An IoT-Aware System for Managing Patients' Waiting Time Using Bluetooth Low-Energy Technology

Reham Alabduljabbar[1*]
ralabduljabbar@ksu.edu.sa
[1]Information Technology Department, College of Computer and Information Sciences, King Saud University, Riyadh, Saudi Arabia
[*]Corresponding Author: Reham Alabduljabbar.

Abstract: It is a common observation that whenever any patient arrives at the front desk of a hospital, outpatient clinic, or other health-associated centers, they have to first queue up in a line and wait to fill in their registration form to get admitted. The long waiting time without any status updates is the most common complaint, worrying health officials. In this paper, UrNext, a location-aware mobile-based solution using Bluetooth low-energy (BLE) technology, is presented to solve the problem. Recently, a technology-oriented method has been gaining popularity in solving the healthcare sector's problems, namely the Internet of Things (IoT). The implementation of this solution could be explained through a simple example that when a patient arrives at a clinic for her consultation. There, instead of having to wait in long lines, she will be greeted automatically, receive a push notification telling her that she has been admitted along with an estimated waiting time for her consultation session. This will not only provide the patients with a sense of freedom but would also reduce uncertainty levels that are generally observed, thus saving both time and money. This work aimed to improve clinics' quality of services and organize queues and minimize waiting times in clinics, leading to patient comfortability and reducing the burden on nurses and receptionists. The results demonstrated that the presented system was successful in its performance and helped achieve high usability.

Keywords:
Internet of things (IoT); location-aware; Bluetooth low energy; beacon

1. Introduction

The delicate nature and the need of all the services being provided by the health institutions could easily be attributed to its direct relation with the health and life of a society. The true measure of success is the unequaled level of devoted services that they provide their people with. In clinics, the long waiting time is the most common complaint, resulting in patients' frustrations and anxiety, and unfortunately, the end result being the patient exiting the clinic without attending her appointment. A research study, carried out in 2015 at the primary care clinic in Gombak, Malaysia, showed that more than half of the patients (53%) were enrolled within 15 minutes in which the average total waiting time was 41 minutes [1]. A study in the Kingdom of Saudi Arabia showed that the waiting time between the predetermined time and the actual doctor's appointment in outpatient clinics is 44.83 minutes [2]. There is various study that focus on the problems of patients waiting time and their consequence. Some of those studies are [3][4][5][6][7][8]. These studies suggest that the patients wait on an average of 30 to 45 minutes in order to get their appointment and treatments. There are three main reasons for the long waiting time [2,3]:

- outnumbered staff in the reception service causing lengthy registration time,
- acute shortage of health personnel in the increasing demand for these services, and
- obvious problems in the registration system, the dates, and the emergence of deliberate and unintentional excesses.

The motive of UrNext is to reduce the waiting time for the patients while also focusing on improving the quality of services to provide comfortability to patients. UrNext, is a location-aware mobile application which uses proximity-aware device technology, such as Bluetooth low-energy (BLE) beacons. Beacons are compact, low-powered transmitters responsible for connecting and communicating with smart devices in a predefined physical radius [9]. This beacon-based Bluetooth technology enables all the patients and doctors on board to simultaneously receive relevant information at the right moment, as per their respective geo-locations. Through the UrNext application, the patients can approximately know the waiting time of their appointments, and they can also view the number of patients in the waiting line. In addition, doctors' problem in receiving a notification when a patient arrives is solved. To the best of the researcher knowledge, no application utilizes beacon technology in the healthcare domain that overcomes the queuing problem. The paper consists of 5 sections. Section 2 discusses the

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foundation and previous studies on the same topic. Section 3 lays down the entire system analysis and its rightful implementations. Section 4 presents the evaluation phase of the system. Finally, Section 5 concludes the paper, along with future directions.

2 Background and Related Works

2.1 Bluetooth Beacons Technology

Bluetooth beacons are hardware transmitters that use BLE technology. They enable smartphones and other devices to convey their identifying elements to other compatible devices in their proximity. [10]. In Figure 1, it shows how the beacon works to give continuous signals. This enables the other compatible devices to pick up the call by only sensing it through their Bluetooth. This generates a unique ID that will be sent to the server. The server will request the application to act, and the user will receive it on the device.

