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Smart library architecture based on internet of things (IoT) and software defined networking (SDN)

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ABSTRACT

Internet of Things (IoT) is being widely developed in various fields, and its penetration rate in daily life is continuously increasing. The nature of the social function of objects and giving them an identity has made it possible to successfully integrate this technology into many traditional systems and improve their performance by automation. Libraries are one of the most obvious examples of smartening by IoT architecture. So far, various architectures have been presented for smartening libraries through IoT technology. However, a low-cost and ideal architecture that can cover all the requirements in a wide range of smart library applications has not been provided. This article attempts to fill some of the existing research gaps in this field by presenting a new architecture for smartening libraries. In the proposed method, Software Defined Networking (SDN) is used to reduce implementation costs and improve the management process of network components. In this architecture, the communication platform of network active objects is formed based on a cluster-based topology. Also, passive Radio Frequency IDentification (RFID) tags are utilized to manage books and library property. Two stages of evaluation have been conducted for the suggested method's performance: actual deployment and computer simulations. Based on the findings, it can be concluded that this study has succeeded in creating an effective and affordable design for smart libraries, which is a major advancement over conventional libraries.

1. Introduction

Internet of Things (IoT) is a new structure for identifying objects and providing a new platform for them to interact with each other. By using this technology, any object can be turned into an active smart device in communication networks [1]. This technology creates an endless list of possibilities and applications in everyday life. So traditional methods can be improved by smartening. Homes, transportation systems, and surveillance systems can become smart by IoT; and IoT efficiency has been proven in these environments [2].

Smartening libraries can be considered one of the most ideal applications of IoT. Because, most of the processes and entities in a library are well compatible with the structure of IoT and this technology can be used to facilitate all matters related to libraries [3]. Therefore, in various studies, solutions for smartening libraries with IoT technology have been presented. The main challenge in these architectures is the high implementation cost and lack of support for all library activities through these architectures. In most previous architectures, the need for the presence of human observers is felt [4,5]. This issue itself causes a waste of cost and labor, which is far from the main objective of IoT and smartening objects. For this reason, smartening all functional fields of the system is the fastest strategy to solve this challenge, which is possible by integrating Software Defined Networking (SDN) technology into IoT architecture.

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Smart libraries are important in the context of IoT due to their ability to efficiently manage resources, enhance security, improve user experience, optimize network management, and make data-driven decisions. Using IoT technologies, smart libraries are able to monitor and control various resources, optimize energy consumption and create a comfortable environment for users. IoT devices help improve security measures and personal experiences, including self-checkout systems and real-time book localization. These objectives can be met by integrating IoT with efficient technologies such as SDN, which enables centralized control of the network infrastructure, leading to improved performance and scalability. Data generated by IoT devices can be analyzed to gain valuable insights, which enable predictive maintenance and customized service delivery. In general, smart libraries in the context of IoT and SDN provide an advanced and user-centric experience.

This research presents a new architecture for smartening libraries based on IoT and SDN. Utilizing SDN increases the flexibility of the proposed architecture from various aspects and provides the ability to smarten objects in all their functional aspects. In this method, it is tried to smarten all the activities carried out in libraries, such as: searching for books, receiving guidance, borrowing and returning books, members authentication, etc. Introducing a new architecture based on SDN and a hybrid member authentication mechanism, are among the innovations of the current research which distinguishes it from previous works. The proposed architecture, implements a new hierarchical topology creation mechanism which is effective in forming a low-cost scalable communication structure for small to large scale libraries. Contributions of the current research are as follows.

- Providing an architecture based on SDN that provides the ability to make libraries smart in small to very large dimensions. In this architecture, a communication mechanism for information exchange in large networks is presented, which provides the possibility of data exchange between parts of a large library (or even libraries located in different regions).
- In this article, a low-cost architecture based on passive Radio Frequency IDentification (RFID) is presented, which is used to validate members and manage processes related to borrowing books, in a fully automatic manner. In this model, machine vision techniques are also used to match the members' IDs with their RFID.

This paper is organized as follows: A few of the earlier studies on library smartening are discussed in section 2. The suggested architecture is explained in part 3, and the outcomes of its simulation and execution are examined in section 4. Section 5 concludes with a summary of the study results.

2. Literature review

Smartening libraries using IoT has been a research interest in various studies due to the ability to adapt its tasks and processes to the IoT model. Some of these techniques are aimed at smartening the book-borrowing process. While some other studies have studied the feasibility of smartening other library activities such as member authentication or monitoring the reading room capacity. In this section, some of these methods are investigated. In Ref. [6], an architecture for smartening libraries using RFID technology was presented. In this architecture, an RFID tag is embedded on each member's card, which identifies the person's ID. Also, barcodes printed on the books are used to identify borrowed books, and this process is done manually by the librarian. This architecture is still far from the ideal mechanism drawn for smart libraries due to its dependence on the supervisor. In Ref. [7], deep learning techniques were discussed to model user behavior in reading books and predict users' needs for new books in smart libraries. In this model, information related to the book-carrying model is gathered by CRFID tags on each book and this information is processed by a Recurrent Neural Network (RNN) to estimate the user's interest and need for that book. This model can be integrated with smart library architectures as a recommender system module.

In [8], a smart architecture for library management based on IoT was proposed. Similar to the model presented in Ref. [6], this architecture uses passive RFID tags to identify members and stores borrowed and returned books in a database with a barcode reader. This model has the same limitations as [6] and cannot provide an intelligent architecture for libraries. In Ref. [9], the combination of blockchain technologies and biometric authentication was utilized to smarten libraries based on wireless networks. In this model, the finger-vein biometrics system is used to authenticate members. Also, information about books is gathered with RFID tags. In this model, all the ID and borrowing information of the book is stored on the blockchain network. Although this model provides a high level of security, it requires a lot of cost and processes, which is not affordable for most libraries.

In [10], a system for determining the library evacuation protocol in emergencies was introduced, which is based on IoT technology. The main structure of this system consists of five components: database, protocol base, IoT sensors, data integration system, and smart evacuation protocol. In this system, the state of the environment is monitored by IoT sensors and this information is stored in the database. To reduce the level of uncertainty in the detection of critical conditions, the Dempster-Shafer method was used as an algorithm for combining the information of sensor nodes. In Ref. [11], face-processing techniques were utilized to authenticate people in smart libraries. In this research, an attempt was made to recognize the capacity of library reading rooms and the people in them by using facial recognition technology based on Machine Learning (ML). Although this method does not benefit much from IoT technology; this research, was a new step in the field of smartening libraries. On the other hand, the face processing strategy used in this research entails a relatively high processing load, which is not cost-effective for large libraries.

