Blockchain integrated multi-agent system for breast cancer diagnosis

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ABSTRACT

The integration of multi-agent system and blockchain technology can be beneficial to healthcare applications by providing intelligent data analysis with security. This paper presents an architecture that integrates multi-agent learning system and blockchain technology to support breast cancer diagnosis in a secured manner. The proposed system is based on a parallel hybrid fuzzy logic approach for supporting the prediction of breast cancer disease. The proposed system showed a classification accuracy of 96.49% in breast cancer diagnosis when testing with the Wisconsin diagnostic breast cancer dataset. The blockchain is used to provide agent security in the proposed system to ensure that the only trusted and reputed agents are participated in the decision-making process.

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1. INTRODUCTION

The innovation of different advanced technologies is continuously being happening every year for satisfying the human needs [1]-[9]. An artificial intelligence (AI) system is one of such technology that are beneficial to the society in different perspectives. Multi-agent system which is based on the distributed artificial intelligence concept is popular among healthcare related applications. Multi-agent system is a distributed software system built with several autonomous agents where the agents communicate with each other and find solutions for the complicated problems. In multi-agent system, the agents are built with characteristics such as every agent has partial knowledge for achieving the goal, individual agents don't have full global view, decentralized data, and asynchronous computation [10]. Each agent will have capacity to operate consistently and autonomously in accordance with the rules. Multi-agent system is developed using agent-based software engineering which is a software design technique based on the distributed artificial intelligence concept [11]. Multi-agent systems are necessary for complex application where the complicated data needs to be managed in an intelligent fashion. Multi-agent system will be able to address the issues that are above the knowledge and capacity of an individual agent. Multi-agent system is gaining popularity for its application in healthcare industry. Multi-agent system is suitable for healthcare applications in which the artificial intelligence algorithms are used to estimate human cognition in the analysis of complicated medical data. Multi-agent system has been designed and developed for many healthcare applications such as medical diagnosis, decision-making for treatment, development of drug design, monitoring, and caring of patients [12]. There are many security frameworks proposed for security in multi-agent system [13]-[19] but enhancing the security in agent decision-making process is a research challenge. That is, only a more trusted and reputed agents should get participated in the agent decision-making process. This issue can be addressed by integrating blockchain technology with the multi-agent system.

Blockchain are tamper resistant decentralized distributed digital ledger that securely stores the transaction between a community of users [20]. The blockchain concept became popular in 2008 during the invention of Bitcoin which is a blockchain based cryptocurrency [21]. The blockchain concept has been implemented to support many applications beyond cryptocurrency such as smart contracts [22], distributed ledger for business [23], secure data storage [24], and online gaming [25]. There are many platforms for developing blockchain applications such as Ethereum [26] and Hyperledger fabric [27]. Although there are many innovations in blockchain related technologies, the similar concepts are used to build the blockchain. Blockchain technology uses cryptographic methods to secure all valuable information and transactions. Asymmetric cryptography algorithms, digital signature techniques, and hashing functions are used in most of the blockchain network. For example, elliptic curve digital signature algorithm [28] is used in bitcoin network to ensure that the transactions in blockchain are done by authorized owners, and hashing algorithm called secure hash algorithm (SHA-256) [29] is used to preserve the transaction data in individual blocks of blockchain to ensure that the transaction data are not modified. In blockchain, a paired private key and public key are given to every user. The public key act as the address of the user and is visible to everyone. The private key is secret one which is used to prove the ownership of the user. The blockchain user uses the private key to sign in and make transaction to another account. After making the transaction, any participant on the blockchain can view the users public key to ensure that transaction is made only an authorized owner who holds the respective private key. Every transaction data is sent through a hash function which converts the input string of any length into a unique hash of fixed length. Each block of the blockchain contains hash function of the current block data and hash function of the previous block data. The transaction data cannot be modified in blockchain as every block contains hash function of the previous block data. The hash function of the transaction data is the public key which is considered as the address of the respective user in blockchain. Consensus algorithms are used in blockchain which provide additional security by validating each new block before it gets added to the blockchain. Each block of blockchain consists of a hash value of the current block, hash value of the previous block, nonce, transaction data, and timestamp. Nonce is a string of random numbers that can be used only once. Timestamp is the record of actual time when the block was created. Timestamp ensures that there are no repeated transactions. The blockchain verifies and validates every transaction without any central authority using the consensus algorithm. The blockchain consensus algorithm is a process in which all the peers of blockchain network reaches a common agreement to add each block in blockchain network. The consensus algorithms require a mining process in which the volunteers (or miners) validate a new transaction by solving a computational problem. Only then a new block is created and in return the miners receive a reward. For example, in the case of bitcoin, the miners solve a cryptographic puzzle for validating a new transaction and in return the miners receive a new bitcoin or transaction fee as reward.

