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Adopting effective hierarchal IoMTs computing with K-efficient clustering to control and forecast COVID-19 cases

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ABSTRACT

The Internet of Medical Things (IoMTs) based on fog/cloud computing has been effectively proven to improve the controlling, monitoring, and care quality of Coronavirus disease 2019 (COVID-19) patients. One of the convenient approaches to assess symptomatic patients is to group patients with comparable symptoms and provide an overview of the required level of care to patients with similar conditions. Therefore, this study adopts an effective hierarchal IoMTs computing with K-Efficient clustering to control and forecast COVID-19 cases. The proposed system integrates the K-Means and K-Medoids clusterings to monitor the health status of patients, early detection of COVID-19 cases, and process data in real-time with ultra-low latency. In addition, the data analysis takes into account the primary requirements of the network to assist in understanding the nature of COVID-19. Based on the findings, the K-Efficient clustering with fog computing is a more effective approach to analyse the status of patients compared to that of K-Means and K-Medoids in terms of intra-class, inter-class, running time, the latency of network, and RAM consumption. In summary, the outcome of this study provides a novel approach for remote monitoring and handling of infected COVID-19 patients through real-time personalised treatment services.

1. Introduction

At the end of December 2019, a deadly coronavirus appeared in the Chinese city of Wuhan, which caused mild to severe respiratory symptoms, with most infection cases occurred in the form of acute pneumonia. Formally known as Coronavirus disease 2019 (COVID-19), the disease has inflicted massive fatality in most countries across the globe [1].

An infected individual could spread the virus by sneezing, coughing, or talking to someone else nearby. Given that the rapid spreading of the disease posed a catastrophic threat to the global community, isolated health care (quarantine) centres have been set up as an alternative strategy to curb the spreading of the disease . In this case, one of the effective frameworks that health institutions must develop is the remote monitoring and handling of infected patients in quarantine centres [2]. The early detection of the coronavirus is also considered the best approach to enhance the survival rate of COVID-19 patients. In view of this, the advanced Internet of Medical Things (IoMTs), cloud computing, fog computing, and Medical Machine Learning (MML) algorithms could be potentially utilised in adopting real-time personalised services to address this issue.

The integration of MML in IoMTs applications would facilitate the adoption of highly intelligent IoMT frameworks considering the

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operational performance and efficiency of all institutions affiliated with the health ministry. Generally, MML algorithms are integrated with IoMTs frameworks to detect a difference in knowledge patterns from the data generated by the IoMT device, which would correlate the nature of the particular disease and the patient's health status. It is expected that MML could address urgent issues once the information regarding the COVID-19 patient is gathered [3]. In addition, MML assists doctors to perform a precise diagnostic process to understand the diagnostic principles. In terms of data science and MML, both medical unsupervised and medically supervised Machine Learning (ML) has been frequently utilised to solve a variety of real-world issues [4]. Since the MML algorithms differ in data pre-processing, training, testing, and computational complexity, IoMT applications could be developed and scaled up from individual IoMT-based devices to broad fog/cloud computing servers [5]. Furthermore, it is possible to gain detailed insight into the treatment quality of various patients by grouping them according to their COVID-19 symptom severity levels. Unsupervised MML is being used in the case of clustering [6,7].

Few researchers have thoroughly examined the use of IoMTs technology to study the spread of COVID-19 infection. Previously, Mwaffaq Otoom et al. [8] proposed an Internet of Things (IoT) framework that includes five main components and employed eight classification algorithms on actual COVID-19 symptom data comprising Naïve Bayes, Decision Table, Decision Stump, Neural Network, K-Nearest Neighbour (KNN), ZeroR, Support Vector Machine, and OneR to detect COVID-19 cases. In another study, Prabhdeep Singh and Rajbir Kaur [9] developed fog/cloud computing that relied on the IoTs to protect and prevent the spread of COVID-19. The study applied three classifiers, namely, Naive Bayes, Random Forest, and Generative adversarial networks, as well as the Root Mean Square Error (RMSE), recall, and response time to evaluate the system. Meanwhile, Rajendrani Mukherjee et al. [10] suggested an Enhanced K-Nearest Neighbour (eKNN) algorithm to assess COVID-19 data of various sizes from the standard data cloud of numerous countries. The findings described a higher performance of eKNN with Ant Colony Optimisation (ACO) compared to that of eKNN without ACO.

In addition, Ameni Kallel et al. [11] suggested an integrated COVID-19 system comprising ML algorithms, fog/cloud, and IoTs for supervision and prediction purposes. The relevant data were collected from both non-medical and medical devices and the classifiers were evaluated in Python's Scikit-learn library, including Linear Support Vector Classification, Adaptive Boosting, KNN, Random Forest, Decision Tree, Multi-Layer Perceptron, Gradient Boosting, and Gaussian Naive Bayes in terms of RMSE, precision, accuracy, F1 score, and training time. Besides, Ajay Singh et al. [12] developed a scalable and time-sensitive infrastructure of IoTs using fog/cloud computing and Deep Neural Networks (DNN) for mask and distance detection. The accuracy, precision, recall, and response time of the system were also evaluated. Based on the available literature, the combination of IoMTs with cloud/fog computing and classification algorithms has been shown to facilitate the early diagnosis of COVID-19 patients and the processing with little cumin of clinical data. Although past studies have proposed several classification algorithms with IoMTs technologies to control the spread of COVID-19, none of them adopted a complete, integrated, and customised framework that uses an effective clustering algorithm to analyse and forecast COVID-19 cases.

Realising that clustering methods are necessary for COVID-19 data analysis, this study was performed to better comprehend the most cutting-edge and useful IoMT integration applications, cloud/fog computing, and MML in the control and forecast of COVID-19 cases. The research question was established, as follows: How does the integrated fog/cloud computing with IoT-based ML algorithms promote the prediction and control of COVID-19 cases? The clustering algorithms were used instead of the classification algorithms of MML since the sensor data in the IoMTs are known to be multi-type and large. Additionally, the data from the sensors is time-sensitive as the sensors acquire different measured values at different times. The large obstacles posed by these features for ML in IoMT applications make it very suitable to predict COVID-19 cases.

