Celal Bayar University Journal of Science
Volume 18, Issue 3, 2022, p 265-273
Doi: 10.18466/cbayarfbe.1028242

Celal Bayar University Journal of Science

Attendance as a Service: A Multi-Layered System Design in Attendance Applications for Covid-19

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Received: 26 November 2021
Accepted: 4 July 2022
DOI: 10.18466/cbayarfbe.1028242

Abstract

During COVID-19, there has been a requirement for a distributed architecture for contact-less and available smart applications that can be deployed in personal mobile devices. However, the single-layer architecture of the other similar applications in the literature has not met the user requirements according to the preliminary tests. Moreover, the conventional ones offer a high-cost architecture. To overcome these challenges, Software as a service (SaaS) has been preferred for the integration of distributed applications in the cloud market in a cost-efficient way. Therefore, we propose Attendance as a Service, i.e., a new multi-layered system which includes such technologies as QR code, face recognition, and fingerprint to meet the reliability and contact-less performance. In the performance evaluation, the proposed system operates with lower delay and higher scalability when compared to conventional ones. It has been observed that the multi-layered structure provides eight milliseconds of gain in delay compared to the traditional one and overcomes the students' inability to attend due to server density.

Keywords: Face Recognition Technology, Fingerprint Technology, Multi-Layered, Software as a Service, QR Technology

1. Introduction

Recently, the importance of smart applications that do not require physical contact in software-based services has tremendously increased by Covid-19 [1,2]. Significantly, some state and local governments have requested the suspension of biometric contact systems in attendance systems used in businesses [3]. To provide contactless execution in applications used with remote work, face recognition or fingerprint services and their distributed implementation on personal mobile devices have been considered [4,5].

There are three different methods in the cloud market for the integration of such applications: Infrastructure as a service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). These services minimize the physical risk and reduce operational and capital expenditures (OPEX/CAPEX) in a different manner. According to the literature, the market sizes of these services are given as $67 billion for SaaS, $34 billion for IaaS, and $11 billion for PaaS [6]. It clearly proves that SaaS is much more preferred than platform and infrastructure-based services because it provides a reliable service with a lower cost [7,9]. Accordingly, the following research question is taken into account: "What kind of architecture should we build for current attendance systems to reduce human contact and provide a higher user experience with a lower cost?"

This paper proposes a novel system that can be easily adapted to wherever attendance is needed efficiently. Thanks to the network-based attendance system, users' participation is controlled in the fastest and contactless way possible by using QR codes and biometric recognition. By adding a network-based middleware, the proposed system overcomes the challenges of the conventional attendance systems that have a single-layer architecture. The literature survey and the problem definition are detailed in the following subsections.

1.1. The Literature Survey and Problem Definition

The attendance systems that have recently been used are exemplified in Figure 1. The usage areas of attendance are for student, employee, cafeteria, and membership systems. The attendance process taken in the classes is a factor that increases the participation rate and performance of the students.

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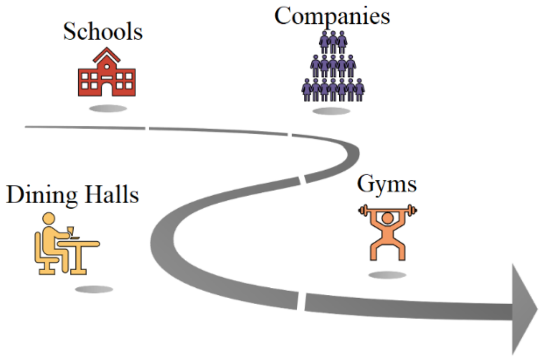

Figure 1. Attendance Systems.

Employee attendance systems are the process of tracking and storing users' coming to work and leaving time. Moreover, in the cafeteria systems, it is possible to track the employees who eat lunch in the cafeteria. On the other hand, membership attendance systems enable determining whether members of the club are in the membership areas such as gyms and fitness centers. The main purpose of all types is the same: managing attendance [10].