The blockchain can be integrated with multi-agent system to support a medical diagnosis problem such as breast cancer diagnosis. Breast cancer is a kind of cancer that emerges in the breast and is mainly detected in the breast cells [30]. This disease is found mostly in women but rarely occurs in men [31]. There were also evidence claiming that the developed countries have the higher cases of breast cancer [32], [33]. Thousands of lives can be saved from the breast cancer if it is detected early. The manual method of detecting the breast tumors: malignant and benign is very complicated and time-consuming process as they share similar structures. The artificial intelligence techniques can give a reliable and faster approach for detecting breast cancer in patients [34], [35]. The artificial intelligence techniques are used in prediction of breast cancer either from the medical images [36]-[43] or from the datasets containing categorical and numerical values [44], [45]. The deep learning approaches are most commonly used for detection of breast cancer from medical images [46], [47]. The traditional machine learning algorithms such as decision tree learning [48], K-nearest neighbors (KNN) [49], Naïve Bayes (NB) [50], random forest [51], and support vector machine (SVM) [52] were most commonly used in many research works [53]-[58] to predict the breast cancer disease from datasets containing categorical and numerical values. The problem with the machine learning classifiers is that it can only classify the data based on the target class of training dataset. Dealing with the uncertain data and finding the risk level of breast cancer disease are some of the research challenges. A fuzzy expert system [59] has the ability to deal with uncertain data and to classify the risk level of patients within the given range if the fuzzy sets and fuzzy rule base are designed appropriately. A multi-agent system can be efficient to deal with uncertain data if it employs several fuzzy systems. There are various hybrid fuzzy approaches proposed for breast cancer diagnosis [60]. The machine learning algorithms or optimization techniques are integrated in the hybrid fuzzy systems to design the fuzzy sets and fuzzy rules [61]. The curse of dimensionality is the main problem in using a fuzzy system for breast cancer diagnosis. The accurate design of fuzzy sets and fuzzy rules based on the application is another problem in designing the fuzzy system. A hierarchical or parallel fuzzy logic approach [62]-[64] can be used to overcome the curse of dimensionality problem. The fuzzy sets and fuzzy rules in fuzzy system can be designed accurately using the benchmark medical datasets and machine learning algorithms.

Blockchain can be beneficial to the multi-agent system such as it can make the agent authentication more secure, it can make the agent communication more secure, it can protect the data from being altered, and moreover, it can ensure that the only trusted and reputed agents are joined in the agent decision-making process. There are recent research works on integration of multi-agent system and blockchain technology. In the research works [65], [66], the blockchain has been used with the multi-agent system for computing the agent reputation where the agent services and their interaction is recorded in blockchain, and the reputation of each agent is computed using a smart contract application. But the integration of multi-agent system and blockchain in data mining applications is a research problem because it requires a suitable consensus algorithm. The two main research questions in designing a blockchain integrated multi-agent learning system for breast cancer diagnosis are: i) can a multi-agent learning system be designed based on an effective hierarchical or parallel fuzzy logic approach?; ii) can an appropriate consensus algorithm be used in blockchain to integrate with the multi-agent learning system?