In [12], a system based on ML was introduced to detect the location of books in smart libraries, which uses the signal strength information received from RFID tags. In this method, the power of the received signal is gathered using a mobile device. This information is pre-processed using Multiscale Principal Component Analysis (MSPCA) and then the Iterative Minimum Redundancy Maximum Relevance (IMRMR) technique is applied to select the appropriate features. In the end, the decision tree was used to classify the features, based on which the location of the books can be recognized. In Ref. [13], the applications of IoT in the smartening of

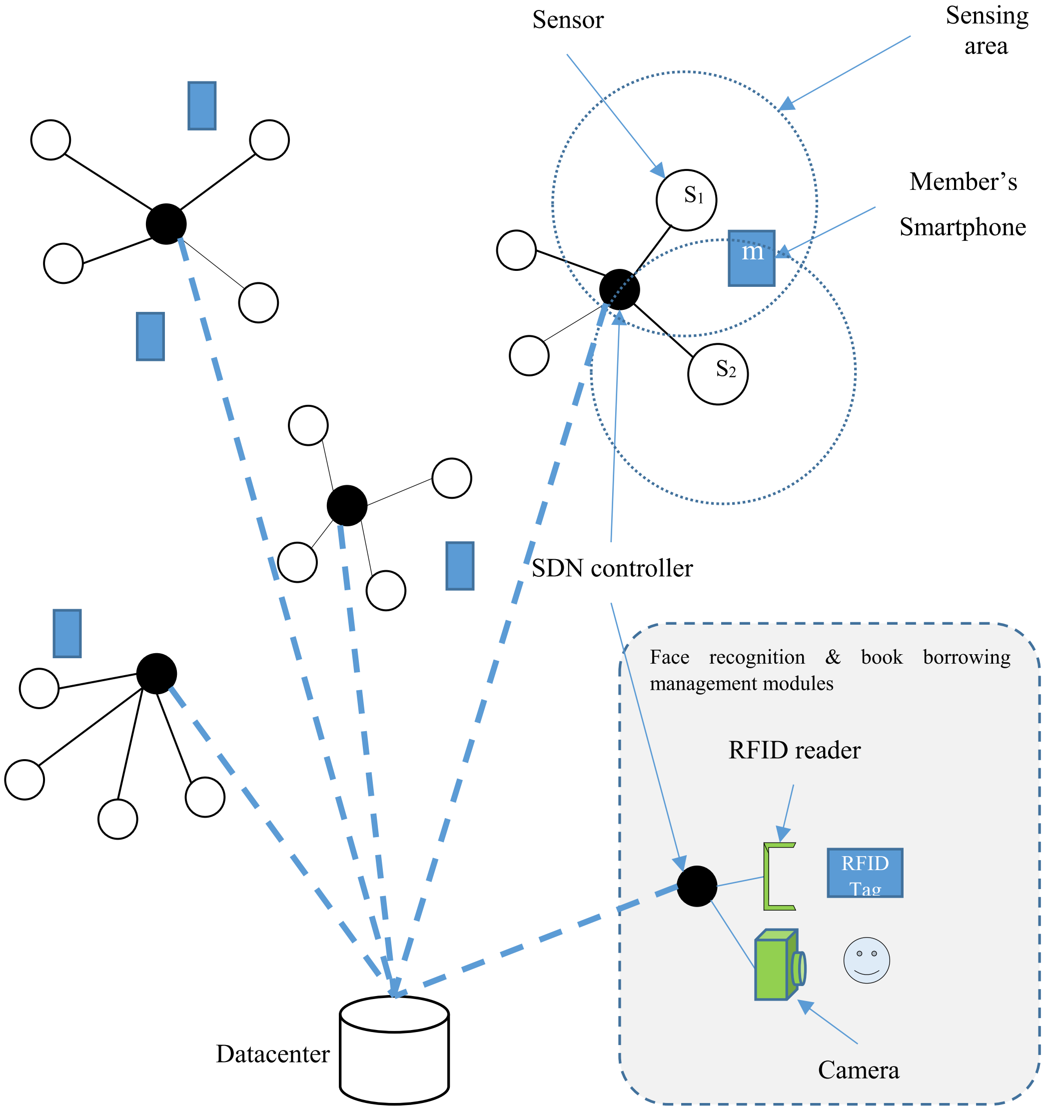

Fig. 1. The system assumed in the proposed smart library.

libraries in Pakistan were studied and the challenges ahead in this direction were identified. The main challenges in this field are the lack of a completely networked and integrated environment, cost problems, the unavailability of policy and strategic plans, and the lack of technical personnel familiar with the mechanism of smart networks. This research is more focused on identifying challenges and has not provided comprehensive and generalizable solutions to solve them.

In [14], a platform for measuring the smartness of libraries is provided. To address this question, five main elements and fifteen sub-elements that make the library smart were identified from a comprehensive review of the literature, and then a fuzzy model was proposed to calculate the smartness index of a library based on these elements. In Ref. [15], the technique of link analysis is used to evaluate the internet portals of smart libraries. The total number of pages, the number of internal links, the number of external links, the ratio of external links to total pages, the Baidu weight criterion, the Sogou weight measure criterion, and the Public Relations (PR) value are the seven effective factors based on link analysis that were used in this research to evaluate smart library portals. In Ref. [16], a method based on deep learning is presented to identify the books on the library shelves. This method includes two successive segmentation steps based on deep learning, in the first step, the books in each section are separated, and in the second step, the characteristics of each book are analyzed in this way, book identification can be performed. This model can be integrated with smart library architectures as a book localization module. In Ref. [17], the changes imposed on libraries during the COVID-19 pandemic were evaluated. According to these studies, the outbreak of the epidemic has caused significant changes for libraries, and a significant part of libraries utilized online services as the best solution. On the other hand, it is possible to reduce the risks of outbreaks in similar situations by smartening libraries and minimizing the possibility of crowding people and face-to-face contact.

3. The proposed model

This section describes the suggested approach for building an IoT-based smart library. A centralized data structure is used in this model to preserve network dynamics and maximize performance. This method uses the SDN model to increase the flexibility of the network and adapt it smartly to the changes in the IoT network. In this architecture, it is tried to operate the most common activities in libraries smartly. These activities include the following cases.

1. Members authentication based on RFID tags and face recognition: every member of the library can be identified using an RFID tag attached to the person's card. This tag contains the user's unique ID in the library database, based on which the user's information (including the registered image of the person's face) can be retrieved. To authenticate each user, the similarity degree of the person's face components in the image of the database with the image recorded through the camera is calculated.
2. Book borrowing and returning with RFID tags: Every book in the library includes a RFID tag, based on which its borrowing information can be accessed in the database. In this process, by passing the books through a tag reader gate, borrowing, and returning processes are done automatically.
3. Information search based on smart things and using a multi-hop routing strategy: All library information is stored in a centralized database. In this way, if the user intends to search for a book (to check its availability, or to reserve the book), the user's request can be sent to the network through a smartphone. This request is sent to the database based on the architecture organized by SDN. This process eliminates the need for a centralized architecture to access library information. Also, the process of sending a request and its response is done using a multi-hop routing strategy, which is explained in this section.

