm is reduced by 24.34%. Percentage reduction in waiting time is calculated with the following equation.

$$\%age\ Reduction\ in\ waiting\ Time = \sum_{i=1}^{n}((WT_{firefly} - WT_{RA})/\ WT_{RA} * 100)\ /n \quad (8)$$

Where WT is waiting time and n represents the total number of requests generated.

5.2. Number of Requests/Tasks Successfully Processed

A comparison regarding the successfully processed requests is presented for both the firefly and random allocation algorithm. The patient's request fog node also executes other requests simultaneously like booking for corona testing, downloading an e-receipt of the report, looking for an oxygen cylinder, etc. It is clearly shown in figure 4.1 and 4.2 that the average number of requests being processed using firefly are 0.75% more for low range scenario and 8.58% more for high range scenario than requests being processed using random allocation.

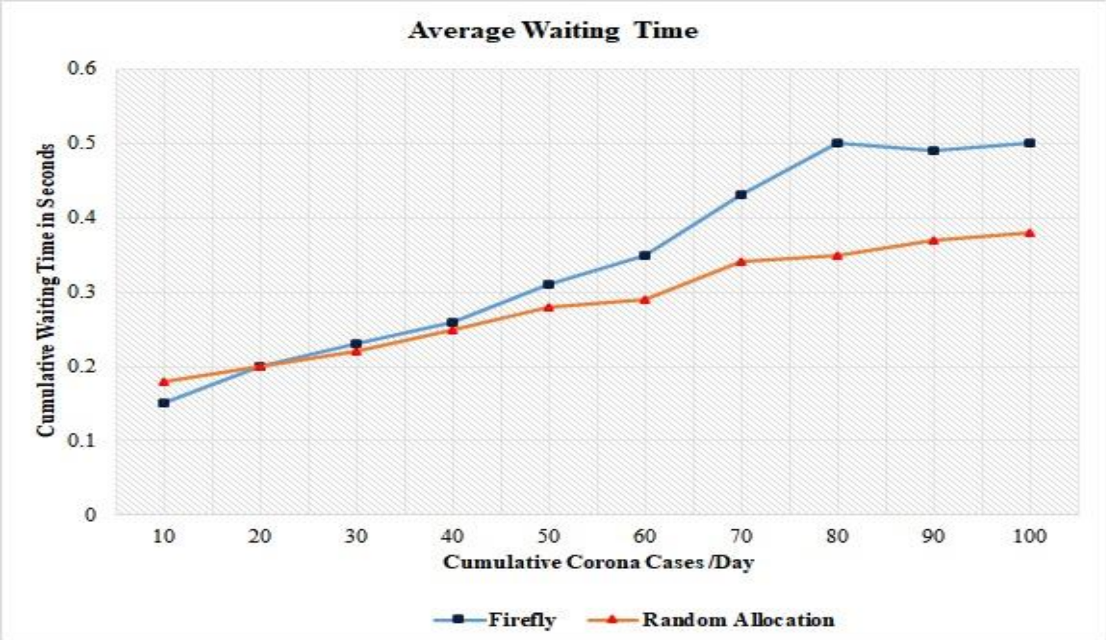

Fig. 3.1 Average Waiting Time for Low Range Scenario

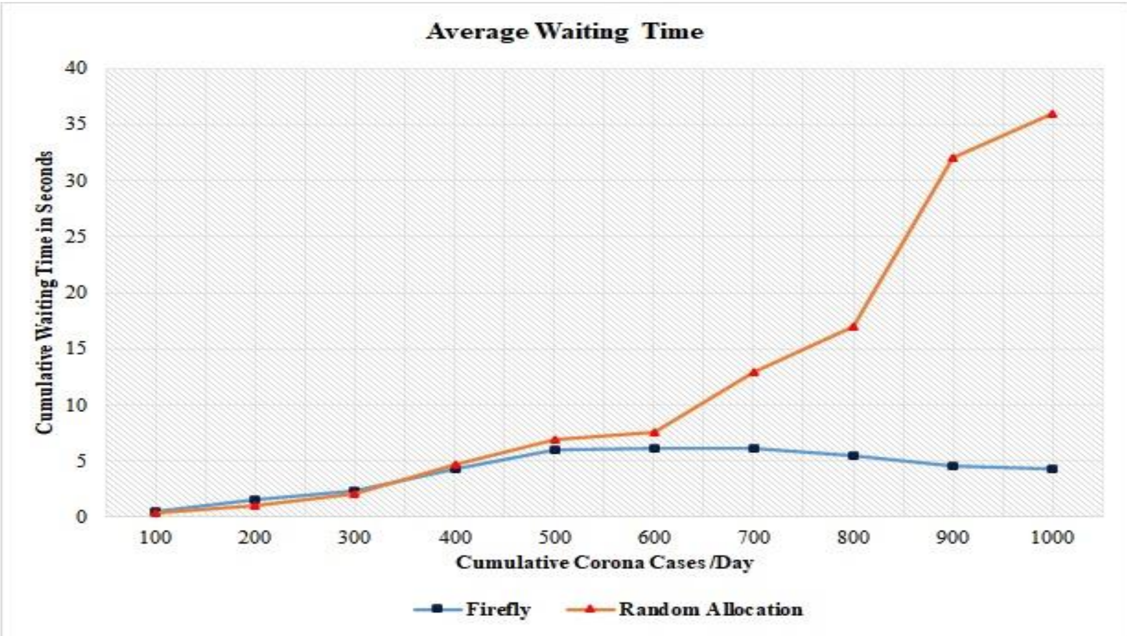

Fig. 3.2 Average Waiting Time for High Range Scenario

Percentage increase in number of requests processed is calculated using equation 9.

$$\%age\ Increase\ in\ Number\ of\ Reqests\ Successfully\ Processed = \sum_{i=1}^{n}((TTC_{firefly} - TTC_{RA})/\ TTC_{RA} * 100)\ /n \quad (9)$$