However, the conventional design of such attendance systems cannot meet end-user requirements because the single-layer architectural design cannot handle features such as the contactless process in today's Covid-19 [11]. Using automatic tracking systems rather than manual systems is safer and more efficient [12]. In a conventional system, the attendance paper is distributed among the students while they are taking attendance, which causes high contact between users. In other cases, the attendance can be taken by reading all the students' names aloud by the lecturers, resulting in huge time consumption. It is also prone to errors [13]. There are QR codes, RFID, wireless communication, fingerprint, iris, and face recognition based architectures in the literature [14].

In the QR code-based attendance system, a QR code that the lecturer projects on the screen is recorded by students' mobile devices. However, this solution ignores the location and authentication of the student. It cannot control whether or not the student attends the lecture in the class. Therefore, this reduces the reliability of the system. There are also other studies in the literature that try to enhance the reliability of such attendance systems. However, they require high expenditure for additional equipment used to increase the system's reliability.

For that reason, conventional QR-based attendance systems block users from participating in the attendance at a high number of incoming attendance requests to the system for a specific time [15,17]. The participation test results of the QR code-based attendance system designed with a single-layer architecture for 10,000 end-users are displayed in Figure 2.

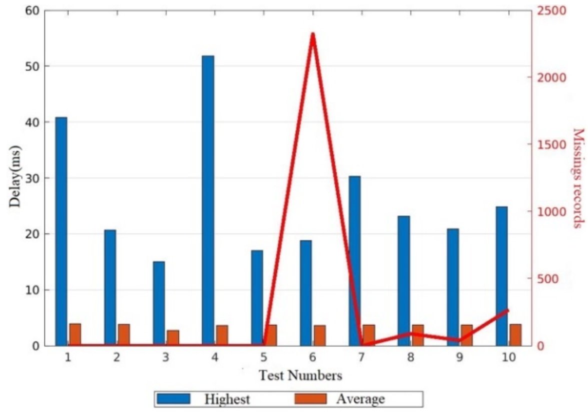

Figure 2. Preliminary Test for Conventional Attendance System.

On the y-axis on the left, the delay in milliseconds is indicated with a bar graph. The y-axis on the right indicates the number of those who could not participate in the attendance (the number of blocked) with a line graph. In light of this, the highest delay is observed at a level of 50 milliseconds, which is rather high above the acceptable level due to the excessive load in single-layered architecture. According to the new generation 5G requirements, it is requested that the delay level of software as a service should not be higher than four milliseconds [18]. Therefore, it is clear that the response time is not acceptable in the conventional single-layered systems, and some of the end-users can be blocked by the system, which reduces the reliability.

1.2. Contributions of Proposed System

In light of the aforementioned studies, a more efficient and reliable architectural design is required. This can only be handled by multi-layered architectural design compared to the conventional single-layer design [19,20]. Therefore, we propose a new Attendance as a Service, a multi-layered system including such technologies as QR code, face recognition, and fingerprint. The whole contributions are listed as follows:

- A novel middleware to reduce the cloud-centric server load,
- Integration of this system with a low cost by a software as a service,
- Minimizing human contact by using personal mobile devices for QR codes, face recognition systems, and fingerprint technology.

The remainder of the paper is organized as follows: In Section II, the analysis of the Attendance-as-a-Service architecture is given by comparing the conventional and proposed system architectures. The implementation details of the proposed system and its cost analysis are given in Section III. The proposed architecture in terms of delay, contactless and scalability metrics has been evaluated in Section IV.

2. Attendance as a Service and System Analysis

2.1. The comparison of conventional and proposed attendance systems

The conventional and proposed attendance systems are compared in terms of layering (Figure 3). Here, the conventional system is a QR code-based attendance system with a single-layered approach. The lecturer starts attendance at the attendance server layer, and by QR code read from the end-user's mobile devices, the attendance data is recorded in the cloud database. On the other hand, the proposed attendance architecture, thanks to added middleware and its multi-layered architecture, increases the reliability that checks that both the student and the lecturer are in the same local network (in the same class).