The proposed architecture is based on the following assumptions.

- • Different radio equipment technologies used in wireless networks might result in varying communication characteristics across network nodes. The presumed IoT structure is hence diverse. A passive RFID tag is used in each book to identify it. This tag contains the unique ID of the registration information for the book in the library database.
- Each member has a membership card with a passive RFID tag, based on which the user's information can be extracted from the database. In each member table record, there is an image of the person's face that can be used for authentication.
- There is a relationship between the distance of two active objects and their received signal strength indication (RSSI). In this way, each pair of objects can estimate the distance by analyzing the RSSI values.
- Fig. 1 depicts the hypothetical system model used in the suggested approach. An Internet of Things-based communication topology is shown in this picture. The following parts make up this model: A data source server (database)
- SDN controller nodes
- Sensors (cameras, RFID tags, tag readers, and smartphones),
- Library members

- Using the approach shown in Fig. 1, the primary operations in a library may be carried out efficiently. In this arrangement, all data pertaining to the library's books, patrons, and transactions is kept in the datacenter. The following details are included in this information: Members' information: In this table, the features of the members are stored and each member is distinguished from the others by using a unique code. This code can be retrieved through the RFID tag attached to each person's membership card. Also, for each member, there is a valid image in the member information table, which is used for authentication.
- Book Information: In this table, the list of all book information (including unique ID, author, storage location, etc.) is stored. The unique ID of each book can be retrieved through the attached RFID tag.
- Book Borrowing Information: In this table, previous tables are linked together, and its records specify the borrowing and returning information of the book.

In addition to the above three tables, there are tables for reserving books and recording information from different sections of the library. Based on the model depicted in Fig. 1, each member with a wireless connection to the library network can send their queries to the data center at any location of the library and receive a response appropriate to their query. The user performs this action through a smart mobile phone, and the process of sending a query and receiving a response is done in the network platform with the cooperation of sensor nodes and SDN controllers, which is discussed in the next sections. Also, member authentication and book borrowing processes are performed through a camera and RFID reader, which is shown in the lower part of Fig. 1. These two nodes are directly connected to an SDN controller that runs the authentication software through face matching. In the rest of this section, processes of book borrowing management, member authentication, and data exchange between network sensors are described in detail.

3.1. Authentication of members based on matching facial features

First, the process of members' authentication with a face-matching strategy is explained. This process is the basic prerequisite for the book borrowing process in the proposed architecture. The face-matching component in the proposed method for the smart library consists of the following components.

1. An RFID tag attached to a person's membership card

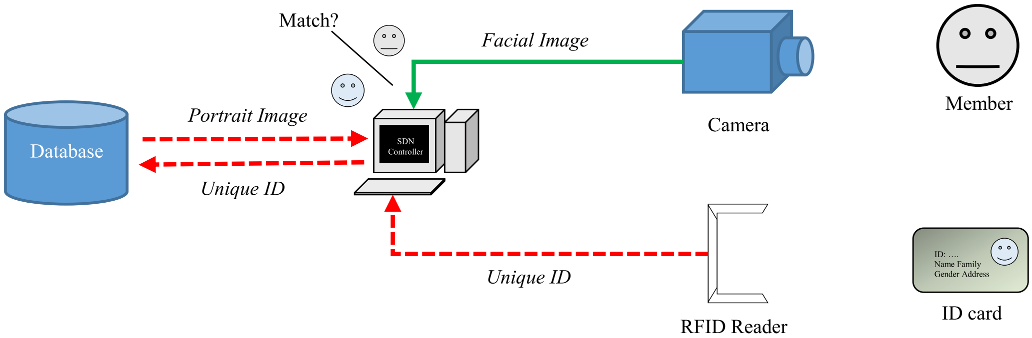

Fig. 2. Member authentication process based on matching the face features.

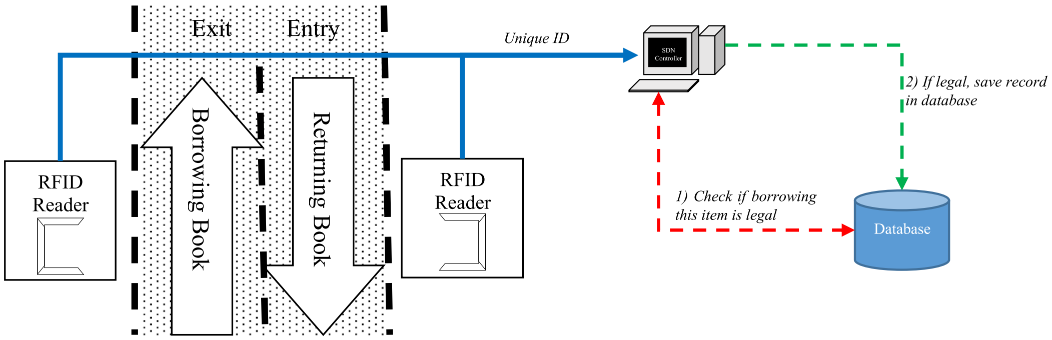

Fig. 3. Architecture of the proposed system to manage the borrowing/returning of the books.

2. A camera to record the image of the person's face
3. An RFID tag reader

The RFID tag attached to the membership card has the unique ID of the member in the database. The camera and tag reader components are directly connected to the SDN controller. This controller node recalls the information recorded by the camera and tag reader and by running the face-matching algorithm, it matches the person's ID with the information recorded in the database.

This process is shown in a diagram in Fig. 2. According to this diagram, first the image of the person's face is recorded using the camera and at the same time, the tag reader extracts the user's unique ID through the RFID tag attached to the person's card. Subsequently, both the individual's unique ID and facial picture data are simultaneously sent to the controller node. In order to get member data and the picture that was captured for that specific person in the database, the controller node sends the member's unique ID to the database as a query. During this process, it is also checked whether the current member can borrow the new book. In the next step, the controller node matches the image extracted from the database with the image recorded by the camera. For this purpose, the open-source library InsightFace [18,19] is used. InsightFace library is an open-source tool for face detection and recognition with high accuracy, which is used in the proposed method to match the face recorded by the camera with the face image in the database. If the two images are successfully matched, the processes related to book borrowing are allowed, and otherwise, by sending an error message, book borrowing processes are prevented.