The objective of this paper is to present a parallel fuzzy logic approach based multi-agent system for breast cancer diagnosis and to integrate the blockchain technology with multi-agent system for providing agent security. An efficient blockchain integrated multi-agent learning system (BMAES) is proposed in this paper for breast cancer diagnosis where each classification agent uses different trained machine learning classifiers that are hybridized with the parallel fuzzy systems. In BMAES, the agents participate in the decision-making process through blockchain to give the final prediction for breast cancer diagnosis. The blockchain is used in BMAES to provide secure decision-making process for the agents. The blockchain needs a suitable consensus algorithm to integrate with the multi-agent learning system. Two novel consensus algorithms are introduced with the BMAES to support the integration of multi-agent learning system and blockchain. The remaining part of this paper is organized as shown in. The BMAES is described in section 2. The performance of BMAES is discussed in section 3. Finally, the conclusion is given in section 4.

2. THE PROPOSED SYSTEM

The architecture of the proposed BMAES is shown in Figure 1. The BMAES contains five classification agents, an intermediate agent and a blockchain. Each classification agent of the BMAES is designed with a three-layered parallel hybrid fuzzy system which is based on a NB based multiple parallel fuzzy reasoning method (NB-MPFR) [67] proposed in our previous work.

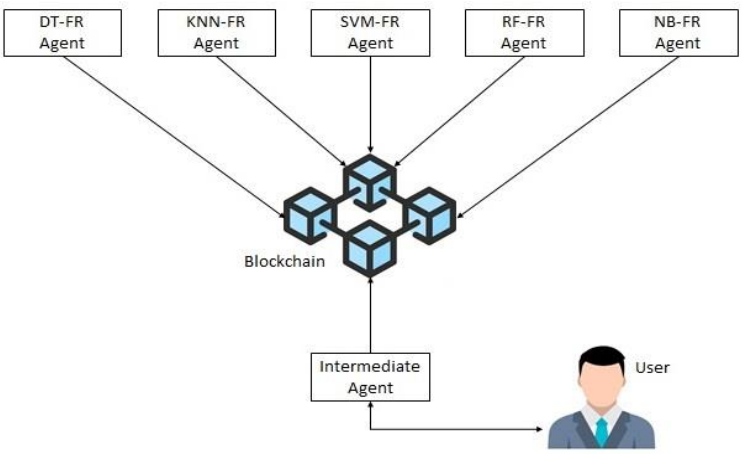

Figure 1. Architecture of the proposed BMAES

According to the NB-MPFR method, a number of sub fuzzy expert system are developed in a parallel structured where their outputs were combined to compute the final solution. The training dataset is used to define the sub fuzzy systems where the dataset is split into several groups based on the attributes in such a way that the data values of maximum of three input attributes and the data of target attribute in contained in each dataset group. The number of sub fuzzy systems are developed based on the number of dataset groups formed. Each sub fuzzy system is based on one dataset group where the inputs and outputs of the sub fuzzy system are the input and output attributes of the respective dataset group, respectively. The fuzzification process in each sub fuzzy system is based on the respective dataset group. In each input fuzzy set, the minimum and maximum data values of input attribute from the dataset group are used to set the x-axis limits. The membership degrees in each input fuzzy sets are set using the gaussian membership function [68]. The parameters of gaussian membership functions in each input fuzzy set are set using four different values which are computed from the data values of respective input attribute based on the quartile concept. Three different quartile values can be computed by dividing the data values of input attributes. The first quartile (FQ) value is identified by taking the median of minimum and median data values of the attribute, the second quartile (SQ) value is identified by taking the median data values of the attribute, the third quartile (TQ) value is identified by taking the median of median and maximum data values of the attribute. Four different gaussian membership functions are designed for each input fuzzy set. In the first gaussian membership function, FQ data value of the respective input attribute is considered as the mean value, and the standard deviation is computed between minimum and SQ data values of the respective input attribute. In the second gaussian membership function, SQ data value of the respective input attribute is considered as the mean value, and the standard deviation is computed between FQ and TQ data values of the respective input attribute. In the third gaussian membership function, TQ data value of the respective input attribute is considered as the mean value, and the standard deviation is computed between SQ and maximum data values of the respective input attribute. In the fourth gaussian membership function, the mean value is considered as the median of TQ and maximum data values of the respective input attribute, and the standard deviation is computed between TQ and maximum data values of the respective input attribute. The trapezoidal membership function [68] is used to set the membership degree in the output fuzzy set. The output fuzzy set of each sub fuzzy system is designed based on the training dataset where the number of membership functions in the output fuzzy set is based on the number of output classes in the dataset. If there are two output classes in the training dataset, then two trapezoidal membership functions are created for the output fuzzy set. The x-axis limits of the output fuzzy set are set randomly and the x-axis is split