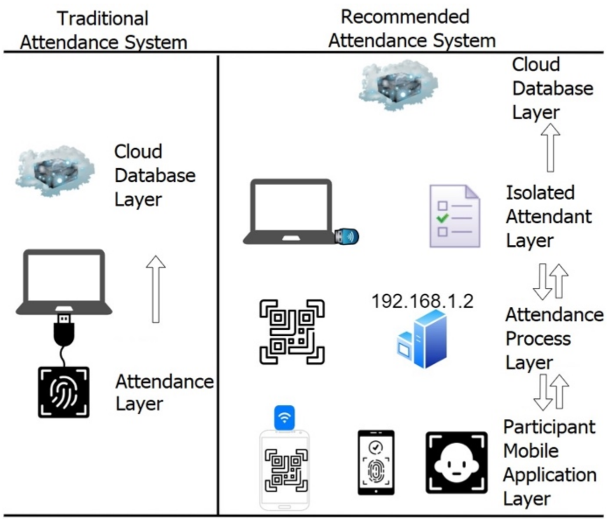

Figure 3. The comparison of conventional and proposed system architectures.

This implementation is performed at a minimal cost. Here, the attendance server layer and the lecturer's computer are used as the middleware, and it is used to open a local network. Students' attendance data first stored on the attendance server layer, i.e., not on a centralized cloud server. Afterwards, the saved attendance data is synchronized with the central server. Thanks to the added middleware, AaaS can be executed and synchronized with the enhanced system's reliability.

2.2. System Analysis

The system analysis of the proposed AaaS is detailed in the following subsections:

2.2.1. Strengths of the proposed AaaS

One of the strengths of the proposed AaaS is biometric data security. It is served to the end-user at the highest level because personal data is saved on the device of the relevant user. According to the Personal Data Protection Law, it is a law that biometric recognition systems should save personal data only on a personal device. In the light of this decision, the proposed architecture complies with this law. On the other hand, it offers a flexible architecture and can be adapted to specific services. For example, if attendance is desired to be implemented as a shift system, the architecture can be easily integrated accordingly. Moreover, taking attendance is based on asynchronous communication; there is no queue when executed. Therefore, the user experience is good.

On the other hand, there are three different packages according to the different customer types: simple, QR, and advanced package. In a simple package, the attendance network includes a mobile application that enables attendance by clicking the attend button, provided that it is connected to the attendance network using the newly added middleware. In the QR package, attendance is tracked by scanning the QR code as an addition to the simple package. Attendance is ensured by using QR codes and biometric control in the advanced package.

Furthermore, the suggested system is more resilient than existing systems. In current systems, systems such as fingerprint, face recognition, and RFID are inoperable in the event of a power outage; however, in the suggested multi-layer design, attendance can be performed asynchronously until the battery on portable computers is depleted. Cloud-based systems cannot function in traditional systems due to server and internet difficulties; however, attendance data can be temporarily saved in middleware in the suggested design, so attendance can still be received.

2.2.2. Weak aspects of proposed AaaS

To isolate the complexity of the middleware from the user, the proposed system acts as a relay against incoming requests. Therefore, any attendance data is portable in the middleware computer. The proposed multi-layer architectures may not be desirable where high security is required. However, in this case, the strength of security can be maximized with encryption algorithms such as SHA-2. Apart from these, a familiarization process is required to adapt to the new generation of technology. It is assumed that mobile users who are especially behind in digitalization can use QR scanning and/or fingerprint scanning on their mobile phones. The system's user interface is kept very simple to increase the user experience and speed up the process.

2.2.3. Possible opportunities with proposed AaaS

There is a new requirement for contactless work by COVID-19. We believe that the newly proposed system will enable mobile devices to be capable of more biometric recognition. Moreover, the significance of

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personal data will increase even more. Thanks to these systems that enable personal and contactless work, digital devices will become more widespread, and incentives for this transformation will increase.

2.2.4. Risk analysis of proposed AaaS

There are also many risks because of the programming background. It may occur that the programming languages in which the proposed system is deployed will not be supported in the future. In order to minimize this risk, the system uses a new generation of MongoDB database that provides high-performance data logging. It is also built on a modular structure with Single Page Application (SPA) support. It is compatible with Angular, a JavaScript-based framework. Back-end services are also written with Node.js. The mobile app is built with React Native. All such technologies are quite valid in todays' deployments. On the other hand, there may be another threat, such as the cost of existing biometric devices. However, it is unlikely to not use a mobile application due to physical device based challenges.