Previously presented architectures for smart library often use one of RFID or facial recognition technologies to authenticate individuals. But since each of these technologies have some limitations, therefore, in the proposed method an attempt has been made to overcome these limitations by using them simultaneously. For example, by using RFID technology alone, it is not possible to automatically identify a person's use of other member's ID cards. On the other hand, if only facial recognition technique is used for authentication, the face matching algorithm must compare the captured image with all the images in the database, which leads to a high computational cost for large libraries (with a large number of members). This is while the proposed method removes the mentioned limitations by using the RFID and facial recognition at the same time.

3.2. Book management in the proposed architecture

The proposed architecture's book borrowing/returning management mechanism is done only by using RFID tags and two tag reader nodes (each one for exit and entry gates of the library). It should be noted that this component only issues permission to borrow the book for the member if the result of the authentication process is positive for the user. The RFID tags attached to each book are passive and similar to the tags attached to members' membership cards. With the difference that these tags reflect the unique ID of the

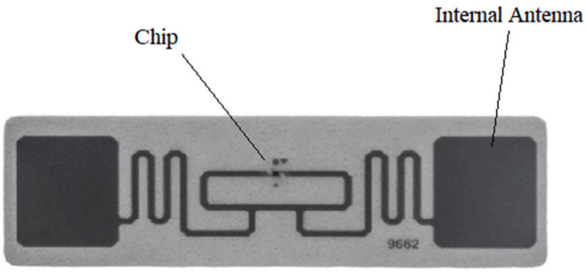

Fig. 4. UHF band passive tag structure used in the proposed architecture.

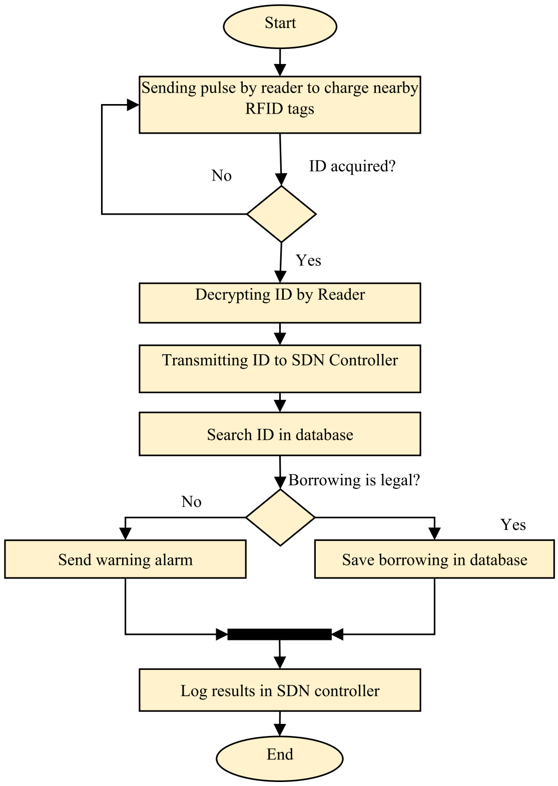

Fig. 5. Book borrowing flowchart of the proposed system.

book. In this way, reading the tag information of each book is done through a tag reader similar to the reader used in the authentication component. By assigning a separate label to each of the books (or library property) and using antennas installed at specific distances from the gateways, it is possible to identify the property easily and remotely. This system can detect the event as soon as the unauthorized removal of books or library property (or even property theft). The design of the suggested system for overseeing book borrowing and return is shown in Fig. 3. It should be mentioned that the entry and exit may be situated at various places and are not need to be in parallel (as shown in Fig. 3).

Passive tags are utilized in the suggested approach to lower the system's overall installation costs. In the suggested approach, the electronic tag serves as an automated data carrier for an RFID-based property management system. Passive RFID tags that function in the Ultra-High Frequency (UHF) band are used in this system's design. The system's scanning range for these tags is six to 10 m. Because a distance greater than 10 m just raises the ultimate implementation cost and is ineffective for controlling the property's condition. Fig. 4 displays the internal organization of the suggested system as well as an example tag that is utilized in it.

As mentioned, passive tags do not have a power source to send the ID to the reader component. The energy required for the operation of these tags is provided by radio frequency pulses sent by the reader component. In this way, when the reader component sends radio pulses, the tag charges the capacitor in it, and after the charge is completed, this capacitor is used as a source of energy supply in the tag. Then the tag information is sent to the reader component through the tag's internal antennas.

According to the paradigm in Fig. 3, the SDN controller node attached to the reader node receives the unique ID information stored in the RFID tags of the book (or property) once it has been retrieved by the tag reader. To get the book's details (authorization of book borrowing), the controller node queries the database using the book's unique ID. If this process is allowed, the controller node sends an "insert" command to record the book-borrowing information to the database. The inserted record includes the book's ID, the member's ID, and the time information of the book's exit. On the other hand, for the book entry process, there is no need to measure the validity of the book exit by the controller node. In this case, after receiving the book ID, the controller node sends an insert command to record the book return information to the database.

Also, if the borrowing of the book with the read unique ID is not allowed, a warning message is sent to the controller node connected to the reader component to prevent the transfer of goods (or possible theft). The process of identifying and recording the incoming and outgoing transactions of books using the proposed system is shown as a flowchart in Fig. 5.

3.3. Network configuration and routing based on SDN

SDN offers a number of advantages, including centralized control, flexibility, optimal resource utilization, increased security, scalability, and cost savings. This technology enables network management and control from a centralized location and simplifies network tasks. SDN enables rapid deployment of new services and applications and adapts quickly to changing business needs. This technology provides optimal use of network resources and improves network performance. SDN enhances network security by providing fine-grained control and complete coverage over network traffic. This technology enables network expansion and saves operational costs, hardware upgrades, energy consumption and maintenance. SDN, provides an efficient architecture for managing and processing numerous data read by RFID. These characteristics made SDN to be considered in the proposed smart library architecture.

In the proposed architecture, an SDN-based routing strategy is used to exchange information between objects. Determining the data routing pattern is one of the requirements for designing IoT-based architectures, based on which the method of data exchange between network components can be determined. In the proposed architecture, data routing is performed between each node (camera, controller nodes, tag readers, and smartphones) and the data center. The user's mobile phone executes the routing procedure in circumstances such as finding or reserving a book. This procedure may be executed in a multi-hop fashion inside extensive networks and libraries, as elucidated in this section. The suggested model for data routing in a smart library based on IoT framework comprises the following steps: Forming a network clustering structure based on SDN.