into two equal parts to plot the two trapezoidal membership functions. The fuzzy rule base in each sub fuzzy system is based on the naïve bayes classifier trained with the respective dataset group. The fuzzy rule base of each sub fuzzy system is defined with all possible combinations of the membership functions between different input fuzzy sets where their outcomes are selected using the trained naïve bayes classifier. The trained naïve bayes classifier is used for setting the consequent membership function for a specific input combination of membership functions between different input fuzzy sets in the fuzzy rule base. Here, the inputs to trained naïve bayes classifier are the median values of each membership function that are used as antecedents in the respective fuzzy rule. Based on the output of trained naïve bayes classifier, the consequent membership function is set to each fuzzy rule in the rule base. The centre of gravity (COG) method [69] is used for defuzzification process in each sub fuzzy system to get the crisp output. The average value of outputs from all the sub fuzzy systems is considered as the final output.

For BMAES, the NB-MPFR method is applied to develop a three-layered parallel fuzzy system for breast cancer classification and the NB-MPFR method is further extended by integrating other popular machine learning classifiers such as decision tree, KNN, random forest, and SVM with the three-layered parallel fuzzy system. These integrations result in five different parallel hybrid fuzzy systems which were employed in different agents of BMAES through an ensembled based approach for breast cancer diagnosis. As shown in Figure 1, the classification agents of BMAES are decision tree based fuzzy reasoning (DT-FR) agent, KNN based fuzzy reasoning (KNN-FR) agent, NB based fuzzy reasoning (NB-FR) agent, random forest based fuzzy reasoning (RF-FR) agent, and SVM based fuzzy reasoning (SVM-FR) agent which uses decision tree, KNN, gaussian NB, random forest, and SVM classifiers, respectively, in their fuzzy rule base. The intermediate agent in BMAES act as an intermediator between the user and the classification agents. Through the intermediate agent, the inputs are given to each classification agent. The intermediate agent gets the outputs from all agents and estimates the final solution.

The wisconsin diagnostic breast cancer (WDBC) dataset [70] is used for developing and testing the BMAES. The WDBC dataset consists of 569 samples where the main input features are radius, texture, perimeter, area, smoothness, compactness, concavity, concave points, symmetry, and fractal dimension of the cell nuclei which are computed from a digitized image of a fine needle aspirate of a breast mass. The mean, standard error, and worst values (mean of the three largest values) of these features are computed for each image which results in 30 input features. The class labels of the WDBC dataset are malignant and benign. The random forest method is used for feature selection from the WDBC dataset. From the feature selection process using random forest method, the selected input attributes are perimeter (mean), area(mean), concavity (mean), concave points (mean), radius (worst), perimeter (worst), area (worst), concave points (worst). As eight input attributes are selected from the feature selection process, three dataset groups are created from the breast dataset where each dataset group contain maximum of three input attributes and the target attribute. The first dataset group "BD_1" contains the input attributes: perimeter (mean), area (mean), and concavity (mean). The second dataset group "BD_2" contains the input attributes: concave points (mean), radius (worst), and perimeter (worst). The third dataset group "BD_3" contains the input attributes: area (worst) and concave points (worst). As three dataset groups are created, a three-layered parallel fuzzy system is implemented in each classification agent of the BMAES. Here, the three-layered parallel fuzzy system consists of three sub fuzzy systems (SF_1, SF_2, SF_3) where the input attributes of BD_1 are the inputs for SF_1, the input attributes of BD_2 are the inputs for SF_2, and the input attributes of BD_3 are the inputs for SF_3. The output classes of the breast dataset are the outputs for all the three sub fuzzy systems. Each of the dataset groups (BD_1, BD_2, BD_3) are further divided into two groups in 80:20 ratio as training dataset groups ($TRBD_1$, $TRBD_2$, $TRBD_3$) and testing dataset groups ($TEBD_1$, $TEBD_2$, $TEBD_3$), respectively. The training dataset groups: $TRBD_1$, $TRBD_2$, $TRBD_3$ are used for designing the fuzzy sets and training the machine learning classifier integrated in each classification agent. The testing dataset groups: $TEBD_1$, $TEBD_2$, $TEBD_3$ are used for testing the performance of each classification agent in BMAES.