3. The implementation of AaaS and the cost analysis

3.1. The implementation of AaaS

The implementation details of the proposed architecture are displayed in Figure 5. It has three layers. The attendant uses layers 1 and 2; whereas, layer 3 manages the communication with the attendance of personal mobile devices.

3.1.1. The Work Flow of AaaS

Firstly, the attendant opens the desktop application, which is newly called QRFace Attendance. The application routes it to the login screen located in Layer 1. After the login is successful, it is routed to Layer 2.1 by transferring the attendant data. The interface opens the attendance network with a button and selects the group to be attended (for example, courses for universities, departments for workplaces, etc.). It starts the timing period for taking attendance. When attendance is initiated, a middleware called Layer 2.2 is automatically built. The attendant projects the QR code and the remaining time on a screen that the participants can see. Attendance requests are taken and routed through Layer 2.2. Incoming requests are temporarily recorded on the attendant's computer, and Layer 2.2 is terminated. When attendance is finished, the attendant confirms the attendance list via Layer 2.1. The process is completed by transmitting data to Layer 1.

Meanwhile, the participant who uses the QRFace mobile app should first connect to the network created by the attendant.

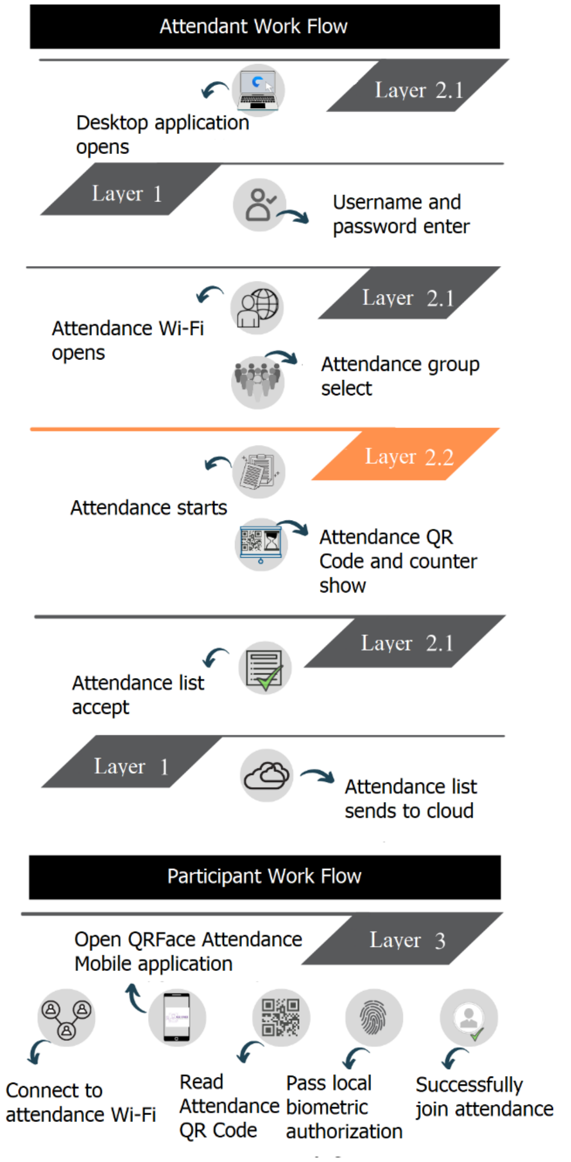

Figure 4. The Work Flows for Attendant and Participant.

The QR code on the screen is read by this mobile app. It is a 2D barcode technology that has common usage in applications. It improves the user experience by easily overcoming the difficulties faced in daily life. As an example in [21], the QR code screen is clearly represented to the end-user so they can easily read it with the mobile device. In [22], the willingness of Romanian people to use QR codes for based shopping is investigated, and the results indicate that the applicability of QR codes and enabling quick access to information about products improves the shopping experience of the respondents. The QR code minimizes the user interaction to transfer any data to the applications which gives altenative to manual entry [23].