Thus, this study adopted the hierarchal IoMTs computing framework, which contains the cloud/fog computing based on the K-Efficient clustering (integrating between K-Medoids and K-Means) to address the basic requirements of interoperability, network dynamics, context discovery, scalability, reliability, and privacy in the case of remote patient monitoring in isolated hospitals in Iraq. The effectiveness of the proposed computation is explained, as follows: Firstly, data processing and IoT sensor systems communicate faster. Secondly, massive amounts of data can be aggregated, integrated, and shared in the system that can be highly scalable and have virtually endless storage space. Based on the research question, numerous articles were collected from different databases, such as Scopus, PubMed, Science Direct, MEDLINE, Web of Science, and Google Scholar. These databases were selected since they provide access to the scientific collection of legitimate and credible published research papers. The key search terms were IoTs, IoMTs, COVID-19, data mining, machine learning, health care, fog computing, patients, and cloud computing. Two Boolean operators, particularly AND and OR, were utilised during the search in the database to provide essential outcomes for the related research articles. This study also highlights the difference between fog and cloud computing as well as the difference between K-Means and K-Medoids clustering, giving it an edge over the rest of the literature.

The organization of paper contains following format i.e in Section 1 determined introduction about clustering, IoMTs, COVID-19, and why this study is important. The Section 2 concise of comprehensive theoretical background. Section 3 is describing the proposed methodology. The Section 4 determine the results and Section 5 describe the conclusion and the future work.

2. Comprehensive Theoretical Background

2.1. Internet of medical things (IoMTs)

It is impossible to follow up on all patients treated using traditional diagnosis methods without proper medical tests. In particular, COVID-patients are separated and quarantined to avoid close contact with caregivers, family members, or even doctors. Hence, it is crucial to implement cutting-edge technology to facilitate the treatment process. IoMTs is a branch of IoTs that offers the best technology for remote monitoring of COVID-19 patients. IoMTs collect and share information to enable easy monitoring of the environment surrounding the patients through the use of smart devices and objects. To date, IoMTs have been applied in healthcare settings with more extensive benefits associated with the remote assessment of patients' conditions and surrounding environments. The application of IoMTs has also contributed to the improved quality of healthcare technology and the health and well-being of patients [13,14]. Fig. 1 depicts the overall set-up of IoMTs.

2.2. Fog and cloud computing

Cloud computing technology is used for computation, processing, convenient sharing of resources, and storage purposes. It is the most effective and appropriate approach to improve the quality of healthcare services because it provides plentiful storage and is suitable to process enormous volumes of low-cost patient data. In comparison, the fog computing approach extends the storage resources and computing closer to users [15]. Fog computing also supplies ultra-low delay in a real-time solution. The advantages of fog computing include reduced latency, enhanced response time, improved compliance, improved security, greater privacy of data, and minimal cost of bandwidth. Since both techniques facilitate access to IoMT-based healthcare applications, they can be integrated into the healthcare sector to address multiple issues [16]. Table 1 compares the features of fog computing and cloud computing.

2.3. K-Means clustering and K-Medoids clustering

K-Means is a form of unsupervised ML. The first step in the procedure is to randomly select k-clusters and data points as cluster centres. Each point is then assigned to the cluster whose centre is the closest to it. The closest distance estimated between x and y centres is determined by the Euclidian distance, as expressed in Eq. (1). The cluster centres are updated and replaced using the cluster points. The procedure is repeated until the clusters reached a stable condition [17,18]. Although K-Means can handle a large amount of data and is easily implemented, it has several limitations. The integer k influences the outcome [19], while the overall method is vulnerable to noise and outliers due to the early convergence caused by the average of the individual points in the cluster. Moreover, non-numerical data, such as categorical and ordinal data, are restricted by this rule [20].

$$d(x,y) = \sqrt{(x_1 - y_n)^2 + \ldots + (x_n - y_n)^2} \tag{1}$$

Interestingly, the structure of K-Medoids is comparably identical to that of K-Means [21]. For K-Medoids, the distance between two objects is first calculated and the medoid is selected as the object with the least average dissimilarity to all other objects. Then, update and replace the medoid by comparing the sum of distances between the medoid and points and the sum of distances between a point