In applying the NP-MPFR method in BMAES, a slight modification is done in the fuzzification process. Initially, the limits of x-axis in the input fuzzy sets are set using the minimum (x_{min}) and maximum (x_{max}) data value of the respective input attribute from dataset group. Four points are selected on the x-axis in input fuzzy sets such that the first point (P_1) is the median of minimum data value and FQ value, the second point (P_2) is the median of FQ and SQ values, the third point (P_3) is the median of SQ and TQ values, and the fourth point (P_4) is the median of TQ value and maximum data value. From the four points identified on the input fuzzy sets, four gaussian membership functions are used to mark the membership degrees. P_1 is given as the mean value and the standard deviation is computed between x_{min} and P_2 for the first gaussian membership function. P_2 is given as the mean value and the standard deviation is computed between P_1 and P_3 for the second gaussian membership function. P_3 is given as the mean value and the standard deviation is computed between P_2 and P_4 for the third gaussian membership function. P_4 is given as the mean value and the standard deviation is computed between P_3 and x_{max} for the fourth gaussian membership function. Table 1 shows the values of four points for all the input fuzzy sets that are computed from the respective training dataset groups ($TRBD_1$, $TRBD_2$, $TRBD_3$). These values are used to plot the gaussian membership functions on the input fuzzy sets. Two triangular membership functions [68] are plotted on the output fuzzy set that represent the output classes (benign, malignant) from the WDBC dataset. The limits of x-axis are set randomly from 0 to 100 for the output fuzzy set where the x-axis is split into two equal parts to plot two triangular membership functions.

Table 1. Data values of input attributes for plotting membership functions

Input Attributes	x_{min}	P_1	P_2	P_3	P_4	x_{max}
Perimeter (Mean)	43.79	61.88	98.06	134.23	170.41	188.5
Area (Mean)	143.5	437.94	1026.81	1615.69	2204.56	2499.0
Concavity (Mean)	0	0.05	0.16	0.27	0.37	0.43
Concave Points (Mean)	0.0	0.03	0.08	0.13	0.18	0.20
Radius (Worst)	7.93	11.08	17.38	23.68	29.98	33.13
Perimeter (Worst)	50.41	72.77	117.49	162.22	206.94	229.3
Area (Worst)	185.2	591.05	1402.75	2214.45	3026.15	3432.0
Concave Points (Worst)	0	0.04	0.11	0.19	0.25	0.29

The machine learning classifiers integrated in each classification agent are trained with the training dataset groups belonging to the respective sub fuzzy systems. The trained machine learning classifiers are used to set the consequent membership function in each rule of the fuzzy rule base. The decision tree, KNN (k=7), gaussian NB, random forest, SVM classifiers are used in DT-FR, KNN-FR, NB-FR, RF-FR, and SVM-FR agents, respectively. The COG defuzzification method is used in the sub fuzzy systems of each classification agent. The final output of each classification agent is the average value of outputs obtained from their sub fuzzy systems. The final output of BMAES is given by the intermediate agent which estimates the average value of outputs obtained from all the classification agents.