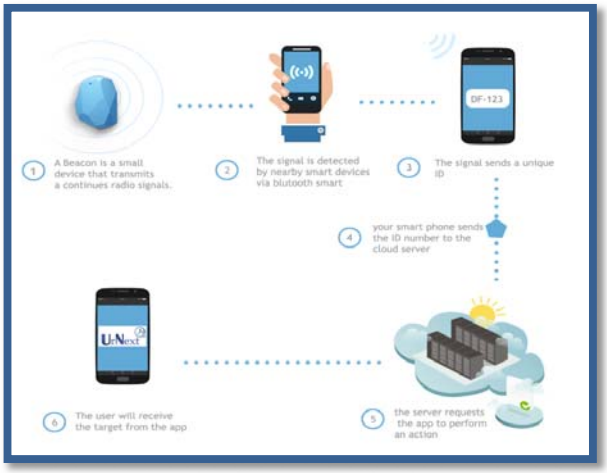

Figure 1: How beacons work.

2.2 Related Works

There are various works done to reduce the patients waiting time and each work was independently done with unique approach. The following are the few works done in this context with various methodologies. The authors in this work [11] have proposed an alternative approach to handle the issue of patients waiting time. They have proposed a queuing management system which ultimately reduces the inconvenience to the patients. They have solved this issue by developing a web application. In another similar work [12], the authors have developed a mobile application to monitor the patients waiting time with the help of IoT devices. This application has the capability of tracking the patient's vital signs like heartbeat, blood pressure and pulse rate. In another work [13] related to patients waiting time analysis, the authors have proposed a methodology which involves servers and their maintenance. The ultimate goal is to monitor the hospital environment which also includes the patients waiting time. This system has the capability to optimize the waiting time and reduce the cost of maintenance. The patients waiting time and queue are monitored in another work [14] where a fully logic technique was implemented to manage the queue and study also analysis the business effect of using this application on hospitals. In the recent times it has been noted that waiting time is effectively influencing the customer satisfaction and it is having diverse effect on moderate loyalty relationship [15]. Patients waiting time is considered as a serious and major issue among the professional healthcare administrators and policy-makers. This issue is very much effecting especially the primary healthcare sector. The waiting time is acting as a barrier in providing the efficient treatment to the patients and also the flow of in patients[16]. As stated before waiting time is acting as a barrier in providing efficient service to the patients. Similarly, in this work [17] the authors discover that waiting time is acting as a barrier for patients care and creating a bad effect on building strong friendly atmosphere between the customer and the clinic. Patients waiting time issue is handled in other countries also like in this work [18] the authors are working in Canada to tackle this issue. In another work [19] relating to the waiting time of the patients. The study shows that some patients can manage 30 minutes of wait and do not mind even if it exceeds 60 minutes but gets agitated beyond this time. Another country also conducted a study relating to patients waiting time.

Like in this work [20] the authors from Nigeria investigated the average waiting time. The study concluded that around 62% of the patients wait more than 90 minutes and around 38% of the remaining wait around 180 minutes. Patients long waiting time is effecting the healthcare as the clinics are losing their patients and effecting the reputation of the clinic. This issue is creating a discomfort to the staff as well [21]. Here, different applications developed using beacon technology are presented and compared to UrNext, to explore all of its benefits and uses that are of great use to all the users, along with also discovering the restrictions that make it difficult or hard to use. QLess [22] is a company based in Pasadena, CA, USA. This company produces software-as-a-service solutions to eliminate waiting lines, known as the QLess app. The application includes a Queue Management Feature, which gives the traditional waiting in queues a modern look and removes the frustration of waiting for long hours for nothing. As soon as the user selects a line for herself, s/he ultimately has to wait, but more conveniently and formally. Users are constantly kept updated with their waiting status, and a timely SMS alert,

call alerts, or visual text notifies them it is finally their turn to order/consult. One of the application's amazing features is the 'Waiting Room Management.' This feature allows the clinic or hospital to adjust their respective patient's timings and appointments. QLess streamlines patients' satisfaction and reduces their waiting time with its "virtual queues" features. The application also enables patients to freely control their booking and visiting schedules while staying within the confines of their homes. The SMS and call alert feature also makes it quite feasible for them to wait for their respective turns. This significantly reduces the waiting time and anxiety which is otherwise seen in people who get tired of waiting for long hours for their turns. The key features of the QLess application are the follows:

-eliminating crowded waiting rooms,

-boosting staff productivity and operational efficiencies,

-reducing patient complaints,

-gaining valuable insights with reports, and

-enhancing communications and patient engagement.