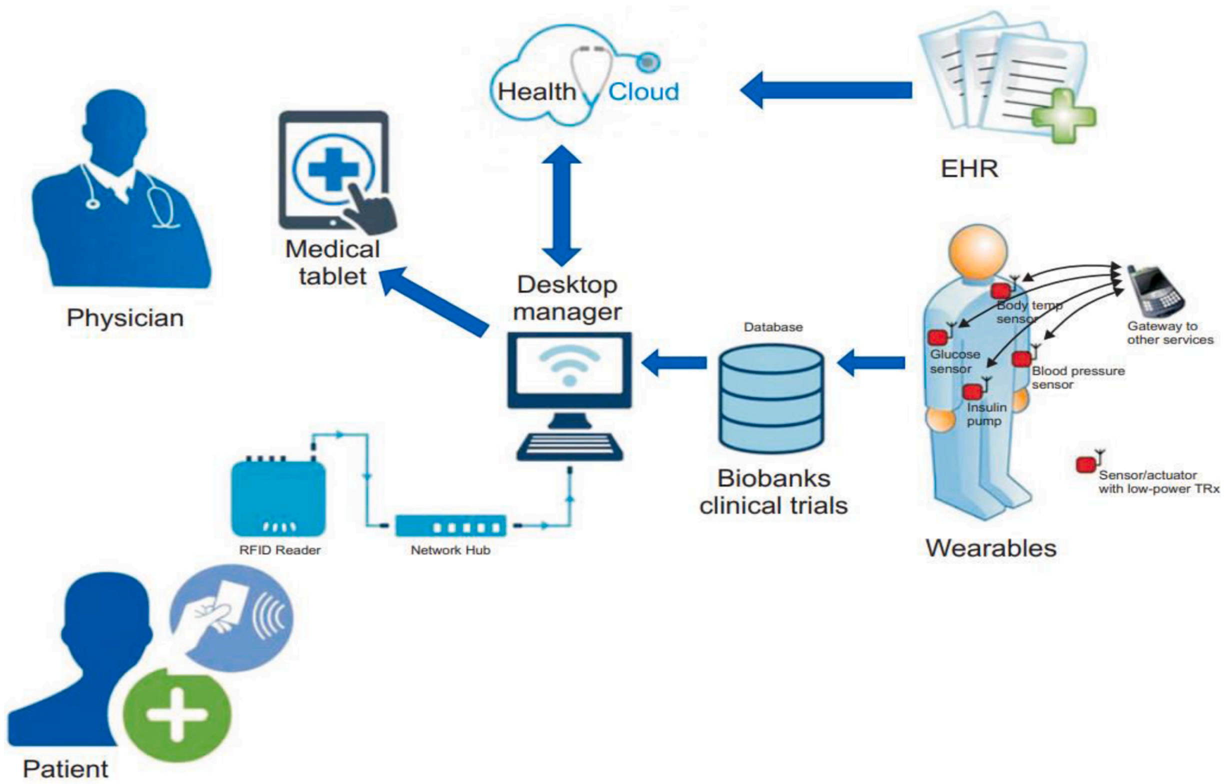

Fig. 1. Overall set-up of Internet of Medical Things (IoMTs).

Table 1
Comparison between fog computing and cloud computing.

Cloud computing	Fog computing
Servers on the internet	Servers at the network's edge
Several hops	Only one hop
No awareness of one's location	Awareness of location
Supports real-time interaction	Supports real-time interaction

and other points. As a result, K-Medoids are more resilient to noise and it is outliers compared to the K-Means. In order to avoid premature convergence, medoids are used to depict the centres and produce relatively successful results [21,22].

3. Proposed methodology

This research aimed to develop an IoMTs platform with a K-Efficient clustering model to analyse and predict the COVID-19 status of patients (positive or negative) in real-time using actual data. This framework enables the best sense of the nature of the COVID-19 virus to achieve accurate and reliable findings and assist decision-makers in hospitals and quarantine centres. Fig. 2 illustrates the proposed adopted efficient hierarchal IoMT computing framework, which consists of three main layers: sensor layer, fog computing layer, and cloud computing layer. Patients can monitor their health using wearable devices with the use of control mechanisms, granting greater choice over their lives and the way they handle their health.

The K-Means was employed in the proposed system given its various benefits, including easy implementation, adaptation to massive datasets, ensuring convergence, ability to move the centres of mass at a comfortable pace, adapts well to new examples, and compatibility with varying sizes and forms of clusters. Table 2 offers the comparison between K-Means and K-Medoids.

3.1. Sensor layer

The sensor layer is also known as the Wearable Devices Layer or Collection and Uploading of Symptom features data. In order to gather the desired COVID-19 data, this layer involves various sensors to collect real-time data and mobile applications to detect human activity, such as contact and travel history through the past month. In this study, wearable health monitoring sensors were used to monitor a patient's physical status. Actual data were collected from isolated centres in different Iraq provinces. Multiple laboratory test factors (symptoms) were collected from numerous sensors, including cough, temperature, headache, taste sense, and smell sense. These symptoms are used to predict the target class. Due to the curfew conditions in Iraq, the proposed system was tested on 724 patients from hospitals across Iraq to evaluate the integral patterns.

3.2. Fog computing layer

Controlling information across all node focuses represents a significant advancement for a distributed cloud. In addition, registration in the fog enables the transformation of the data centre into a client-facing distributed cloud platform. "Fog" is an extension that

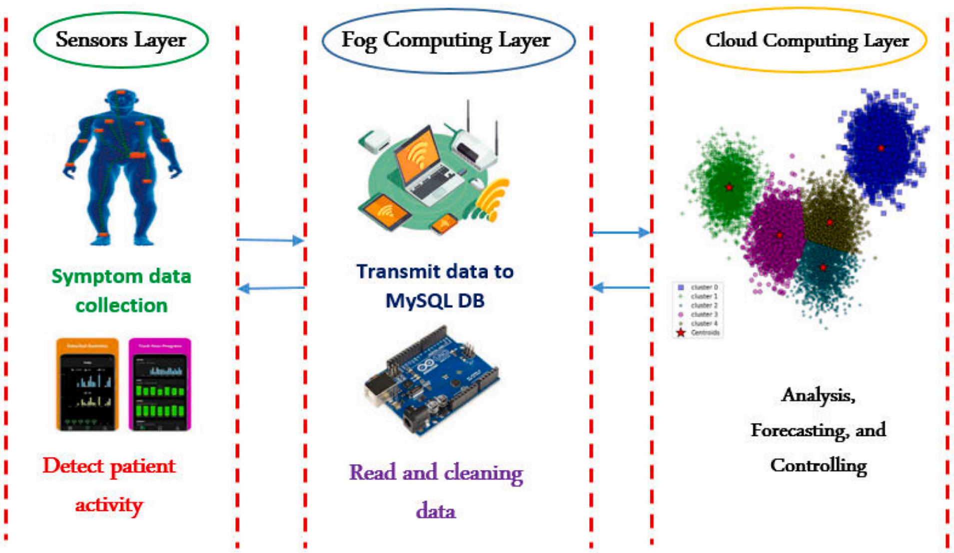

Fig. 2. The overall framework of the adopted hierarchal IoMTs computing with K-Efficient clustering.

Table 2
Comparison between K-Means and K-Medoids.

K-Means clustering	K-Medoids clustering
More effective	Less effective
Sensitive to outliers	Not sensitive to outliers
Easy implementation	Complex implementation
The initial partition affects the results and runtime	The initial partition affects the results and runtime
Requires advanced specification of k	Requires advanced specification of k

expands on the concept of "cloud" administrations. It broadens the scope of cloud computing to the system's edge, which aids in the creation of novel applications. Analysis of various acquisition of data methods and techniques have been performed to collect and analyse the data from IOTs-based devices by applying it to search for the upcoming events of enhancing them. Fog computing also minimises security risks.