TTC is the total tasks completed and can be evaluated using the following equation.

$$Total\ Tasks\ Completed(TTC) = Total\ Tasks\ Generated - Failed\ Tasks \quad (10)$$

Tasks fail due to high delay, mobility, and unavailability of resources. According to this framework, whenever a corona patient searches for a suitable hospital for treatment, the request goes to the local fog server, where data is stored from various hospitals. After applying the firefly algorithm, the best suitable option is notified to the patient. Because of less execution delay, the task failure rate is less in the firefly algorithm than in the random allocation algorithm.

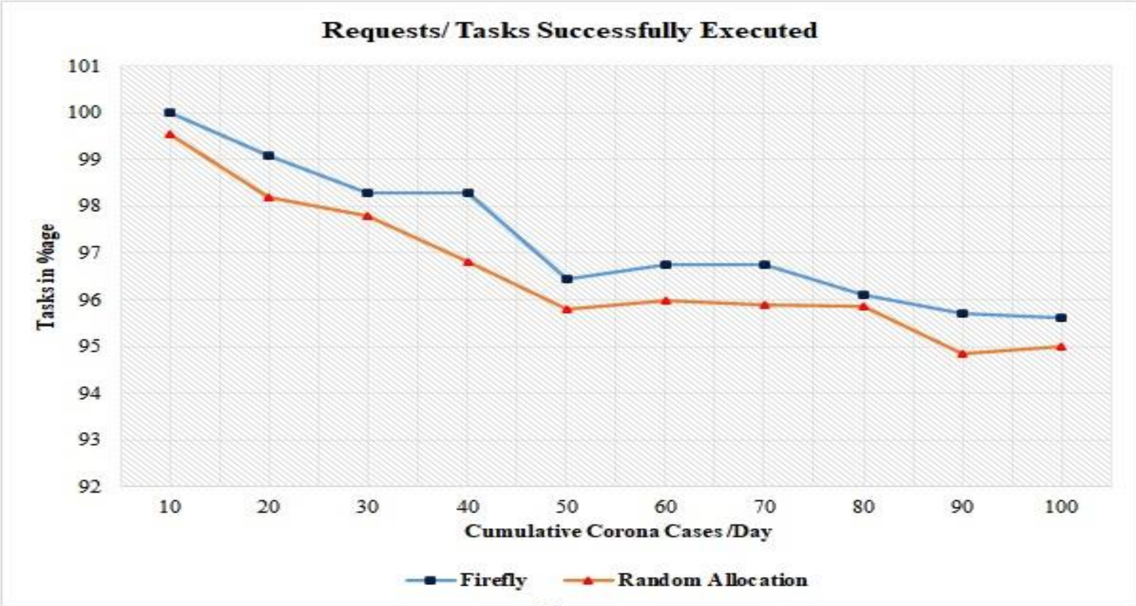

Fig 4.1. Number of Requests Successfully Executed for Low Range Scenario

5.3. Resource Utilization

It is quite obvious that fair and maximum utilization of resources is possible with an optimized firefly algorithm. When hospitals are allocated based on random selection, the resources of some of the hospitals will be over-utilized, and the resources of other hospitals will be underutilized. As shown in Figures 5.1 and 5.2, the firefly algorithm provides approximately 35.16% and 46.50% better resource utilization than the random allocation for low range and high range scenarios.