Live Wait Times application[23] helps the patients in choosing the best national health service (NHS) accident and emergency service or walk-in center for patients' circumstances. The application allows searching local NHS sites, either by postcode, geographic area, phone, or device location. In each site, the waiting time is displayed, and more information such as treatments offered, parking, and opening times are displayed when the site is tapped. The application can also locate and navigate to the nearby NHS sites. The application's primary function is to provide the latest known waiting time estimations, thus helping the patients make an informed choice on an appropriate NHS site to visit. The key features of the Live Wait Times application are the follows:

-searching for local NHS sites,

-providing information such as treatments offered and parking and opening times about sites,

-locating and navigating nearby NHS sites, and

-providing the latest known waiting time.

NoWait application [24] allows its users to book a place or spot for themselves. All that the user has to do is simply search up the home or restaurant, or anywhere that she is looking for. Then, the results would notify the user of the possible waiting time that her selected place requires so that she reaches there on time and without having to wait unnecessarily. The application also can notify the user of the waiting time and how many people are there in front of the line. The key features of the NoWait application are as follows:

-saving time by getting in line from home, work, or a private yacht; and

-gaining peace of mind by knowing how long the wait time is at any nearby restaurant.

BeHere application [25] is a companion application for education. BeHere is a full set of solutions, increasing classroom experience and improving the institution and the student's interaction. The BeHere application using iBeacon automatically registers the students' attendance as soon as they walk through the door. Teachers can see and interact with students in real-time and can have a full schedule at a glance. Also, teachers can seamlessly share documents with all students, which can also be stored for offline use. The key features of the BeHere application are as follows:

-usage of the beacon,

-opening the application automatically when iBeacon identifies the device,

-providing a full schedule in a glance,

-providing shared documents with a swipe to all students, and

-storing the documents for offline use.

A comparison of the related applications by features is shown in Table 1.

Table 1: Comparison of the related applications

Features/applications	UrNext	QLess	Live Wait Times	NoWait	BeHere
Language	English	English	English	English	English and Portuguese
Uses beacon technology	✓				✓
Provides automatic registration	✓			✓	✓
Sends a greeting message	✓			✓	✓
Provides an estimated waiting time	✓	✓	✓	✓	
Provides queue number	✓	✓	✓	✓	
Gets notified when it is your turn	✓	✓	✓	✓	
Provides personalized entertainment content	✓				
Serves healthcare domain	✓	✓	✓		
Tracks queue outside the boundaries of the building	✓	✓	✓	✓	

The above table quite clearly indicates that the BeHere application is the only application that employs beacon technology. BeHere applies to the educational sector, and UrNext revolves around the healthcare sector. The same

applies to QLess and Less Wait Times applications. However, these applications do not use beacon technology. Furthermore, most apps do not provide an electronic registration feature. Based on the comparison and discussion, we developed a location-aware mobile application using proximity-aware device technology. The developed application will serve the healthcare community targeting adult patients. The system performs four basic functionalities: sends a greeting message when the patient walks into the clinic, notifies the doctor and nurse when a patient arrives, informs the patient of an estimated waiting time and queue number, allowing with also being a time-saver and before-handily informing the patients if the doctor is out due to any personal reasons.

3 System Analysis and Implementation

3.1 System Overview

A location-aware mobile application was developed using BLE beacons, where mobile devices can be aware of the input locations. UrNext is designed to target four different types of users: doctors, receptionists, nurses, and doctors, respectively. To gain a broad and precise perspective of the problem in front of us, several interviews were run with doctors, nurses, and receptionists by circulating random questionnaires to them [26].

The system provides different uses for each party. The scenario of the solution) is as follows. The patients are required to first turn on their mobile phone's Bluetooth only after installing the required application. The application must also be granted full access to the user's location and GPS. When this has been done, the application connects itself to the patient's Bluetooth device, resulting in the generation of a customized greeting message, an estimated waiting time, and a queue number on the mobile device. UrNext completely takes care of the patient-doctor communications and keeps both of them well-informed at all times. The arrival of a patient, the cancellation of an appointment, and the doctor's unavailability are all told as it is to the patient.