The data from the sensors were sent to the main computer system in real-time via a Wi-Fi-based communication network between Arduino and laptops to read the sensor data since the sensors were inherently unable to translate symptom data. Each sensor was connected to the Arduino microcontroller. Symptom data were then transmitted to higher levels from the sensor and Arduino. Based on the placement of appliances, a collection of sensors with Arduino boards is deployed in each room. Because of irregularities and

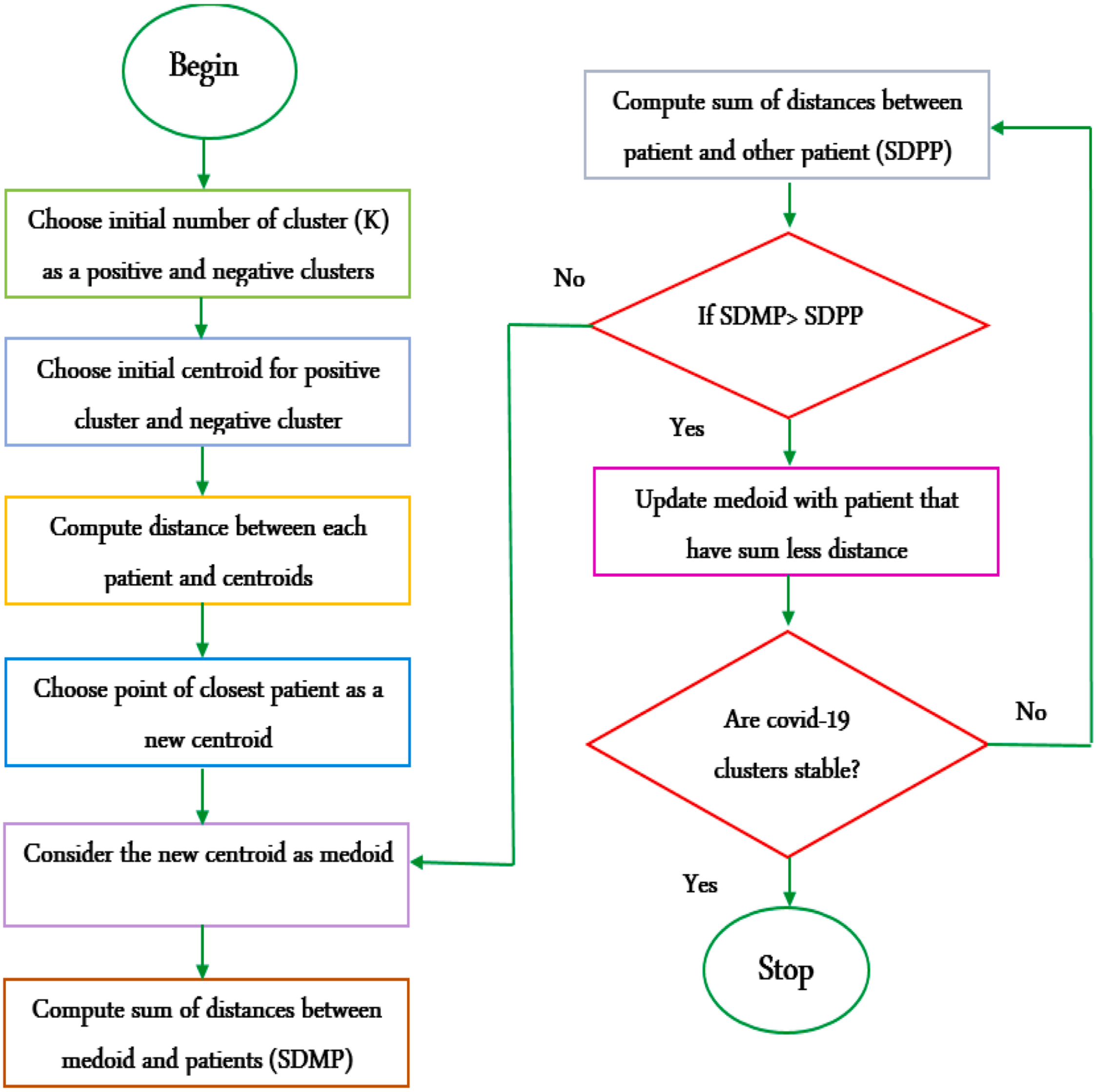

Fig. 3. Flowchart of K-Efficient clustering algorithm.

mistakes that must be extracted, fog processing and storage were conducted near the source of information on the network's edge, which is critical for real-time monitoring. The data pre-processing and refinement remove missing values and outliers from the dataset. As a result, data generalisation is regarded as one of the techniques for data reduction. The cleaned data was then passed into a locally hosted MySQL database in a fog server (laptop), which is an easy method to store the data. Subsequently, the data were pre-processed and organised for an efficient clustering algorithm in the cloud computing layer to make the data more useful. Finally, the COVID-19 data were stored on the public Amazon for the convenience of cloud computing given its large storage space that allows for huge information scalability.

3.3. Cloud computing layer

The online COVID-19 data were accessed through the public Amazon Elastic Compute Cloud (EC2) via the pay-per-usage method from any laptop, phone, or other device. Among the advantages of a cloud computing server include the ability to transfer the recommendations of doctors, monitor personal health information, transfer the outcomes of the prediction results, allow for information storage, and enable the upload of symptom features of each patient at any particular time. Therefore, the cloud computing server is required to support the K-Efficient clustering analysis.