In BMAES, the blockchain technology is integrated with the multi-agent system to provide agent security. Through this integration, various security issues in multi-agent system are addressed such as agent authentication and secure data sharing. Here, the blockchain allows only trusted and reputed agents to join in the decision-making process of multi-agent system.

According to the BMAES architecture, the input data and output data are stored in blockchain to ensure that the data are not altered during agent decision-making process. The blockchain allows only an authenticated agent to store on blockchain. Each block in the blockchain contains data, sender agent's name, information about the data, index, timestamp, previous hash, and current hash. Initially seven blocks are created in blockchain. The first block is the genesis block. The other six blocks are for all the agents of multi-agent system where each block contains description about each agent. The initially created blocks in blockchain do not contain information about the sender agent. The current hash function of the blocks created for the agents is used as the sender agent's name when the respective agent stores the input and output data in blockchain. SHA-256 hashing algorithm is used to compute the hash value of each block. The agent authentication is processed using rivest-shamir-adleman (RSA) [71] cryptographic method. For each agent, the public and private keys are created using RSA method. A random number is encrypted using the respective agent's public key. If the agent correctly decrypts the encrypted text using its private key, then the agent is considered as authenticated agent to store the data in blockchain. In addition to the agent authentication, agent needs to solve the consensus algorithm to create new block for storing new data. Two different consensus algorithms are defined with the blockchain used in BMAES. The consensus algorithm called proof of input-output (IO) limits is used in BMAES for the intermediate agent and classification agents where it checks whether the each of input given by the user is within the limits of minimum and maximum values as given in the training dataset for the respective input attribute and the output given by each classification agent is within the limits of expected output values. If the inputs and outputs are not within the limits, then the new block is not created in blockchain for storing the inputs and outputs. Another consensus algorithm called proof of agent performance is used in BMAES for the classification agents where it checks whether the accuracy of the classification is above 70%. Only when the classification agent shows the classification accuracy of above 70%, it will be able to create new block in blockchain to store its output data. Once the data in stored in blockchain, the stored data can be retrieved by all the agents but the stored data cannot be altered. The agents check the sender agent's hash function and retrieve data from the respective block in blockchain. In this way, when the user gives input to intermediate agent, the intermediate agent stores the data in blockchain with its hash function as the sender agent description. When the intermediate agent request for creating new block in blockchain, the blockchain validates the block by checking whether the input data satisfies the proof of IO limits consensus algorithm. If the proof of IO limits consensus algorithm is satisfied, then the block is added to blockchain. The other classification agents check the latest block in blockchain. If the hash function given in the sender agent matches with the current hash function of intermediate agent block, then the classification agents retrieve the data from blockchain and use the input data for predicting the breast cancer disease. Each of the classification agent request for creating new block in blockchain to store its output. If the classification agent satisfies the proof of agent performance and proof of IO limits consensus algorithms, then new block is created in blockchain to store the output of the respective classification agent.

If the five classification agents: DT-FR, KNN-FR, NB-FR, RF-FR, SVM-FR satisfies the proof of agent performance and proof of IO limits consensus algorithms, then five new blocks are created in blockchain that store the outputs of different classification agents with giving their current hash functions as the sender agent description. The intermediate agent checks whether the hash function of the sender agents given in the latest five blocks matches with the current hash function of the respective classification agent blocks. If the sender agent's hash function of all the newly created blocks matches correctly, then the intermediate agent retrieves data from the newly created blocks and computes the final output by taking the average value of all outputs obtained from the classification agents.