1) Forming a network hierarchical tree topology
2) Data routing using the formed structure

During the first stage of the routing phase, the SDN domain is partitioned into many subdomains by clustering. Each subdomain is then furnished with a controller to facilitate the interchange of security rules with other subdomains. Under the suggested approach, every controller furnishes a compilation of authorized entities associated with its own domain to other controllers. Thus, when there is a need to establish communication between an item and the data source server, the validation of the sensor is achieved by exchanging messages between controllers. Once the object's ID is verified by a controller, the process of routing data and transmitting information is executed. The local least spanning tree and Prim's algorithm [20] are used for network topology control. Ultimately, the data is directed to the target via the hierarchical tree structure. Below, each of these processes is elucidated.*3.3.1. Network clustering structure based on SDN*.

Firstly, in this stage, the coordinates of each node are specified as (x,y). The positional data is used to group network nodes using the Fuzzy C-Means (FCM) algorithm. This approach involves clustering sensors with comparable positional data. The FCM algorithm [21] is a very significant and often used clustering method. This technique partitions network sensors into clusters according to their positional data. The process of data clustering using FCM involves the following sequential steps:1. Approximating primary clusters with Equation (1) [21]:

$$u_{ik} = \frac{1}{\sum_{j=1}^{c} \left(\frac{d_{ik}}{d_{ij}} \right)^2} \tag{1}$$

In the above relation, u_{ik} is sensor i belonging degree in cluster k. Also, d_{ik} is the Euclidean distance between the i-th node and the k-th cluster.

2. Calculating cluster centers with Equation (2) [21]:

$$v_k = \frac{\sum_{i=1}^{n} u_{ik}^2 x_i}{\sum_{i=1}^{n} u_{ik}} \tag{2}$$

where v_k is the center of the k-th cluster and x_i is the i-th sensor node. Also, n specifies the total number of network users.

3. If $|U_{i+1} - U_i| \le \varepsilon$, the algorithm ends, and otherwise the mentioned steps are repeated.

In the mentioned steps in this section, clustering is done in an unsupervised manner. By applying the positional information of the

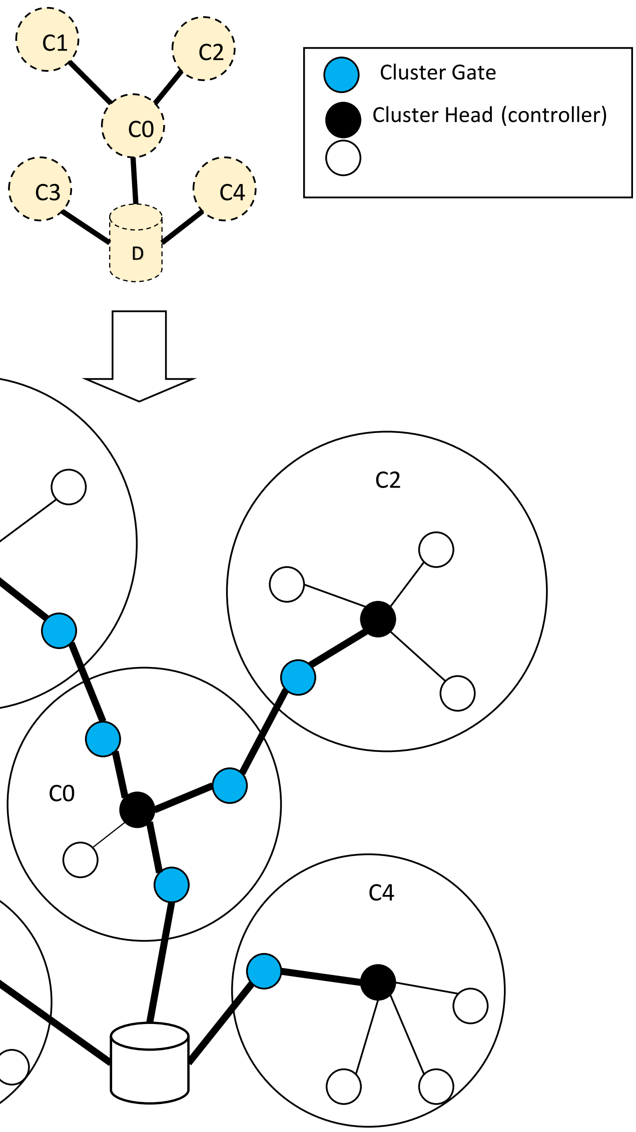

Fig. 6. A tree topology structure formed in the proposed method.

network users to the FCM algorithm, the centroids of the clusters are selected and modified based on the described algorithm. After doing this, all network nodes (mobile users in the library environment) are placed in clusters according to their positional pattern.

In the subsequent phase of the proposed approach, the cluster head is designated as the SDN controller. The objective of this phase is to verify the identity of network users by means of the SDN controller in order to mitigate potential security threats both inside and outside the clusters. Once the SDN controller is identified as the cluster head, each controller calculates the most efficient route to the central node C_t by passing via intermediate nodes, which function as cluster gateways. The following explanation outlines this technique.*3.3.2. Forming network hierarchical tree topology*.

During this stage, the network's clustered arrangement from the previous phase transforms into a hierarchical structure. To achieve this objective, the establishment of the hierarchical topology begins with the server node of the data source. The central node is regarded as the primary node in the hierarchical tree, since it serves as the endpoint for all data queries and the origin of all library information. In the proposed approach, the controller nodes, which were found in the previous stage, identify their neighbors by broadcasting all the control packets. This data is used to provide weights to network connections, enabling the creation of a hierarchical topology that incorporates the most appropriate characteristics. The technique utilizes congestion information, as well as the distance and energy of the node weights connections within the network, to construct the best appropriate hierarchical tree. The suggested technique determines the weight of network connections by taking into account both the congestion degree parameter and node energy. The suggested technique calculates the weight of each finite link to node i using Equation (3).

$$W_{ij} = \left(\frac{C_j \times D_j}{E_j}\right) \tag{3}$$

where C_j is the congestion degree of child node j, which is calculated by node j with Equation (4).

$$C_i = \frac{T_{service}}{T_{arrival}} \tag{4}$$

Furthermore, Dj denotes the approximated distance between the current node and its neighboring node j, whereas Ej signifies the remaining energy of node j. Every node appends the aforementioned parameters to its ACK packets and transmits them to the transmitter node in response to the control message. Also, all the values of C_j, D_j, and E_j parameters are normalized by the weight calculation node using Equation (5), before using Equation (3).

$$N_i = \frac{n_i - n_{min}}{n_{max} - n_{min}} \tag{5}$$

The primary benefit of using this approach is to mitigate congestion at a node by selecting routes with lower congestion levels and higher energy efficiency. Once the weight of all links is determined using Equation (3), a hierarchical tree structure is created. Once the weight of network connections is determined, the server node of the data source (also known as the central node) has the combined weight of all connections as well as a comprehensive list of all network clusters. Given this characteristic, the network clustering structure takes the form of a hierarchical tree topology, as seen in Fig. 6.