This study proposed the K-Efficient clustering algorithm that depends on the integration of K-Medoids and K-Means to predict, analyse, and control COVID-19 cases. Fig. 3 presents an overall flowchart of the K-Efficient clustering algorithm. Theoretically, the setup is similar to that of K-Medoids, where it is the middle of K-Medoids and K-Means. Because the third instruction is implemented with fewer iterations, it is therefore innately similar to K-Means. In comparison to the random beginning centres, K-Means produces good ones. Thus, the K-Efficient clustering is not only able to manage big data sets but is also considered the most successful approach compared to K-Means since the K-Means results are enhanced. Additionally, the K-Efficient clustering is at least as effective as the K-Medoids. The only remaining drawback is the random number k initialisation, which is less biased due to the simultaneous call of the K-Medoids and K-Means.

4. Results and discussion

The K-Medoids, K-Means, and K-Efficient clustering were applied to label and group new patients according to the positive and negative clusters depending on the similar symptom data taken from the IoMTs sensor applications of the isolated Iraqi hospitals as the test case. In order to evaluate the effectiveness and performance of the adopted framework, various experiments were conducted using Java. The performance of the three algorithms was compared based on the inertia of the inter-class, the inertia of the intra-class, and the execution time. Firstly, two types of inertia were considered to measure the effectiveness of the algorithms, namely, the intra-class inertia, which represents the distance between negative and positive clusters, and the inter-class inertia, which calculates the remoteness between the data points of patients of clusters and the centroid or medoid [23].

Fig. 4 depicts the inertia experiments for the three clustering techniques. It was noticed that the distance between the positive and

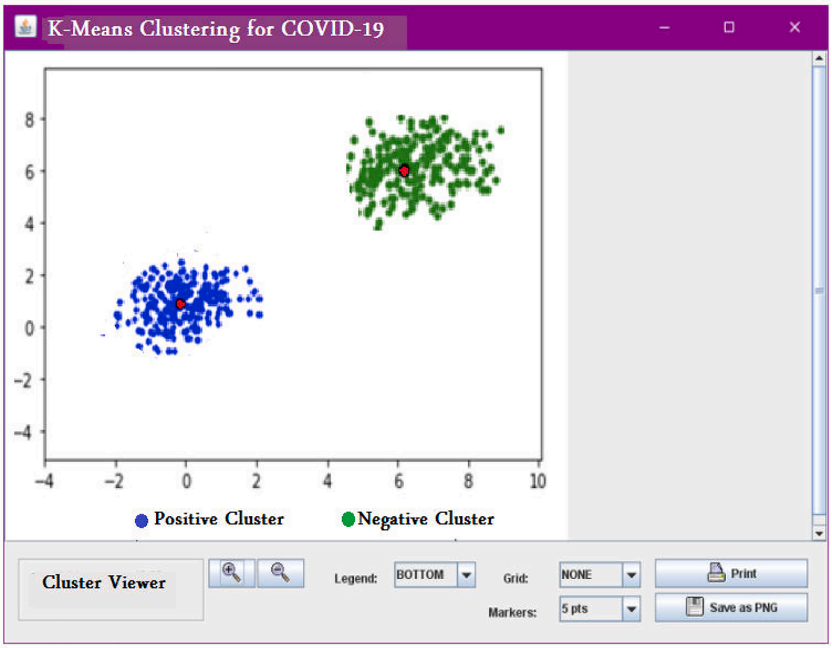

Fig. 4. Positive and negative clusters of the K-Means.

negative clusters in the clustering K-Means was relatively large, while the distance between the patients and the centroid was low. Meanwhile, Fig. 5 shows that the intra-class of K-Medoids is lower compared to the intra-class of K-Means, and the inter-class is larger than K-Means. Additionally, Fig. 6 indicates that the clustering of K-Efficient recorded the smallest distance between the negative and positive clusters (inertia of intra-class) and the largest inertia of inter-class. Simply put, the K-Efficient clustering patients were distributed over the clusters of COVID-19 cases in the better method compared to other algorithms. Therefore, it was deduced that the K-Efficient clustering exceeds the inertia of the different techniques.

Secondly, the running time of the three clustering algorithms was analysed, as shown in Fig. 7. Generally, the K-Efficient clustering took longer to predict the COVID-19 cases compared to the running time of K-Means but lesser time than the K-Medoids. This conforms to the earlier expectation that the K-Efficient clustering is faster than K-Medoids. For the benchmark, K-Efficient clustering achieved the best of both algorithms in terms of the K-Means speed and K-Medoids precision. The proposed system exhibit several novel aspects, including the ability to collect real-time COVID-19 data from IoMTs, the presence of layers of IoMTs, the ability to determine positive and negative COVID-19 clusters of varying sizes, the ability to remove and detect data noise/outliers, and its applicability to high-dimensional data. Interestingly, Habiba Drias et al. [24] recorded similar findings using the COIL-100 pictures and breast cancer data set to assess the performance of K-Medoids, K-Means, and K-Efficient clustering.

Fig. 8 shows the memory usage for allocating and processing data packets in cloud servers and fog nodes. The network use was decreased by allocating the data packets to the edge of networks. In addition, the RAM was employed to quantify the heap allocation, while various topology sizes and input workloads were simulated. The consumption of RAM is shown in Table 3 and Fig. 8. Besides, the latency of the network is presented in Table 4 and Fig. 9. By strategically placing the fog nodes at the network's latency, the algorithms implemented in iFogSim assisted in maintaining a minimum level of latency. Oppositely, the network latency rose when huge amounts of data were transferred between IoTs-based devices and cloud servers.

The fog computing and cloud computing performance in terms of communication latency across a variety of topology configurations is illustrated in Fig. 10 and Table 5. In this simulated scenario, the sensors initially produced a tuple and transmit it to the associated routers, gateways, and fog nodes. The fog server examined the incoming packet after the tuple arrives at the fog node and transfers the packet to a different fog node. Subsequently, the fog node transmits the data packet to the final recipients. When data packets are sent between the fog computing and IoMTs servers, the number of hop counts was reduced.