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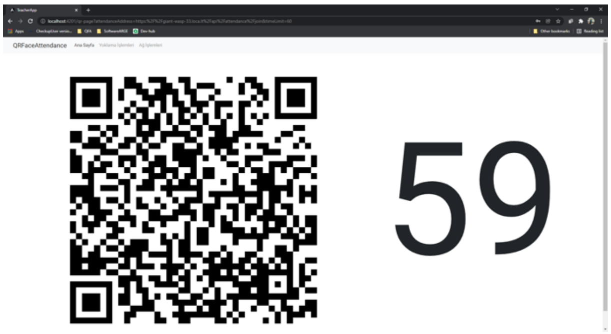

Figure 5. An example for QR code implementation in Layer 2.

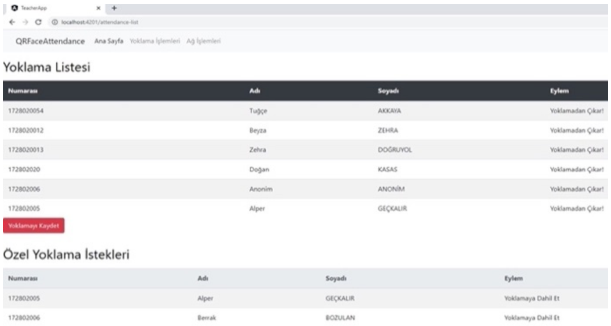

Figure 6. An example for Attendance List in Layer 2.

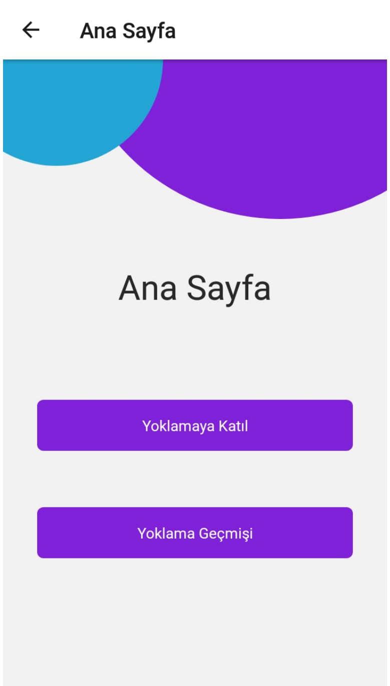

Figure 7. Main page in Layer 3.

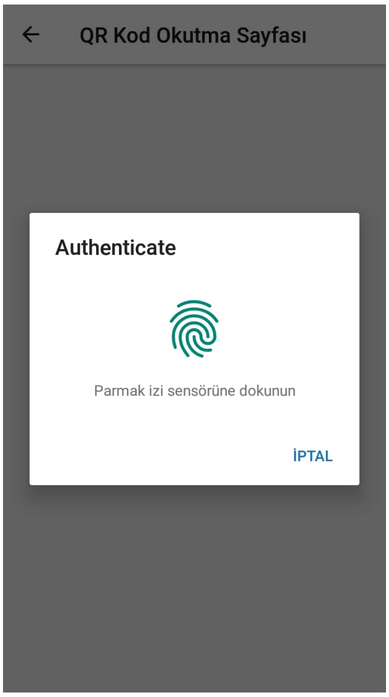

Figure 8. FingerPrint check-in Layer 3.

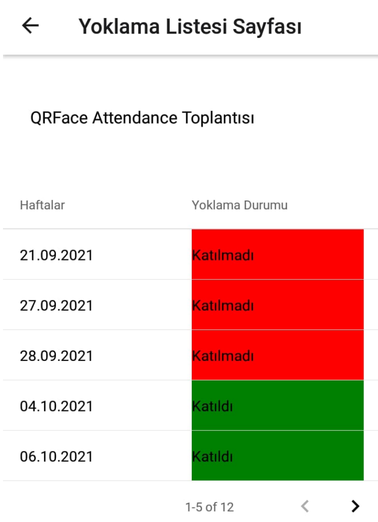

Figure 9. Attendance Status in Layer 3.

Furthermore, a mobile application is analyzed in terms of user experience that use a QR code- based payment system in [24]. It is believed that such designs make users more comfortable in COVID-19 pandemics because there is no need for any touch to the screen. According to analyze which has many respondents from Sarawak and Malaysia, the fast loading time and QR code based payment are prioritized according to their important factors. Therefore, we use QR code in our application to accelerate taking attendence. According to user experience literature of QR code technology, we designed this screen by using a QR code that is placed centrally and implemented as plug-in service [25].