In the upper part of Fig. 6, the hierarchical communication structure of the network at the cluster level is displayed. Each node shown in this figure (C0 to C4) represents a cluster in the network. In this figure, node D is determined as the topology center and all clusters are connected to this server node. In the lower part of Fig. 6, this structure is displayed at the node level. In this figure, each cluster head node and neighboring nodes connected to it are considered a cluster in the network. Communication between clusters is done through gateway nodes (shown in gray). Furthermore, the hierarchical tree communications among the leaders of the clusters are shown as bold lines. The selection of routes is based on the weights assigned to network connections, with preference given to routes with the lowest weight between the central node and the controller nodes of each cluster.*3.3.3. Data routing using the formed structure*.

Once the hierarchical tree topology is established, it serves as a means for data routing, specifically for library information. Given the tree topology, it is evident that there is a single path connecting each subdomain to the data center. The controller node queries its member list for the source ID. If there is a match, it transmits the sensor request to the central node via the unique path in the hierarchical tree. Upon receiving this message, the central node cross-references the sensor ID provided by the requester with the corresponding information ID. If the information is verified as accurate, the requested media is sent to the controller node over the established pathway.

4. Results

The assessment findings for the suggested architecture are shown in this section. There were two stages to the evaluation: simulation and implementation. In order to do this, the suggested design was first put into practice in a medium-sized library with around 2307 vol, and its effectiveness in enhancing the execution of library procedures was examined. Also, in the simulation phase, the proposed routing strategy was studied in networks with different dimensions to ensure the accuracy of its performance in wide environments. In the following, the results of the implementation of each of these phases are presented and the findings are analyzed.

4.1. Implementation of the proposed architecture

- In this section, the results of the proposed architecture implementation are analyzed. The implementation of the proposed architecture was done for a library containing 2307 books and 416 members. The software interface of the system was implemented using the C#.net programming language in the Visual Studio 2020 environment, and the data center uses the SQL Server 2018 database management system. In addition, the face-matching component was implemented using the InsightFace module, an open-source Python utility for face processing and identification. To assess the effectiveness of an architectural design in enhancing the intelligence of libraries in real-world situations, it is necessary to evaluate its performance from several perspectives. This section examines the efficacy of the suggested architecture in enabling the execution of library procedures from many perspectives. To achieve this objective, the performance of the suggested design is examined based on the following factors. Processing time: Processing time is the total time spent to finalize the entry/exit record of library books using the proposed architecture. The total processing time in the proposed system can be calculated as the sum of the times required for: "reading tag information", "processing information by a computer system", "searching the tag ID in the database" and "saving the transaction".
- All criteria related to the computer network system depend on the hardware used in this system. In the experiments, a computer system with a Windows 10 operating system 64-bit version with 8 GB main memory and an Intel Core i7 4500U processor with a frequency of 2.8 GHz was used.
- Error rate: The error rate indicates the ratio of errors that occurred in the transfer record of library items (books/properties) and is calculated according to Equation (6):

$$Error_{rate} = \frac{E}{N} \tag{6}$$

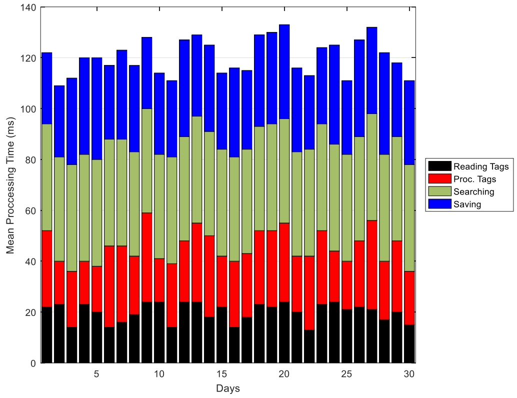

Fig. 7. The mean processing time of the proposed system for recording the transaction of library items.

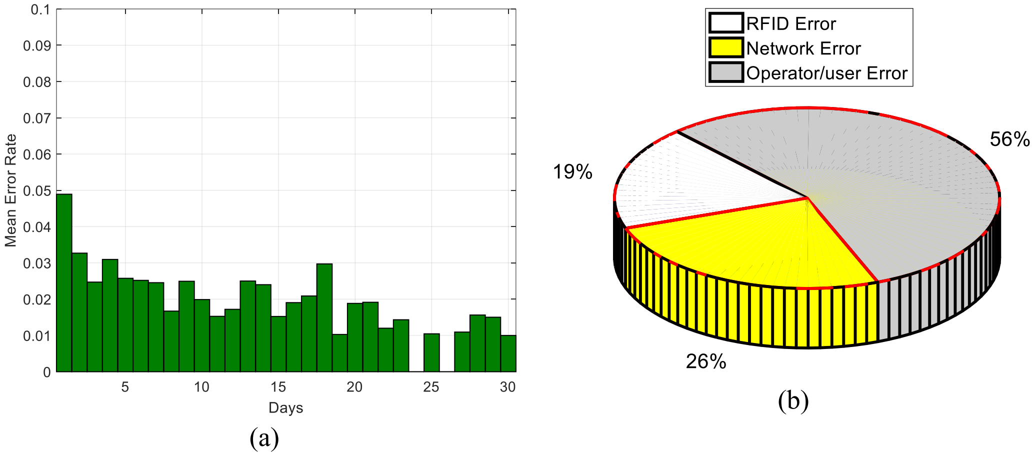

Fig. 8. Transaction record error (a) Mean error per day (b) Frequency of errors.

where N is the number of all evaluated items and E is the number of items that one of the following situations has occurred for them.

✓ The ID of a valid item cannot be read. This error may occur if there is a problem with the system, the label is distorted, or there are interference factors.
✓ Recording transfer of an item (entry or exit) illegally. This error occurred in the case when the transfer of an item that is not allowed to leave the library; is recorded by the system.

In all these cases, the performance of the proposed architecture in the tested smart library with the state of the same library before smartening; has been compared. Fig. 7 shows the mean processing time of the proposed system for recording the transaction of library items. In this diagram, each bar indicates the mean processing time in one day, and the vertical axis indicates the processing time in each operation in milliseconds.

However, prior to implementing the intelligent library system and adopting standard information capture methods, these activities often took an average of 4 min. Consequently, the suggested design has the potential to greatly save time and enhance procedures associated with book borrowing management. According to the findings shown in Fig. 7, the tasks of tag recognition and tag ID processing need the shortest amount of processing time. On the other hand, the tasks of tag search operations in the database and transaction storage require the longest amount of processing time. Fig. 8 a shows the average error rate in the items transaction record every day. In this diagram, the vertical axis indicates the proportion of items where an error occurred in the first attempt to record their transaction, and the system had to repeat the processes of tag reading, search, matching, and storage.