5. Conclusion and future work

This study successfully adopted a fog/cloud-integrated IoMTs platform to forecast and control COVID-19 cases by examining the K-Medoids, K-Means, and K-Efficient clustering. Based on the experimental validity of the K-Efficient clustering technique using the COVID-19 data set from Iraqi hospitals, the K-Efficient clustering achieved better results compared to that of K-Means as well as K-Medoids in terms of excellent intra-class, inter-class, and running time. This study also found that fog computing was more efficient than cloud computing with respect to the latency of network, the latency of communication, and the consumption of RAM. As the general public in Iraq becomes more aware of the spread of COVID-19, the findings in this study would assist health officials and doctors in Iraqi hospitals to step up their efforts to combat the spread of COVID-19. Nevertheless, future work should focus on enhancing the security aspect of the proposed system using Advance Encryption Standards (AES) to manage the sensitive data of

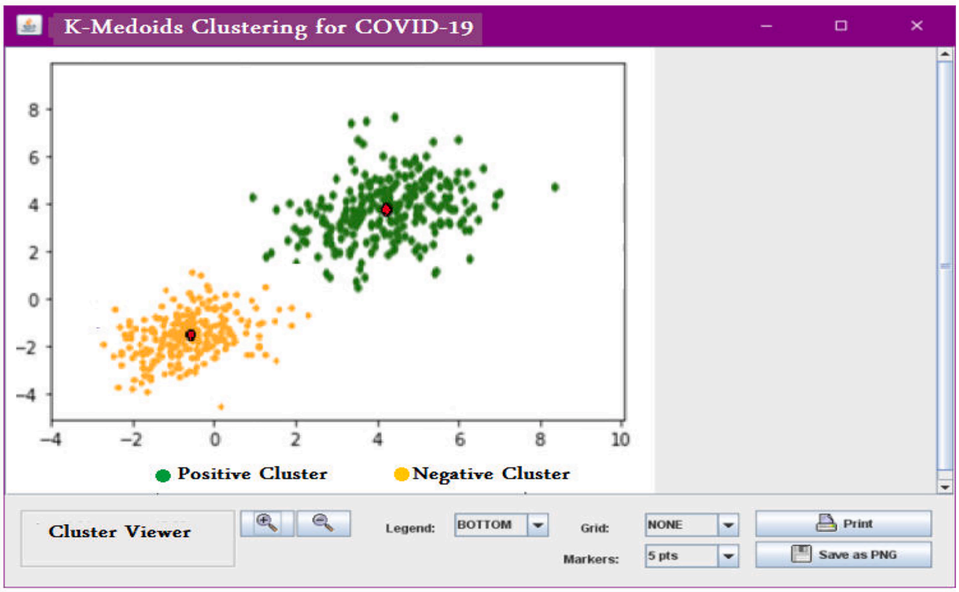

Fig. 5. Positive and negative clusters of the K-Medoids.

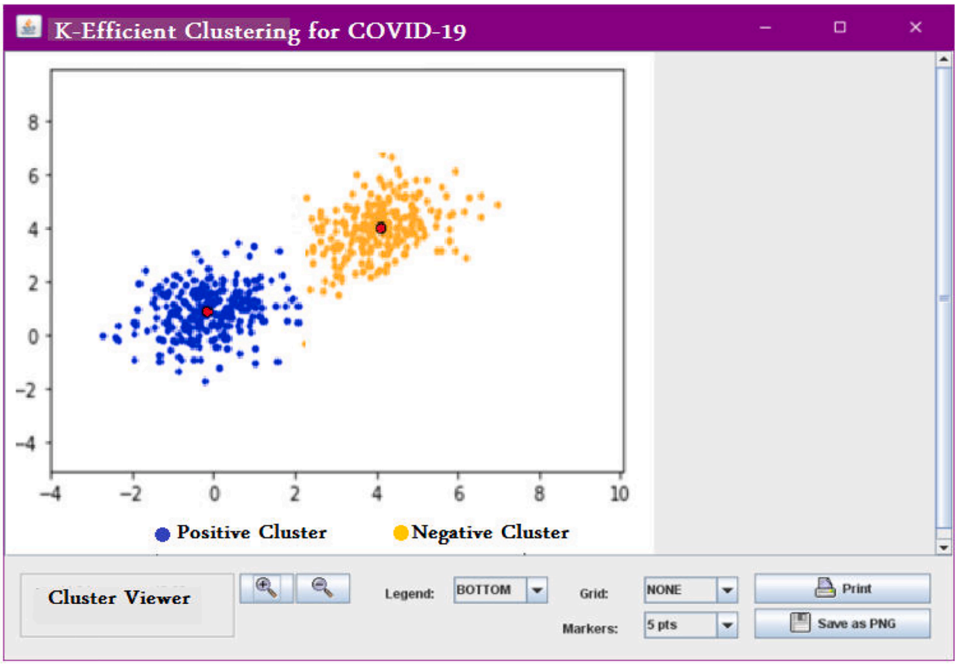

Fig. 6. The positive and negative clusters of K-Means.