Resource utilization and percentage increase in resource utilization are calculated using equations 11 and 12, respectively.

$$Resource\ Utilization = \frac{Allocated\ Resources}{Total\ Resources} \quad (11)$$

$$\%age\ Increase\ in\ Resource\ Utilization = \sum_{i=1}^{n}((RU_{firefly} - RU_{RA})/ RU_{RA} * 100)/n \quad (12)$$

Where RU stands for Resource Utilization and n are the total number of corona cases.

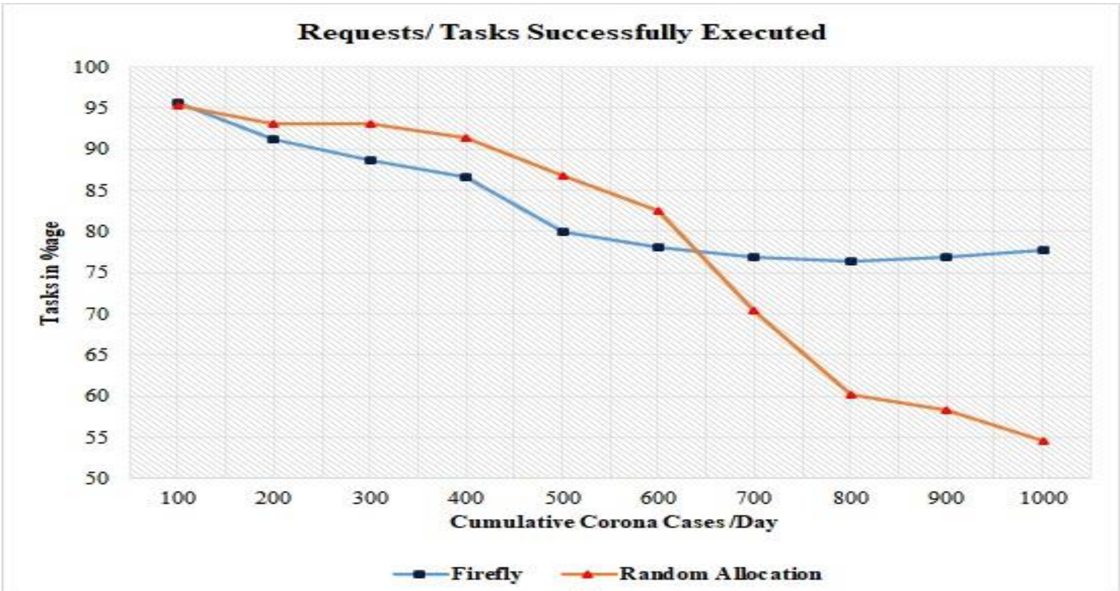

Fig. 4.2 Number of Requests Successfully Executed for High Range Scenario

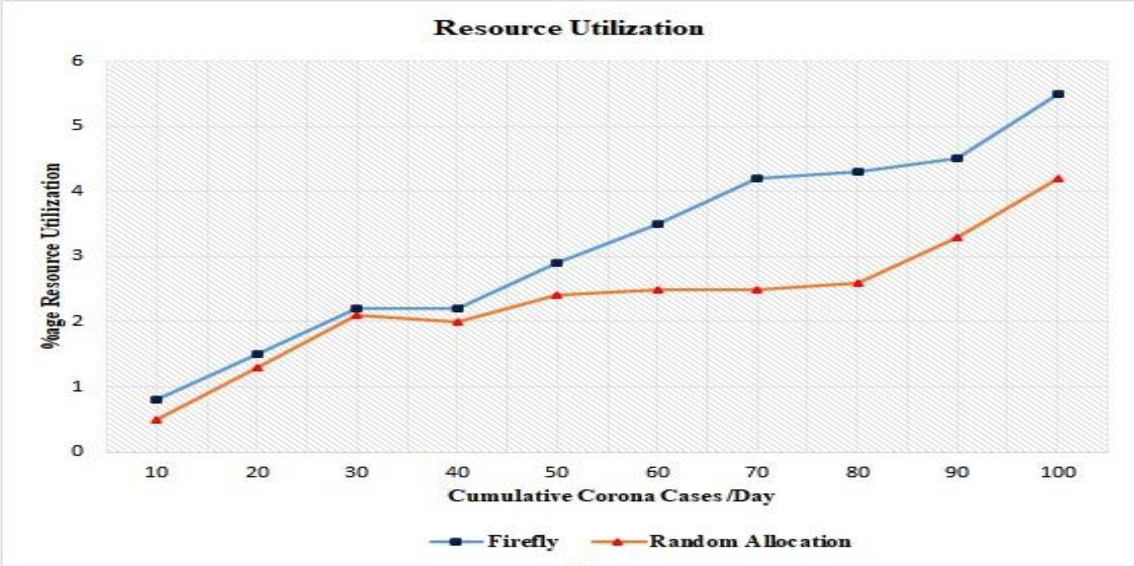

Fig. 5.1 Resource Utilization for Low Range Scenario

6. Conclusion

COVID-19, caused due to Corona Virus, is a worldwide public health emergency growing exponentially. It has introduced new research challenges and issues to global researchers. To tackle this pandemic, medical experts and technical