As the results in Fig. 8 show, the highest error rate in the proposed system is 0.047 and the lowest accuracy rate is zero percent. Based on these results, the use of IoT technology in smartening the library and managing its affairs can achieve high accuracy and almost eliminate the error caused by human factors.

Fig. 8 b shows the frequency of each type of error in the experiments. Based on the information displayed in this figure, one of the following situations can cause an error in the system.

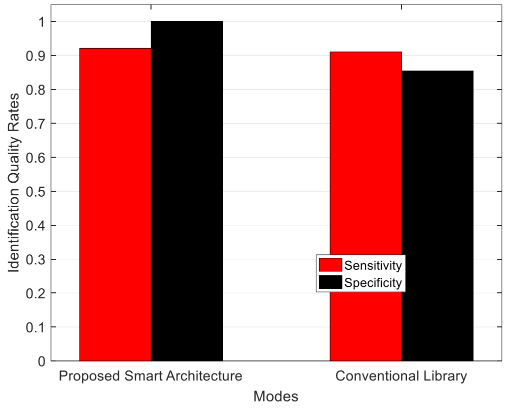

Fig. 9. Sensitivity and specificity comparison of the proposed method with the traditional method.

Table 1
Evaluation results of the proposed method and the traditional property management method.

Traditional library	Proposed architecture for smart library	
4 min and 3 s	120.33 ms	**Mean processing time**
0.1621	0.01924	**Error rate**
0.9104	0.9211	**sensitivity**
0.8542	1.0	**specificity**

According to Tables 1 and it is concluded that by using the proposed architecture, the waiting time of the members can be reduced as well as the possibility of errors in the library system, and as a result, the efficiency of the system can be improved.

Table 2
Simulation parameters.

Value	Parameter
200 m * 200 m	Dimensions of the library environment
25 to 75 fixed sensor nodes +100 to 300 mobile visitor nodes	Number of nodes (sensor + visitor)
random between 0.5 and 1 J	The initial energy of each sensor
variable between 50 and 150 m	Radio range of each node
40 m	The sensing radius of each sensor node
0.1 demand per second	Visitor demand rate

- Error in the reader device while reading property tag information
- User error in working with the software system
- Error in exchanging information through the network computer system (defect in the network)

As shown in Fig. 8 b, the minimum frequency of error is related to the tag reader device. Also, the maximum frequency of error is related to the user's error in working with the software system, and this defect can be caused by the user's lack of familiarity with the new software system. As can be seen in Fig. 8 a, the mean error graph has a downward trend, and this is due to the increase in users' familiarity with the software and reducing the probability of error. These results show that by using the proposed architecture based on IoT technology as a reliable tool, authentication can be performed with less error.

The sensitivity and specificity criteria obtained by implementing the suggested architecture for enhancing library intelligence are contrasted with those of the classic model (prior to enhancement) in Fig. 9. The sensitivity criteria quantifies the proportion of correctly identified valid IDs among all valid identifiers, and is computed using Equation (7):

$$Sensitivity = \frac{TP}{TP + FN} \tag{7}$$

TP represents the count of legitimate IDs (belonging to both members and books) that are correctly identified, whereas FN represents the count of illegitimate IDs (such as the use of an invalid membership card by members or unlawful item exit) that are mistakenly identified as genuine IDs. The specificity criteria are used to quantify the number of accurately identified invalid IDs. The calculation of this criteria is determined by Equation (8).

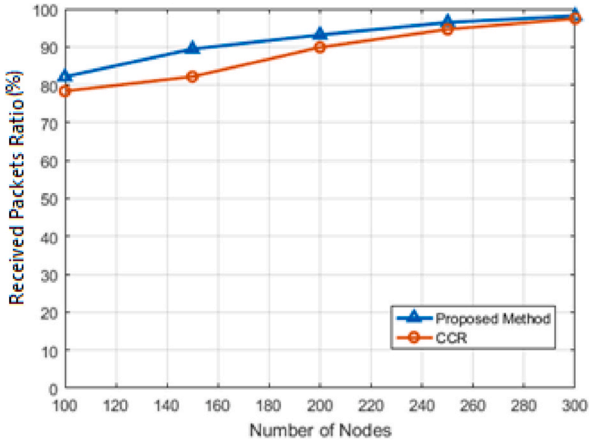

Fig. 10. PDR for different numbers of visitor nodes.

$$Specificity = \frac{TN}{TN + FP} \tag{8}$$

where TN refers to the invalid IDs that have been truly recognized as invalid and FP demonstrates the invalid IDs that have been recognized as valid.

Fig. 9 indicates that using IoT technology in the proposed design enables more precise management of book borrowing control. The increased sensitivity value in this graph indicates that the suggested technique has a greater likelihood of accurately identifying genuine IDs compared to human observers. Also, the higher value of the specificity criterion in the proposed architecture means that in a smart library, invalid IDs can be identified more reliably. In Table 1, the summary of the results obtained from the library smartening by the proposed architecture is compared with the same library before the smartening. The values presented in this table are the average results in thirty days (see Table 2).

4.2. Simulation of the routing algorithm

The effectiveness of the suggested routing algorithm based on SDN is assessed in a simulated environment during the second experiment phase. This experiment aims to verify the accuracy of the suggested design in large-scale libraries. The MATLAB software environment was used to carry out the simulation. In a hypothetical 200 × 200 m2 library (along with the buffer), the distribution of nodes, or persons with smartphones, is thought to be random and typical. The aforementioned nodes travel in a Random Way Point pattern throughout the library. The network controllers in libraries are immobile and do not know where they are with relation to other objects. A node's life is finished and it cannot be utilized once its energy is depleted. Additionally, the noise coefficient of 7 was taken into consideration in order to account for the effects of fading and impediments in the library environment.

To perform the studies, the number of visitor nodes was adjusted between 100 and 300, and the number of network sensors was equal to one-quarter of the visitor nodes in each scenario. These studies' findings were compared to the Content-Centric Routing (CCR) technique [22]. When a visitor enters the sensing domain of a sensor node or controller, the operation of requesting information from the data source is conducted in accordance with the visitor's demand rate, and this information is sent to the visitor via the sensor. It should be noted that, owing to the overlapping of detecting zones, transmission is performed by the sensor nearest to the visitor. The network nodes have a data rate of 100 kilobits per second. Using Equation (9), divide the number of successfully transmitted packets to the destination by the total number of sent packets to determine this criteria.

$$DeliveryRatio = 100 \times \frac{D}{T} \tag{9}$$

where T represents the number of packets created by the source nodes and D represents the number of packets received by the destination. Fig. 10 depicts the outcomes of this experiment. According to the findings of this test, the suggested technique has a greater Packet Delivery Ratio (PDR) when the number of visiting nodes increases. Furthermore, by finding more optimum routes, the routing algorithm may increase network performance in data packet delivery.