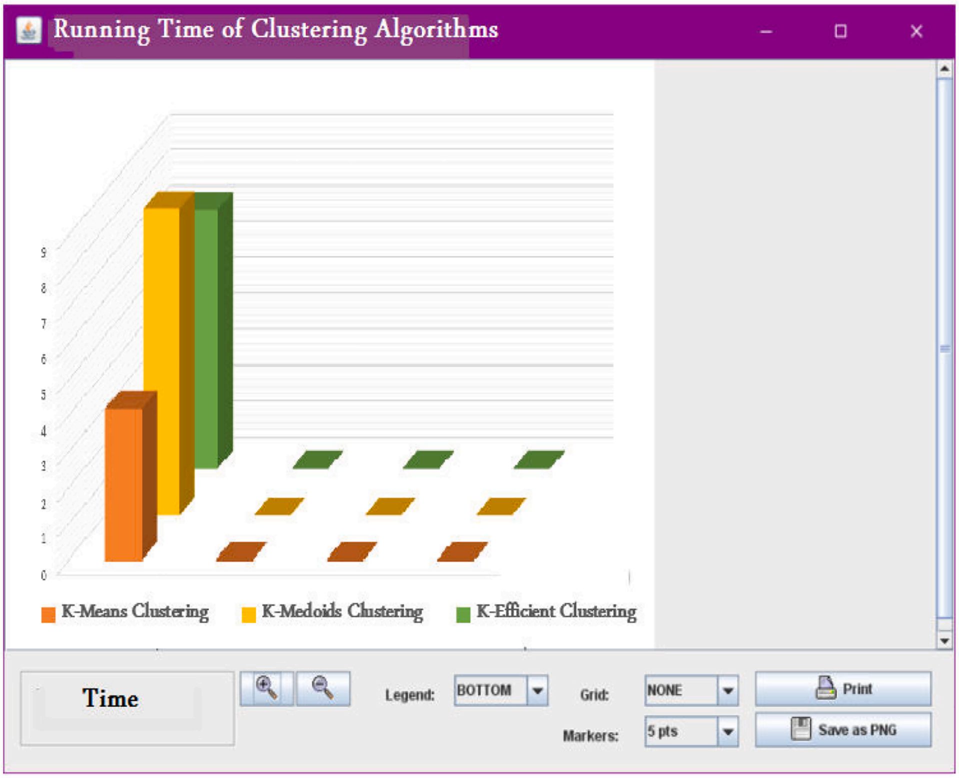

Fig. 7. Comparative of running time for clustering algorithms.

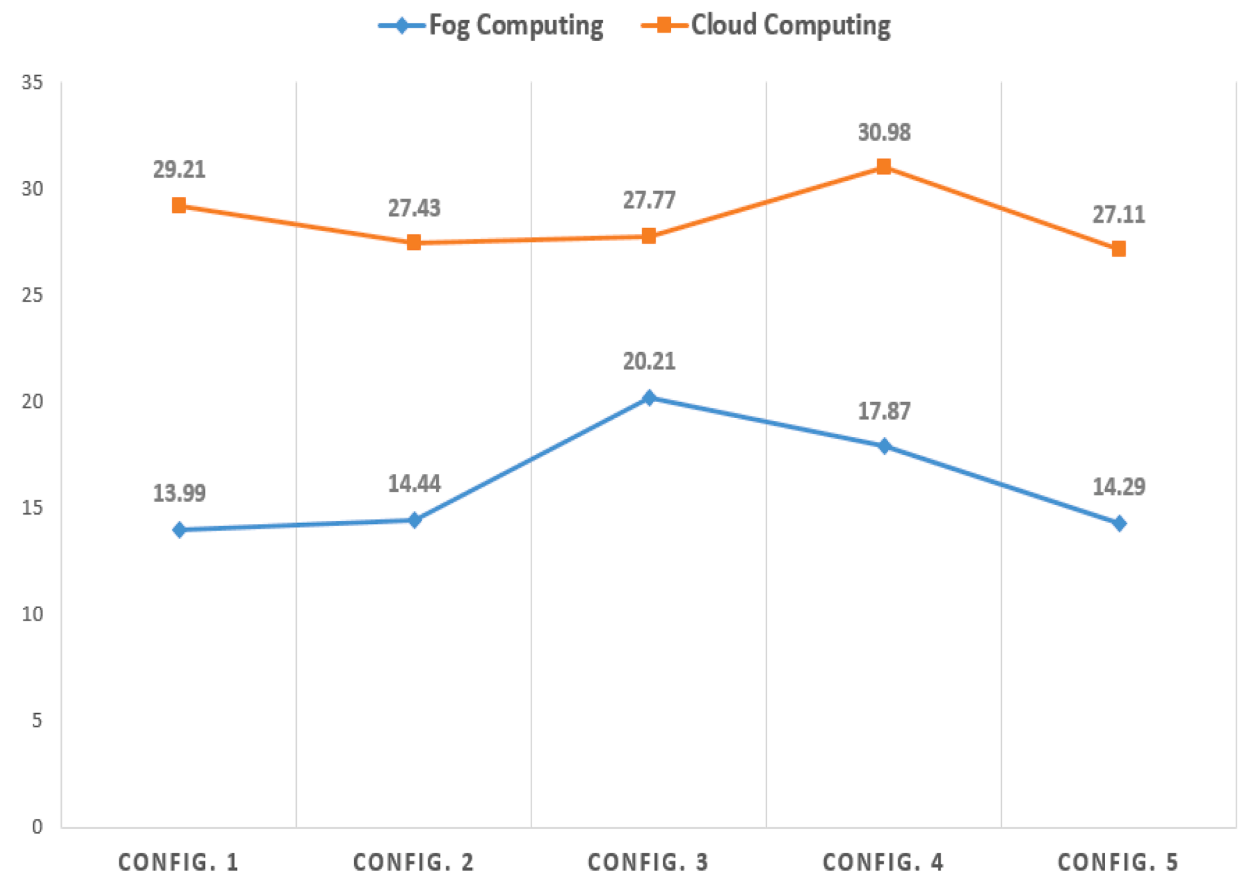

Fig. 8. Consumption of RAM.

Table 3
Consumption of RAM.

Configuration number	Fog computing	Cloud computing
Config. 1	40.65	120.99
Config. 2	50.66	140.78
Config. 3	59.88	140.92
Config. 4	70.44	150.79
Config. 5	100.92	200.42

Table 4
Latency of network.

Configuration number	Fog computing	Cloud computing
Config. 1	13.99	29.21
Config. 2	14.44	27.43
Config. 3	20.21	27.77
Config. 4	17.87	30.98
Config. 5	14.29	27.11

patients.

Declaration of Competing Interest

The authors declare that they have no competing interests.