expertise are also needed. Keeping in view the millions of affected people and scarcity of resources, efficient resource management is paramount. A multi-faceted approach is required to deal with the situation, which is bound to be multi-disciplinary.

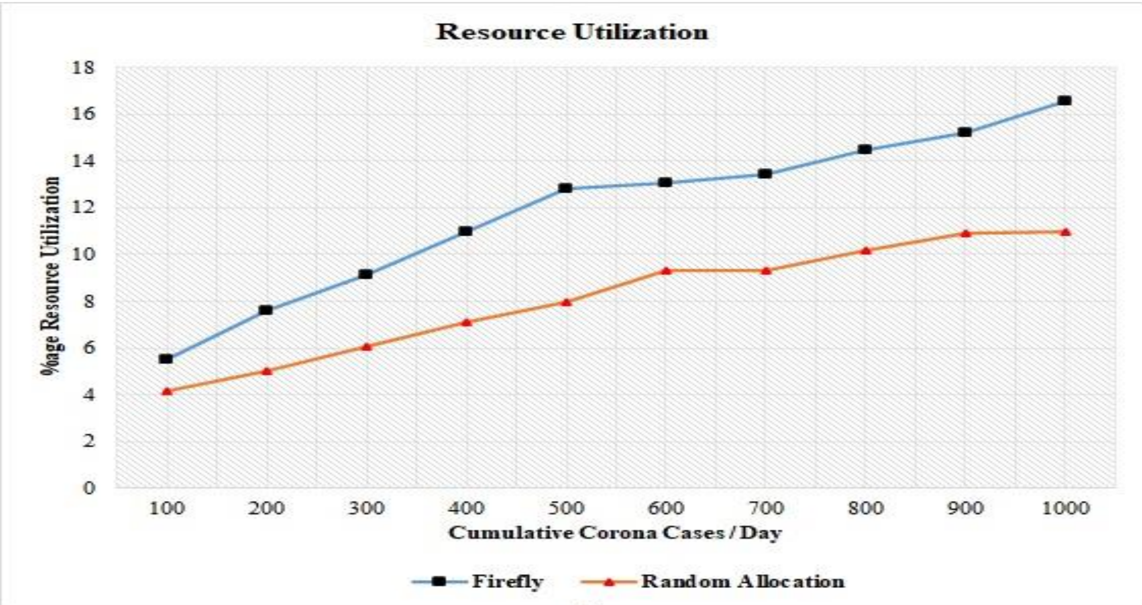

Fig. 5.2. Resource Utilization for High Range Scenario

This paper presented how fog computing and an intelligent bio-inspired metaheuristic algorithm can address and contribute to healthcare resource provisioning. Optimization of resources has been achieved using the firefly optimization algorithm. The comparative analysis of firefly and the random allocation algorithm is summarized in table 1. This algorithm enhanced the optimized resource utilization by 35.16% for the low range and 46.50% for the high range, reducing the average waiting time by 24.34% for the high range scenario.