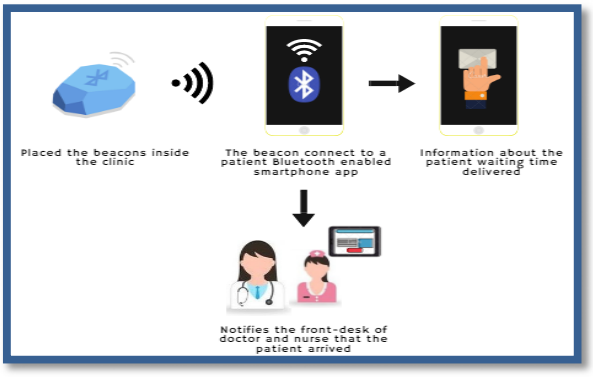

Figure 2: UrNext solution.

In the system, it is assumed that the patient who logs in to the system has an appointment already, and the walk-in patients who have no appointments cannot log in to the system.

3.2 System Architecture

UrNext uses a client–server architecture to ensure that the server is always available and that files and applications can be accessed at any time. The server also acts as a centralized hub for storing and sharing files and supports remote access, enabling clinic staff and patients to access data on the server without physically being in front of the system [27]. The architecture design of the application is shown in Figure 3. During implementation, the clinic's external database was queried for some values (appointment information such as time, patient, and doctor) to calculate estimated waiting time and queue number and get the doctor and nurse's information.

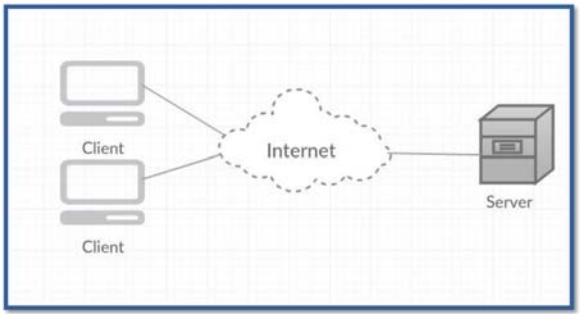

Figure 3: System architecture.

3.3 System Analysis and Design

A user-centric design method was adopted to develop the application. Two types of questionnaires were designed: a hard-copy questionnaire for doctors and nurses and an online questionnaire for patients. The questionnaires were distributed to the system stakeholders to understand the problem more broadly and precisely understand the needs and requirements. The questionnaires were first distributed to several doctors, nurses, and receptionists to obtain detailed information about the problem of waiting in clinics and the impact on the work process and to know the procedures of scheduling appointments. Also included in the questionnaire is their expectation from the system. Next, the online questionnaire for patients and clinic auditors was distributed to obtain a clearer picture of their needs and see how they will respond to an application that solves the waiting problem. The survey results provided the researcher increased confidence about the system's importance to the health officials and patients and its usage in facilitating the process of organizing queues and minimizing waiting times in clinics. In the system's development process, the UrNext system uses an object-oriented analysis and design (OOAD)

approach instead of structured analysis and design approach. This approach focuses on objects rather than data or processors. This approach was followed because an object-oriented programming language was used in developing the UrNext system. OOAD also guarantees that the system shall have a longer life and less maintenance cost because most of the processes are encapsulated. Also, OOAD provides reliability and flexibility to the system [28]. In Figure 4, a use case diagram is presented, showing the main actions performed by the system's different users.

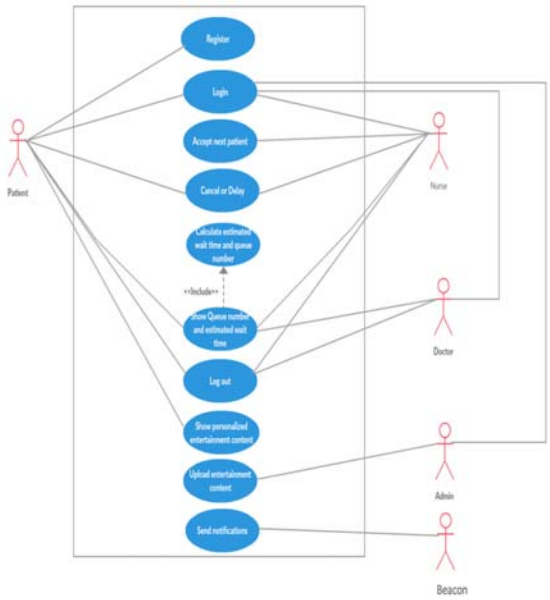

Figure 4: Use case diagram.