After the QR code screen, the user recognition should be performed. If the device supports face recognition or fingerprints for biometric checks, they are used. For example, the fingerprint screen is designed uniquely for all mobile applications to meet user requirements as also mentioned in [26]. If the device does not support biometric recognition, it performs biometric control with the alternative face recognition system, which is available in the mobile application. This is currently used in such systems to check the personality with a quick response time [27]. The AdaBoost algorithm is used to enhance the performance of face detection [28]. According to the studies [29,30], the fingerprint is not suitable while compared to face recognition in terms of possible treats and hygiene. Therefore, we design our face recognition module which is implemented to mobile application as plug-in service in the light of these literatures. When the check is successful, the data is transmitted to Layer 2.2. Figures 5-6 illustrate the examples the proposed designs of Layer2 for web platform; whereas, the examples of Layer3 for mobile platform are given in Figures 7-8-9.

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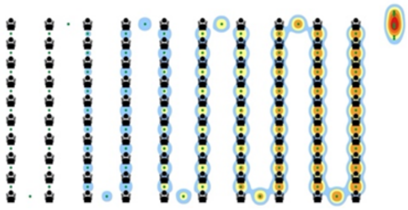

Figure 10. Contacts in Conventional System.

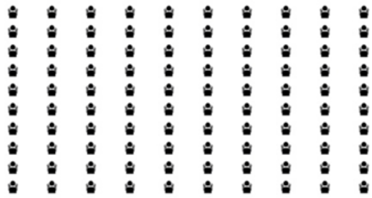

Figure 11. Contacts in RFID based Systems.

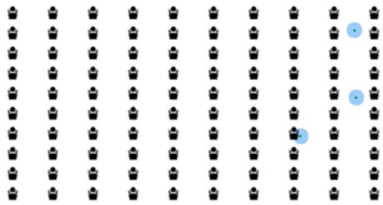

Figure 12. Contacts in Proposed System.

3.1.2. Technology Stack of AaaS

There is MongoDB with NoSQL in the technology stack, which performs high-performance data logging and flexible data modeling for the database. It has a modular structure with Single Page Application (SPA) in Angular, which divides the application into parts and enables it to be reusable, and it is easy and fast to develop projects with third-party frameworks. It also uses Node.js, which is compatible with JavaScript and enables new updates. Mobile applications use a cross-platform language named React Native that enables fast testability, a high user experience, and compatibility with the JavaScript back-end. The whole technology stack for the proposed AaaS is listed as below:

- In the first layer, MongoDB, Angular for the web interface, and a Node.js server for Create, Read, Update, Delete, operations on cloud databases are implemented.
- The second layer has two sublayers, as layer 2.1 layer and layer 2.2 (middleware). Layer 2.1 runs on "localhost" and includes Angular, which provides the interface for the participant, There is also a Node.js server that enables network operations, attendance listing, or sending data. The middleware is executed by the local IP address of the attendance network (For example, 192.168.1.2), and it contains the Node.js server that receives the incoming attendance requests.
- In the third layer, if the participant's device does not support biometric recognition, an alternative React Native application with face recognition is also available.

3.2. The Cost Analysis of AaaS

Table 1. Cost comparison of Cloud Database for a system that serves 100.000 participants.

Service	Conventional Attendance System	Proposed Attendance System
Cloud Database	$749/month	$57/month (-92%)

The cost analyses of the conventional system and the proposed multi-layered system are given in Table 1. Here, the cost of the MongoDB database dated 15.03.2021 is given for both cases. In the conventional system, the workload is executed on the cloud because of the lack of middleware. There is a bottleneck which results in an ability to participate in attendance. To overcome this challenge, more costly database services are needed. On the other hand, the proposed multi-layered architecture greatly reduces the cost and handles the inability to participate in the attendance without any extra expenditure. It is indicated in the performance evaluation that it overcomes the case of not being able to participate in the poll by minimizing the incoming load to the cloud database. Therefore, the database cost for multi-layered architecture is 92% lower than the conventional one for the same user experience.