Sensitivity, specificity, and accuracy measures which are based on the confusion matrix are used to evaluate the performance of the multi-agent system. The confusion matrix is used to compare the final output of the multi-agent system with the actual output given in the dataset using the test outcomes: true positive (TP), true negative (TN), false positive (FP), false negative (FN). Here, TP represents the number of samples that has been classified correctly with the class label of malignant, TN represents the number of samples that has been classified correctly with the class label of benign, FP represents the number of samples that has been classified incorrectly with the class label of malignant, and FN represents the number of samples that has been classified incorrectly with the class label of benign. Then, the sensitivity, specificity, and accuracy measures are estimated using (7), (8), and (9) [72].

$$\text{Sensitivity}=\frac{TP}{TP+FN} \quad (1)$$

$$\text{Specificity}=\frac{TN}{TN+FP} \quad (2)$$

$$\text{Accuracy}=\frac{TP+TN}{TP+TN+FP+FN} \quad (3)$$

3. RESULTS AND DISCUSSION

The BMAES is implemented using Mesa framework [73]. The testing dataset groups ($TEBD_1$, $TEBD_2$, $TEBD_3$) are used to test the BMAES. Table 2 shows the sensitivity, specificity, and accuracy of BMAES. Table 3 shows the sensitivity, specificity, and accuracy of the classification agents in BMAES. Table 4 compares the accuracy of BMAES with other classifiers that were applied for breast cancer diagnosis problem using the WDBC dataset. It is evident based on the comparison that the BMAES based on a parallel hybrid fuzzy method showed a better classification accuracy in breast cancer diagnosis. The receiver operating characteristics (ROC) graphs [74] were also used to examine the performance of BMAES. Figure 2 shows the ROC curves of BMAES for the WDBC dataset.

Table 2. Performance of BMAES

Proposed System	Sensitivity (%)	Specificity (%)	Accuracy (%)
BMAES	86.67	100	96.49

Table 3. Performance of classification agents in BMAES

Agents	Sensitivity (%)	Specificity (%)	Accuracy (%)
Decision tree based fuzzy agent	92.31	97.73	96.49
KNN based fuzzy agent	85.19	96.55	93.86
NB based fuzzy agent	86.67	100	96.49
Random forest based fuzzy agent	86.67	100	96.49
SVM based fuzzy agent	85.19	96.55	93.86

Table 4. Comparison of BMAES with other classifiers

Classifiers	Accuracy (%)
Proposed BMAES	96.49
Support Vector Machine [53]	61.96
Decision Tree [54]	94.03
Naïve Bayes [55]	91.18
K-Nearest Neighbor [53]	92.77
Random forest [56]	89.37
Mamdani-Fuzzy Inference System [57]	90.8
Sugeno- Fuzzy Inference System [57]	94.8
Fuzzy-ID3 [58]	94.53

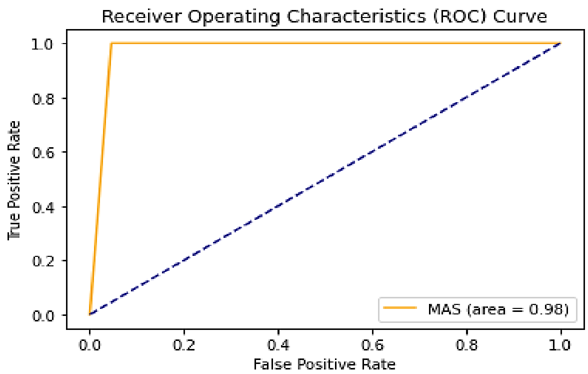

Figure 2. ROC of BMAES

The BMAES provides a security to multi-agent learning system by allowing only the trusted and reputed agents to get participated in the decision-making process for breast cancer diagnosis. In this way, the data that are shared between agents during the decision-making process are not altered. The consensus algorithm plays a main role in the performance of blockchain for providing security. Designing an appropriate blockchain consensus algorithm according to their application is a research problem in blockchain based applications. There are different consensus algorithms like proof of work [21], and proof of stake [75]. That were suitable for applications such as bitcoin, smart contracts, and cloud data security. For agent security, two consensus algorithms (proof of IO limits and proof of agent performance) were presented in BMAES. The comparison of the proposed two consensus algorithms with other existing blockchain consensus algorithms are shown in Table 5. The performance of blockchain in BMAES can be also evaluated by measuring the time used for creating every new block in blockchain during the execution process. As the agents are integrated with blockchain in BMAES, the block creation time is also based on the computational time of agents. Here, the computational time of agent is based on a three-layered parallel fuzzy system implemented in the agent. As the parallel fuzzy reasoning method takes a high computational time, the blockchain used in BMAES also takes a high computational time for creating new blocks.