The following are the descriptions of each use case.

Register. Create an account for the patient, so s/he can get services from the system.

Login. To log into the system.

Accept next patient. This use case begins when the nurse wants to accept the next patient when the current patient is almost finished.

Cancel or delay. This use case begins when the nurse wants to notify all next patients when the doctor has emergency reasons and write a comment, including a delayed appointment.

Calculate estimated wait time and queue number. When doctors, nurses, and patients choose to display queue operations, cancel an appointment, accept the next patient, or cancel and delay, this use case will be initiated. The estimated waiting time and the queue number are calculated according to the algorithm presented in Figure 5..

Show queue number and estimated wait time. Doctors and nurses can choose to display a queue number to see the next patient and how many patients are in the queue. A patient can also see her queue number, estimated waiting time, and how many patients before her.

Log out. Allows doctors, nurses, admins, and patients to log out from the system.

Show personalized entertainment content. Allows the patient to show personalized entertainment contents.

Upload entertainment content. The system administrator can upload entertainment contents to the database.

Send notifications. The beacon will send a message to the patient's mobile by Bluetooth to notify the patient that s/he is in or out of the beacon range.

BEGIN
RETRIEVE *appointment time of patients under doctor ID* ***THEN***
RETRIEVE *arrival time of each patient*
CALCULATE *queue number which EQUAL the number of patient before this patient* ***THEN***
CALCULATE *current waiting time which is the SUBTRACT of appointment time from arrival time* ***THEN***
UPDATE *queue number*
UPDATE *estimated wait time*
DISPLAY *queue number and estimated waiting time*
STORE *estimated waiting time in database*
END

Figure 5: Algorithm of calculating estimated waiting time and queue number.

3.4 System Implementation and Integration

In developing the system, several essential software, external tools, and hardware were used to satisfy the system's needs.

Beacon [29]**.** A Beacon is a compact transmitter of radio waves. It is similar to Bluetooth. The signals that it transmits are picked up by other devices that are in close proximity to it. One thing worthy of noting is that the radio signals are in the form of different and unique combinations of letters and numbers. The speed of transmission of these signals is $1/10^{th}$ of the speed of a second. Any phone or a smart device that has Bluetooth can pick up these signals.

Android mobile devices. Samsung, Huawei, and LG smartphones.

Android Studio [30]. Official Integrated Development Environment for Android application development based on IntelliJ IDEA.

Notepad++ [31]. It is a free source code editor that is

used because of its support for several languages.

Android SDK. These tools are selected for developing different applications on Android. It allows users to debug libraries, relevant documentation for the Android application program, interfaces, and emulator created by Google [32].

CPU Monitor Advanced Lite. This application lets all the information get recorded, which are related to all the processes being run on the device.

Monkey command line tool [33]. This tool allows 'N' (number) of events to be created. It runs over the ADB commanding line. The commands include features like touches, gestures, other events.

Node.js. allows JavaScript to be implemented for the development of different web servers and other tools related to networking. It is able to handle different cores and their functionalities. These modules use an API design that does not let their writing get too much complicated [34].

Firebase database [35]. This database is hosted by a cloud and is a real-time testing system. In this database, the data is synchronized and stored as JSON to be provided simultaneously to the client.

During the initial development of the UrNext system, we started working on each function separately. In the integration of the system, we conducted it at three levels. In the first level, we worked on basic functions such as sign up, sign in, log out, and forgot password. In the second level, we implemented each user separately (patient, doctor, nurse, and admin). In the third level, we integrated all components