4. The performance evaluation of AaaS

Table 2. Testbed Environment for Performance Evaluation.

Network Adapter	RAM	CPU	Disk Speed (Read/Write)
Internal, External	8GB	Intel (R) Core (TM) i5 7300HQ 2.5Ghz	2000MB/s-1500MB/s
Local	12GB	Intel (R) Core (TM) i7 7700HQ 2.81Ghz	500MB/s-500MB/s

The performance of the proposed system is evaluated in 10 runs of real tests where the details are given in Table 2. Here, there are three network definitions such as "internal", "external", and "local". These shows in which real environment the performance tests are performed. The internal network adapter is the existing network adapter in the computer. The external network adapter is the network adapter used with USB. If it is local, it is treated as the local computer's IP address, also known as "localhost".

4.1.1. The Physical Contact HeatMaps

In Figures 10-11-12, the physical contacts resulting from the conventional or proposed attendance system are given in heatmaps. Here, the red color indicates the

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points where there is high physical contact between participants, while the blue color indicates the contact is low, which is suitable for COVID-19 spread. The contact status of conventional methods when taking attendance of between 100 participants is given in Figures 10 and 11. The proposed AaaS is given in Figure 12. In the first one, there is a high level of contact and attendance queue formation is observed due to the attendance queue and the location of the participants. Due to the location of the RFID and biometric recognition devices, the physical contact and attendance queues are observed according to the proximity between the participants at a high level. However, in the proposed system, the physical proximity between the participants is very low, as it can be understood that only blue colors are seen on the heat map. Compared to biometric and conventional attendance systems, this proposed one has both less contact and physical proximity between participants and fewer attendance queues.

4.1.2. Delay Analysis

Table 3. Delay gain of Proposed Attendance System while comparing the conventional one.

The Number of Participants	Average Delay	Observed Maximum Delay
25	6.122 msecs	8.428 msecs
50	5.065 msecs	3.338 msecs
100	2.857 msecs	4.071 msecs

As in Table 3, it is indicated that the gain in user experience for the proposed multi-layered architecture compared to the conventional one. It has been observed that the average delay is reduced to 8 milliseconds by the use of middleware. The factors affecting delay are the computer's hardware features, the network adapter and the number of participants.

As indicated in Figures 13 and 14, the average delay results for the conventional and the proposed architectures are given according to the increasing number of participants. It has been observed that while the average delay is in the order of 8 milliseconds in the conventional one, it is decreased to the level of 2 milliseconds in the proposed architecture thanks to the multilayered architecture. In both graphs, the average values decrease as the number of participants increases. This is because of a queue to participate in attendance. The narrowing of the confidence interval means that the high delay is less than the other ones as the number of participants increases. When the highest delay values of the conventional architecture are examined, it is clear that the confidence interval is wider in the 54-person tests and the highest delay is more minor in the 108-person tests. When the outputs are analyzed, it is clear that the system is working at optimum performance between 54 and 108 people, which caused a delay between 27 and 54 people because they are not used to the attendance system.

According to the adapter type used in the proposed architecture, internal values are slower than external and external values are slower than local ones. Despite the increase in the number of participants, the average delay values obtained are very close due to the isolation of the workload to the middleware and the complexity to the end-user.

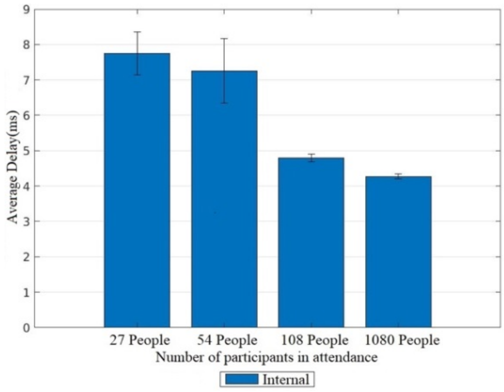

Figure 13. The Average Delay for Conventional System.