The average waiting time for the low range scenario is 15.66% higher for the firefly algorithm because, initially, all resources are free, and optimization is not needed. The average number of requests processed using firefly is 0.75% more for the low range and 8.58% more for the high range scenario. As a result, the firefly algorithm's overall performance in allocating healthcare resources in a smart healthcare environment is exquisite and substantial.

Table 1. Comparison of Firefly with Random Allocation Algorithm

Parameter	Low Range scenario	Impact	High Range scenario	Impact
Average waiting Time	+15.66%	No need for optimization initially	-24.34%	Improvement
Number of Tasks Successfully Executed	+0.75%	Improvement	+8.58%	Improvement
Resource Utilization	+35.16%	Improvement	+46.50%	Improvement

References

[1] J. L. Martin, H. Varilly, J. Cohn, and G. R. Wightwick, Preface: Technologies for a Smarter Planet, IBM Journal of Research and Development, 54 (4) (2010) 1–2. doi: 10.1147/JRD.2010.2051498.

[2] M. Nasajpour, S. Pouriyeh, R. M. Parizi, M. Dorodchi, M. Valero, and H. R. Arabnia, Internet of Things for Current COVID-19 and Future Pandemics: an Exploratory Study, Journal of Healthcare Informatics Research, 4(4) (2020) 325–364. doi: 10.1007/s41666-020-00080-6.

[3] S. Tian, W. Yang, J. M. L. Grange, P. Wang, W. Huang, and Z. Ye, Smart Healthcare: Making Medical Care More Iintelligent, Global Health Journal, 3(3) (2019) 62–65. doi: 10.1016/j.glohj.2019.07.001.

[4] L. Diallo, A. H. A. Hashim, M. J. E. Salami, S. B. O. Elagib, and A. A. Zarir, The Rise of Internet of Things and Big Data on the Cloud: Challenges and Future Trends, International Journal of Future Generation and Communication Networking, 10(3)(2017) 49–56. doi: 10.14257/ijfgcn.2017.10.3.06.

[5] S. Kaur, A. Hans, and N. Singh, An Overview to Internet of Things (IOT), International Journal of Future Generation and Communication Networking., 9(9) (2016) 239–246. doi: 10.14257/ijfgcn.2016.9.9.21.

[6] I. H. Memon, Y. Jiaoyun, M. T. Hassan, and A. Ning, The Role of the Internet of Things (IoT) and Wireless Sensor Network (WSN) in Healthcare, International Journal of Engineering Trends and Technology., 67(7) (2019) 92–96. doi: 10.14445/22315381/IJETT-V67I7P218.

[7] M. Zhang and C. C. Yang, Classifying User Intention and Social Support Types in Online Healthcare Discussions, in 2014 IEEE International Conference on Healthcare Informatics, Verona, Italy, (2014) 51–60. doi: 10.1109/ICHI.2014.15.

[8] H. Demirkan, A Smart Healthcare Systems Framework, IT Professionals, 15(5)(2013) 38–45. doi: 10.1109/MITP.2013.35

[9] P. Hu, S. Dhelim, H. Ning, and T. Qiu, Survey on fog Computing: Architecture, key technologies, Applications and Open issues, Journal of Network and Computer Applications, 98(2017) 27–42 doi: 10.1016/j.jnca.2017.09.002.

[10] R. Mahmud, R. Kotagiri, and R. Buyya, Fog Computing: A Taxonomy, Survey and Future Directions, in the Internet of Everything, B. Di Martino, K.-C. Li, L. T. Yang, and A. Esposito, Eds. Singapore: Springer Singapore, (2018) 103–130. doi: 10.1007/978-981-10-5861-5_5.

[11] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli, Fog Computing and its role in the Internet of things, in Proceedings of the first edition of the MCC workshop on Mobile Cloud Computing - MCC '12, Helsinki, Finland, (2012)13. doi: 10.1145/2342509.2342513.

[12] A. - and A. Singhrova, "Prioritized GA-PSO Algorithm for Efficient Resource Allocation in Fog Computing, Indian Journal of Computer Science and Engineering., 11(6)(2020) 907–916. doi: 10.21817/indjcse/2020/v11i6/201106205.

[13] X.-S. Yang, "Firefly Algorithm, Stochastic Test Functions and Design Optimisation, International Journal of Bio-Inspired Computation, 2(2) (2010) 78-84, [Online]. Available: http://arxiv.org/abs/1003.1409.