According to the simulation findings, the suggested technique outperforms the comparison method in all scenarios, with a minimum and maximum PDR of 82 % and 98 %, respectively. Furthermore, the suggested technique outperforms the compared method in terms of picking routes with less traffic, and the proposed method's packet loss rate is lower than the comparable method's packet loss ratio. One of the most important factors in evaluating the effectiveness of wireless networks with constrained resources is their energy efficiency. The model described in Ref. [23] was used to calculate how much energy was used for node-to-node communications. Equation (10) is used in this model [23] to calculate the energy needed to send N bits of data between each pair of nodes.

$$E_{TX}(N,d) = N \times \left(E_{elec} + E_{amp}.d^2\right) \tag{10}$$

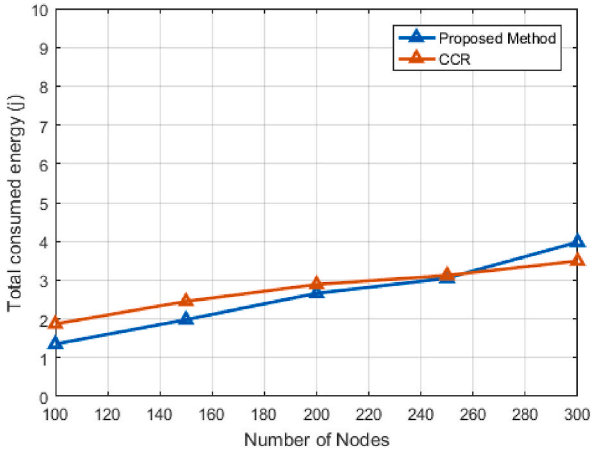

Fig. 11. Energy consumption of the network for different numbers of visitor nodes.

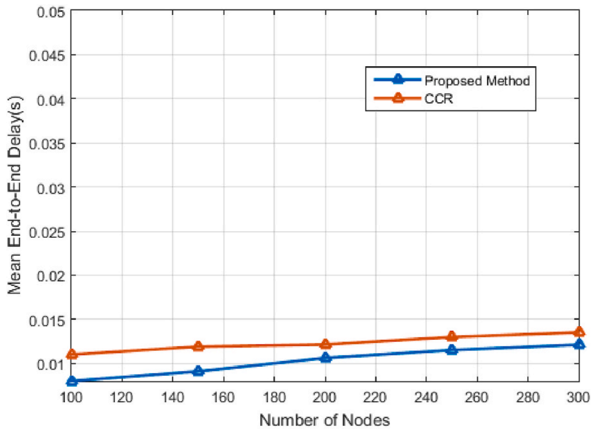

Fig. 12. Mean end-to-end network delay for different numbers of visitors.

where d refers to the distance between transmitter and receiver, E_{elec} demonstrates the energy required for each bit of data in the receiver and transmitter circuits, and E_{amp} is the energy consumed per bit in the RF amplifier. Also, Equation (11) is used to measure the consumed energy for receiving N bits of data [23].

$$E_{RX}(N, d) = N \times E_{elec} \tag{11}$$

The energy consumption of each node for varying node counts is shown in Fig. 11. The experiment's findings demonstrate that, for varying node counts, the suggested technique's rise in energy consumption is smaller than that of the comparable approach, and that the suggested algorithm can regulate energy consumption more effectively. The selection of more energy-dense pathways for data routing is responsible for the suggested method's greater energy consumption efficiency. However, the energy consumption of the suggested technique is higher than that of the other way when the number of host nodes is raised to 300 (75 sensors). The increased PDR in the suggested method is the cause of this rise. The network nodes consume more energy for data routing in the network while using this strategy since PDR is greater than CCR.

The graph of mean end-to-end latency for varying visitor counts is shown in Fig. 12. The time difference between the source node sending data and the destination node receiving the packet is known as the end-to-end latency. The experiment's findings clearly show that the end-to-end latency in the network rises as the number of visitor nodes increases. However, the suggested technique has reduced the end-to-end latency in comparison to the other way by utilizing the congestion degree and distance characteristics as criteria for weighing network connections and creating a hierarchical topology based on these criteria.

In comparison to earlier approaches, the suggested design may enhance the network's performance in terms of energy consumption, latency, and PDR, according to the findings of the suggested method performance simulation. The suggested method's use of SDN architecture, which enables more effective routing in big networks, is responsible for this improvement.

5. Conclusion

The introduction of IoT led to the formation of a wide range of facilities for smartening activities and systems that in the past required considerable expenditure and manpower. Libraries are one of these cases. By using IoT technology, most of the activities carried out in libraries can be done smartly. To achieve a smart library based on IoT, it is necessary to be able to perform most of its laborious activities automatically and accurately. On the other hand, a suitable architecture for a smart library should be scalable and able to cover libraries of different dimensions. This article is an attempt to fulfill these goals by using IoT and SDN. In the proposed architecture, SDN is used for clustering network components and forming a hierarchical tree topology structure, based on which data routing is possible in networks with different dimensions efficiently. This strategy makes a wide range of library activities smarter, such as: searching for books by mobile phone, reserving books, accessing information of different departments, etc. In the proposed architecture, passive RFID tags are used to identify books and members. Face recognition and image-matching has also been used to authenticate members. In this way, by this architecture, many application scenarios can be made smart in libraries. The evaluation of the proposed architecture was done in two phases. In the first phase, this architecture was used to smarten a medium-sized library, and its efficiency was evaluated based on the criteria of processing time, error rate, sensitivity, and specificity. These results showed that by using the proposed architecture, it is possible to reduce the waiting time of the members as well as the probability of errors in the library system and thus improve the efficiency of the system. The effectiveness of the suggested SDN-based routing algorithm was assessed in the second phase. The results show that the suggested architecture for smartening big libraries is scalable, and on the basis of this, the network's performance can be enhanced in terms of PDR, latency, and energy usage. Relatively small size of the library and the short evaluation period in the implementation phase of the proposed architecture can be considered as limitations of the current study. In future research, this deficiency can be solved by implementing it in a larger library (with more books and members) and recording the results for a longer period. Also, the use of the proposed architecture in this research for similar application scenarios such as smartening storage systems can be the subject of future research.

Data availability

All data generated or analyzed during this study are included in this published article.

CRediT authorship contribution statement

Qi Zhou: Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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