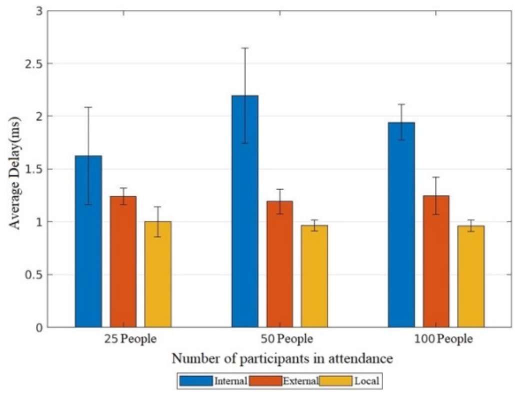

Figure 14. The Average Delay for Proposed System.

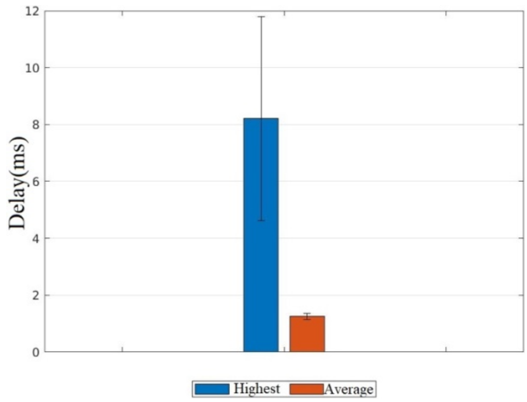

Figure 15. The Scalability of Proposed AaaS.

4.1.3. Scalability Analysis

The scalability of the AaaS architecture proposed in Figure 15 has been examined by simulating the attendance of 100,000 participants. Delay values are obtained by sending 1000 attendance requests to the database, where each contains the data of 100 participants. In this evaluation, the attendance of 100,000 participants was successfully saved in the database. On the other hand, the delay values obtained are at the level of 2 milliseconds for each 1000 participants saving, while it reaches the order of 8 milliseconds at the most. Despite this high user participation, the user delay can be kept at an acceptable level. On the other hand, the proposed system reaches the delay value (8 milliseconds) that the conventional method can provide at a low user level. Namely, the proposed system can be scalable up to 100,000 participants.

5. Conclusion and Future Work

Due to the contactless requirement of COVID-19 on smart applications, we propose an Attendance as a Service (AaaS) system with its multi-layered architectural design. The proposed system is easily integrated into the contactless working conditions brought about by COVID-19 compared to conventional single-layer attendance systems. Here, a distributed multi-layer architecture is executed on personalized mobile devices. It is implemented by software integration as a service in the cloud market, and the security level is increased by the use of technologies such as QR codes, face recognition, and fingerprints.

These biometric systems in attendance are highly used but not implemented as plug-in services in the conventional ones. The distributed implementation of the personnel check system on the attendance application keeps privacy without any data on central servers. There are also other studies in the literature that try to enhance the reliability of such attendance systems. However, they require high expenditure for additional equipment used to increase the reliability of the system. By using QR codes and mobile device-based checks (face recognition and fingerprints) on personal devices, there is no extra expenditure to build such a proposed system. Namely, it is easily implemented with low OPEX and CAPEX. According to the performance evaluation, the proposed AaaS serves end-users with a lower delay and a high scalability level compared to the conventional attendance systems commonly used today.
In the future, the proposed multi-layered design can be easily applied to other research and application-based areas that require low operational costs while also providing higher security. For example, blockchain-based systems can easily be integrated with this proposed multi-layered architecture without any need for centralized authority. Therefore, the data privacy and integrity in an application can also be handled at the same time.

Acknowledgement

This study was supported with the project number *** within the scope of the 2209-A University Students Research Projects Support Program of the Scientific and Technological Research Council of Turkey (TUBITAK).

Author's Contributions

Alparslan Çay: Conceptualization, methodology, preliminary analysis, front-end and back-end implementation, mobile application, writing-original draft.
Doğan Kasas: Conceptualization, face recognition algorithm, mobile application, back-end implementation, writing-original draft.
Müge Erel-Özçevik: Conceptualization, methodology, validation, preliminary analysis, performance evaluation, writing-original draft, consultancy.

Ethics

There are no ethical issues after the publication of this manuscript.

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