[14] E. J. Emanuel et al., Fair Allocation of Scarce Medical Resources in the Time of COVID-19, The New England Journal of Medicines, 382 (21) (2020) 2049–2055. doi: 10.1056/NEJMsb2005114.

[15] N. Leventhal et al., The Ethics of Creating a Resource Allocation Strategy During the COVID-19 Pandemic, Pediatrics, 146(1) (2020) e20201243, doi: 10.1542/peds.2020-1243.

[16] S. Zaza et al., A Conceptual Framework for Allocation of Federally Stockpiled Ventilators During Large-Scale Public Health Emergencies, Health Security., 14(1) (2016) 1–6. doi: 10.1089/hs.2015.0043.

[17] A. Dawson et al., An Ethics Framework for Making Resource Allocation Decisions Within Clinical Care: Responding to COVID-19, Journal of Bioethical Inquiry, 17(4) (2020) 749–755. doi: 10.1007/s11673-020-10007-w.

[18] M. Ordu, E. Demir, C. Tofallis, and M. M. Gunal, A Novel Healthcare Resource Allocation Decision Support tool: A Forecasting-simulation-Optimization Approach, Journal of Operational Research Society, 72(3) (2021) 485–500. doi: 10.1080/01605682.2019.1700186.

[19] A. Bahari and F. Asadi, A Simulation Optimization Approach for Resource Allocation in an Emergency Department Healthcare Unit, Global Heart, 15 (1) (2020) 14. doi: 10.5334/gh.528.

[20] L. Sun, G. W. DePuy, and G. W. Evans, Multi-objective Optimization Models for Patient Allocation during a Pandemic Influenza Outbreak, Computers and Operations Research, 51 (2014) 350–359. doi: 10.1016/j.cor.2013.12.001.

[21] M. Yousefi, M. Yousefi, R. P. M. Ferreira, J. H. Kim, and F. S. Fogliatto, Chaotic Genetic Algorithm and Adaboost Ensemble Metamodeling Approach for Optimum Resource Planning in Emergency Departments, Artificial Intelligence in Medicines, 84(2018) 23–33. doi: 10.1016/j.artmed.2017.10.002.

[22] Z. A. Collier, J. M. Keisler, B. D. Trump, J. C. Cegan, S. Wolberg, and I. Linkov, Value-Based Optimization of Healthcare Resource Allocation for COVID-19 Hot Spots, in COVID-19: Systemic Risk and Resilience, I. Linkov, J. M. Keenan, and B. D. Trump, Eds. Cham: Springer International Publishing, (2021) 103–114. doi: 10.1007/978-3-030-71587-8_7.

[23] S. Oueida, M. Aloqaily, and S. Ionescu, A Smart Healthcare Reward Model for Resource Allocation in Smart City, Multimedia Tools and Applications, 78(17) (2019) 24573–24594. doi: 10.1007/s11042-018-6647-4.