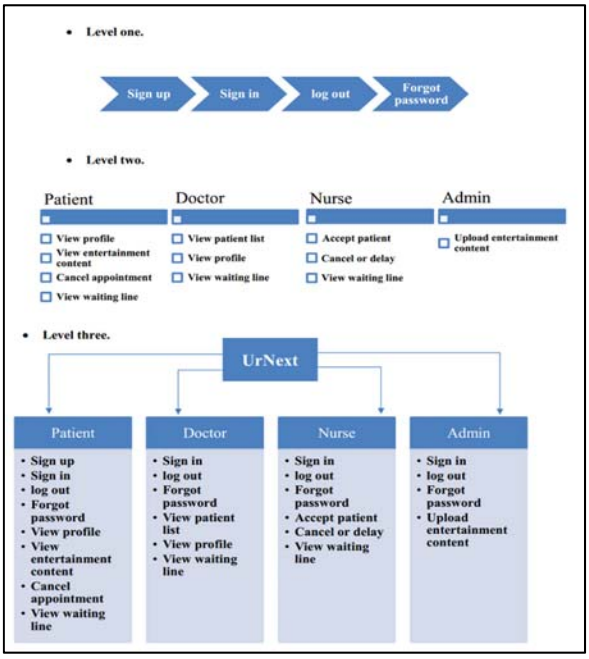

Figure 7: UrNext integration stages.

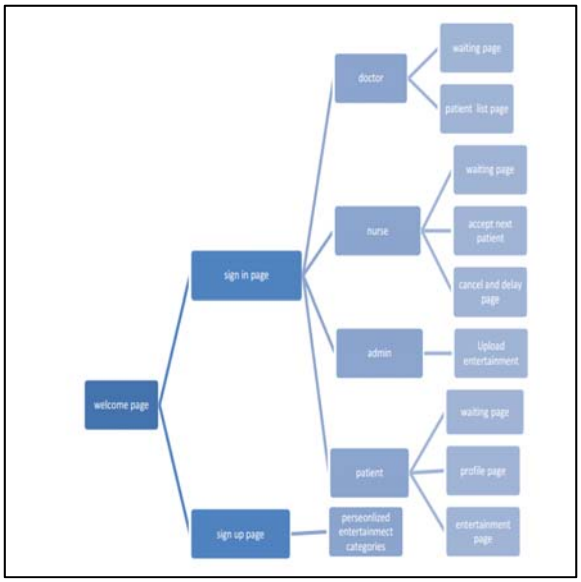

Figure 8: The layout of the UrNext application

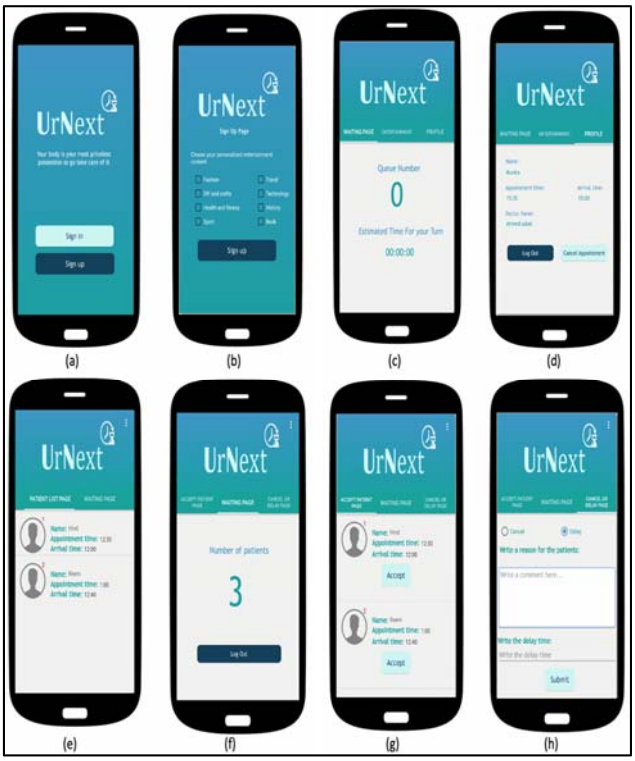

Figure 6: Snapshots of the primary interfaces of UrNext: (a) home page; (b) patient interface showing the signup part of patients; (c) patient interface showing the queue number and estimated waiting time; (d) patient interface showing the patient's profile, such as name, appointment time, arrival timee

to the clinic, and doctor's name; (e) doctor/nurse interface showing the arrival list and patients' information, such as name, appointment time, arrival time to the clinic, and position number; (f) doctor/nurse interface showing the number of patients in the waiting line; (g) nurse interface showing the acceptance for admission of the next patient; and (h) doctor/nurse interface showing the cancellation or delay of an appointment in which the patient will be notified.