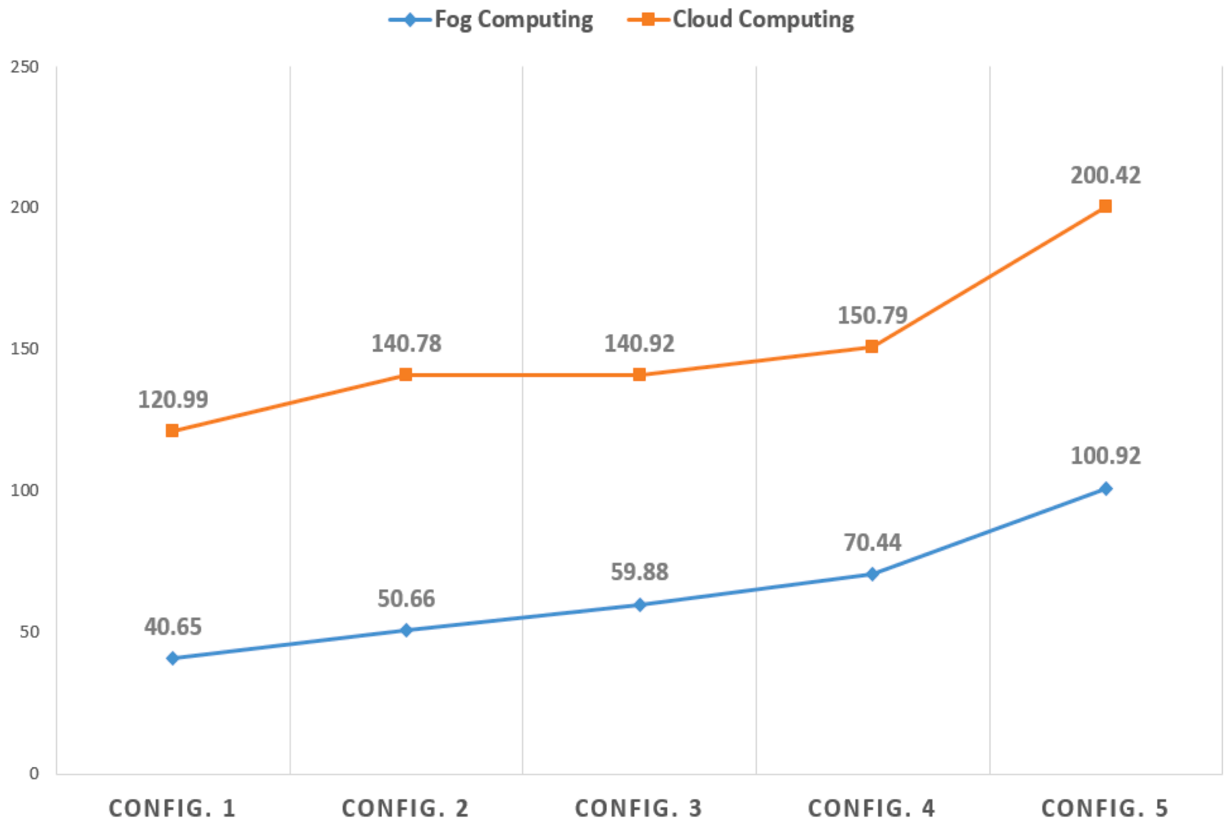

Fig. 9. Latency of network.

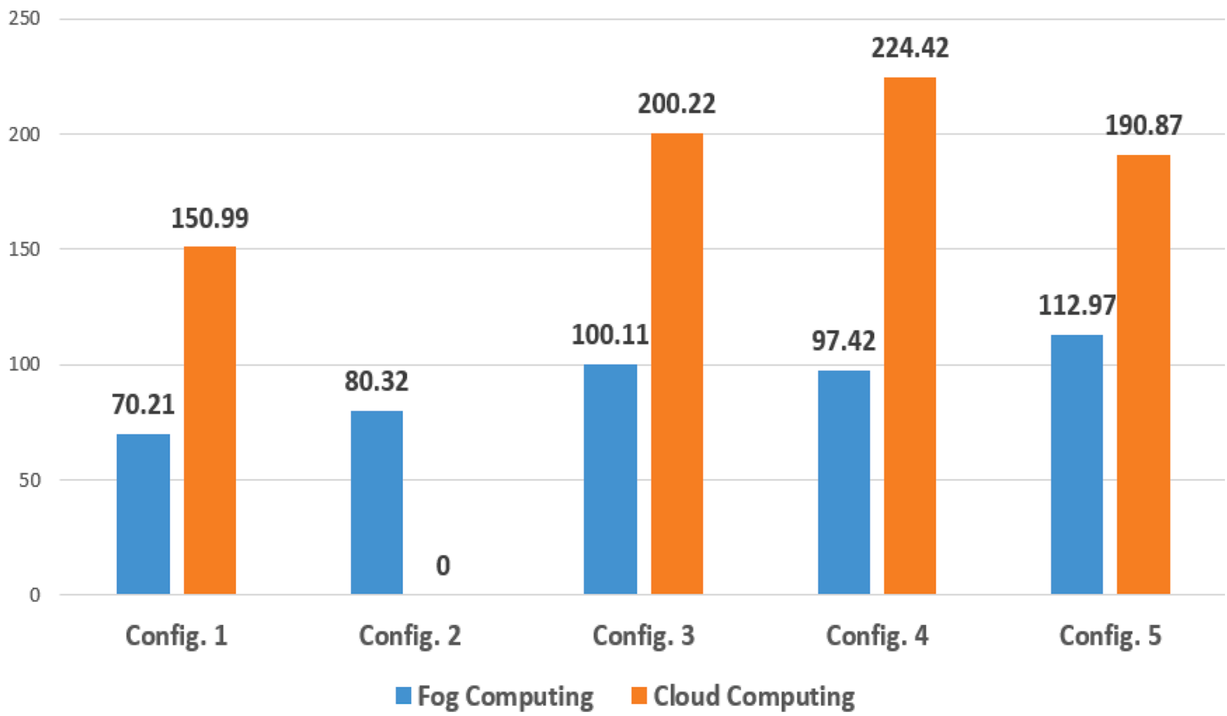

Fig. 10. Latency of Communication.

Table 5
Latency of communication.

Configuration number	Fog computing	Cloud computing
Config. 1	70.21	150.99
Config. 2	80.32	180.41
Config. 3	100.11	200.22
Config. 4	97.42	224.42
Config. 5	112.97	190.87

Data availability

Data will be made available on request.

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Further reading

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