[24] R. P. Singh, M. Javaid, A. Haleem, and R. Suman, Internet of Things (IoT) Applications to Fight against COVID-19 Pandemic, Diabetes Metabolism Syndrome Clinical Research and Review., 14(4) (2020) 521–524. doi: 10.1016/j.dsx.2020.04.041.
[25] Y. Yin, Y. Zeng, X. Chen, and Y. Fan, The Internet of Things in Healthcare: An overview, Journal of Industrial Information Integration, 1(2016) 3–13. doi: 10.1016/j.jii.2016.03.004.
[26] V. M. Rohokale, N. R. Prasad, and R. Prasad, A Cooperative Internet of Things (IoT) For Rural Healthcare Monitoring and Control, in 2011 2nd International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology (Wireless VITAE), Chennai, India, (2011) 1–6. doi: 10.1109/WIRELESSVITAE.2011.5940920.
[27] L. M. R. Tarouco et al., Internet of Things in Healthcare: Interoperability and Security Issues, in 2012 IEEE International Conference on Communications (ICC), Ottawa, ON, Canada, (2012) 6121–6125. doi: 10.1109/ICC.2012.6364830.
[28] O. Bibani et al., A Demo of IoT Healthcare Application Provisioning in Hybrid Cloud/Fog Environment, in 2016 IEEE International Conference on Cloud Computing Technology and Science (CloudCom), Luxembourg, Luxembourg, (2016) 472–475. doi: 10.1109/CloudCom.2016.0081.
[29] J. Hu, W. Liang, Z. Zeng, Y. Xie, and J. Yang, A Framework for Fog-Assisted Healthcare Monitoring, Computer Science and Information System, 16 (3)(2019) 753–772. doi: 10.2298/CSIS180930025H.
[30] A. M. Elmisery, S. Rho, and D. Botvich, A Fog Based Middleware for Automated Compliance with OECD Privacy Principles in Internet of Healthcare Things, IEEE Access, 4 (2016) 8418–8441. doi: 10.1109/ACCESS.2016.2631546.
[31] A. M. Rahmani et al., Exploiting Smart E-Health Gateways at The Edge of Healthcare Internet-of-Things: A Fog Computing Approach, Future Generation. Computer Systems., 78 (2018) 641–658. doi: 10.1016/j.future.2017.02.014.
[32] P. H. Vilela, J. J. P. C. Rodrigues, R. da R. Righi, S. Kozlov, and V. F. Rodrigues, Looking at Fog Computing for E-Health through the Lens of Deployment Challenges and Applications, Sensors, 20 (9) (2020) 2553. doi: 10.3390/s20092553.
[33] M. P, K. K, M. B, and M. D, The Innovation for Smart Patient Screening Platform via IoT System, International Journal of Engineering Trends and Technology, 70(2) (2022) 192–200. doi: 10.14445/22315381/IJETT-V70I2P223.
[34] J. Nayak, B. Naik, P. Dinesh, K. Vakula, and P. B. Dash, Firefly Algorithm in Biomedical and Health Care: Advances, Issues and Challenges," SN Computer Science, 1(6)(2020) 311. doi: 10.1007/s42979-020-00320-x.
[35] B. P. Battula and D. Balaganesh2, Prediction of Hospital Re-admission Using Firefly Based Multi-Layer Perceptron, Ingénierie des Systèmes D Information, 25 (4)(2020) 527–533. doi: 10.18280/isi.250417.
[36] K. Rahul and R. K. Banyal, Firefly Algorithm: An Optimization Solution in Big Data Processing for The Healthcare and Engineering Sector, International Journal of Speech Technology, (2020) doi: 10.1007/s10772-020-09783-y.
[37] R. Singh, C. Dutta, N. Singhal, and T. Choudhury, An Improved Vehicle Parking Mechanism to reduce Parking Space Searching Time using Firefly Algorithm and Feed Forward Back Propagation Method, Procedia Computer. Science. 167 (2020) 952–961.doi: 10.1016/j.procs.2020.03.394.
[38] E. Fatnassi, N. Guesmi, and T. Touil, An Application of a Discrete Firefly Algorithm in the Context of Smart Mobility, in Artificial Intelligence Trends in Intelligent Systems, R. Silhavy, R. Senkerik, Z. Kominkova Oplatkova, Z. Prokopova, and P. Silhavy, Eds. Cham: Springer International Publishing, 573 (2017) 434–443. doi: 10.1007/978-3-319-57261-1_43.
[39] A. Saba, A. Khalid, A. Ishaq, K. Parvez, S. Aimal, and N. Javaid, Home Energy Management using Firefly and Harmony Search Algorithm, 12th international Conference on P2P, Parallel, Grid, Cloud & Internet Computing, (2017).
[40] B. Farahani, F. Firouzi, V. Chang, M. Badaroglu, N. Constant, and K. Mankodiya, Towards Fog-driven IoT eHealth: Promises and Challenges of IoT in Medicine and Healthcare, Future Generation Computer System, 78 (2018) 659–676. doi: 10.1016/j.future.2017.04.036.
[41] N. F. Johari, A. M. Zain, M. H. Noorfa, and A. Udin, Firefly Algorithm for Optimization Problem, Applied Mechanics and Materials., 421(2013) 512–517. doi: 10.4028/www.scientific.net/AMM.421.512.
[42] Y. Eren, İ. B. Küçükdemiral, and İ. Üstoğlu, Chapter 2 - Introduction to Optimization, in Optimization in Renewable Energy Systems, (2017) 27–74. doi: 10.1016/B978-0-08-101041-9.00002-8.
[43] C. Mechalikh, H. Taktak, and F. Moussa, PureEdgeSim: A Simulation Toolkit for Performance Evaluation of Cloud Fog and Pure Edge Computing Environments, in 2019 International Conference on High-Performance Computing & Simulation (HPCS), Dublin, Ireland, (2019) doi: 10.1109/HPCS48598.2019.9188059.
[44] https://www.covid19india.org/