Table 5. Comparison of different blockchain consensus algorithms

Consensus Algorithms	Benefits	Drawbacks
Proof of agent performance, proof of IO limits (Proposed)	Enhancing agent security in blockchain integrated multi-agent system	Consumes high computation time for block creation
Reputation based Consensus [65]	Tracks the reputation of agents in blockchain integrated multi-agent system	Depends on what basis the reputation is analyzed
Proof of work [76]	Smaller chance for 51% attack, fine security	Consumes high computational energy
Proof of stake [77]	Eradicating energy waste, enhancing the decentralization process	Risk of monopolizing the entire communication network by coin holders
Practical byzantine fault tolerance [78]	Verification not required, eradicating energy waste	No measure is taken for replacing the malicious or ineffective nodes
Proof of integrity [79]	Protects the data integrity	Slow and less user friendly because of large-scale computational capacity
Proof of validation [79]	Validating the data integrity	Used only in integration proof of integrity consensus algorithm
Proof of primitiveness [80]	Preserves the blockchain data	Suitable only for few applications
Proof of interoperability [81]	Verifies the interoperability of incoming data	Difficulty in measurements and analysis of healthcare data
Proof of conformance [82]	Depends on one authorized user for validating blocks	Suitable only for few applications

4. CONCLUSION

This paper proposed BMAES which integrates multi-agent system and blockchain for breast cancer diagnosis problem. In using the medical datasets for diagnosis of various types of diseases such as breast cancer, it may involve some incomplete or uncertain data which are difficult to handle. This issue can be handled by using fuzzy logic. But there are some problems in using fuzzy logic approaches. If the design of fuzzy sets and fuzzy rules in the fuzzy system is inappropriate, it may lead to poor results. The curse of dimensionality is another major problem in the fuzzy systems when dealing with many input attributes. To overcome these issues, BMAES employs several parallel fuzzy reasoning systems through various agents. In each classification agent of BMAES, two or more fuzzy systems are implemented in a parallel architecture to overcome the curse of dimensionality problem. Here, the WDBC dataset is used to effectively design the fuzzy sets and the machine learning classifier trained with WDBC dataset is used to define the fuzzy rules. Five different classification agents are used in BMAES where each agent is implemented with different hybrid fuzzy systems that are created based on decision tree, KNN, naïve bayes, random forest and SVM classifiers. The average score obtained from all classification agents is the final prediction for breast cancer diagnosis. By testing with WDBC dataset, the BMAES showed a classification accuracy of 96.49% in breast cancer diagnosis. In BMAES, the agents share their data through blockchain for making final prediction. The advantage of using blockchain in BMAES is that the data that are shared in blockchain cannot be altered. The blockchain technology in BMAES allows only the trusted and reputed agents to participate in the decision-making process. Here, two consensus algorithms (proof of agent performance and proof of IO limits) are used to evaluate the agents for sharing any data in blockchain. In this way, the blockchain ensures agent security by allowing only the trusted data to be shared in decision-making process. The BMAES presented an approach for enhancing the security in multi-agent learning system. As several hybrid fuzzy systems based on different machine learning classifiers are involved in BMAES, it takes a high computational time for reasoning and block creation process. This computational time may differ according to the computational models used in agents. The BMAES can be applied to similar types of medical diagnosis problem and will be beneficial to the healthcare organizations. The BMAES has capacity to extract the risk levels of patients from medical datasets as it employs several parallel fuzzy reasoning systems. The BMAES architecture can be extended to support the medical diagnosis problem more effectively by integrating it with the distributed planning and optimization techniques.

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