3.5 Application Layout and User Interface

We developed the system by adding all the functionalities and making it easier to use. Because the visual presentation of the user interface elements has a great impact on an application's user experience, we made sure that the UrNext components are well organized within the system for easy navigation and interaction. Figure 6 shows a hierarchy diagram for the main layout of UrNext.

The interfaces were specifically designed to be kept as user-friendly, simple, and consistent as possible. Figure 6 shows the main UrNext interfaces followed by a simple description.

4. Evaluation

After evaluating UrNext through system testing with different strategies and user acceptance testing (UAT), the results are discussed in this section.

4.1 System Testing

In system testing, it shows any errors encountered during the development process, ensuring the system's performance effectiveness. For the evaluation of UrNext, we applied the following methods: unit testing, integration testing, performance testing, and stress testing.

4.1.1 Unit Testing

Unit testing aims to test the individual part of the software application before integrating it to the main application and ensure that every component works as expected [28]. All elements of the UrNext system passed this test, as shown in Table 2..

Table 2: Unit testing

User	Component name	Component name	Result
All users	Component A	Sign in	Pass
	Component B	Logout	Pass
	Component C	Reset password	Pass
Admin	Component D	Upload entertainment content	Pass
Doctor	Component E	View patient list	Pass
	Component F	View profile	Pass
Nurse	Component G	Accept patient	Pass
	Component H	Cancel or delay	Pass
Patient	Component I	Signup	Pass
Doctor, nurse, patient	Component J	View profile	Pass
	Component K	View entertainment content	Pass
	Component L	Cancel appointment	Pass
	Component M	View waiting time	Pass

4.1.2 Integration Testing

In software testing, integration testing is when an individual software module is combined and tested as a group, which is usually performed after the testing of the unit and before validating the test. In this type of testing, those modules of input are used which have already been tested before. The process involves grouping up these modules into combinations, then combining them into even larger groups, and then subsequently conveyed to a plan testing system that was already designed for this purpose. [28]. The testing of the integration in UrNext was performed using the bottom-up approach. The testing of modules takes place in ascending order, with the higher modules preceding the lower ones. This method successfully enabled all the UrNext modules to be tested.

4.1.3 Performance Testing

Performance testing was carried out to determine the overall quality of the designed system, considering CPU usage as one of the selected metrics in evaluating the performance of an application. We conducted the performance testing using CPU Monitor Advanced Lite and chose the Android Profile option in the Android studio, in which the system showed a good response time. Figure 9 shows the CPU usage over the last minute of the UrNext application. In Figure 9, it shows the average and maximum usage of memory and network, in which the average CPU utilization rate is 3%, and its maximum speed is 7%, implying that the system is lightweight.

Figure 9: Performance testing

4.1.4 Stress Testing

Stress testing is the process of determining and specifying the robustness of the system. It is also used to see and observe the response of the system under loading from the user. For this application, we used the Monkey command line tool, which works by sending an imaginary or pseudo-random sequence of user events to a running emulator. It acts as a stress test on the application. After 500 events generation, the UrNext worked as expected.

4.2 UAT

UAT aims to ensure that the requirements are met, in which the target users perform to make sure that it is reliable and could be trusted in reality-based scenarios, too [36]. A total of 12 users participated in the UAT, in which five of them were students from the female section of the College of Computer and Information Science, King Saud University, three doctors, three nurses, and one admin. The usability of the system was tested in two different criteria.

Efficiency. It is done by measuring the time the user took to complete a task.

Satisfaction. We measured it by asking the users to fill a survey to find out what the user's reaction was when using the app. Table 3 shows the results of the UAT of some tasks for UrNext users.

Table 3: Results of the UAT of some tasks for the UrNext users

User	Number	Task	Average time (s)
Admin	1	Sign in	7
	2	Logout	3
	3	Reset password	20
	4	Upload entertainment content	32
Doctor	1	Sign in	8
	2	Logout	3
	3	Reset password	25
Nurse	1	Sign in	8
	2	Logout	3
	3	Reset password	25
	4	Accept patient	20
	5	Cancel or delay	20
Patient	1	Signup	28
	2	Sign in	8
	3	Logout	3
	4	Reset password	25
	5	Cancel appointment	3

In Table 3, the highest task in time was upload entertainment content, which is reasonable because it depends on the uploaded media's size. On the other hand, sign in, logout, and cancel an appointment for patient requests between 3 and 10 seconds only. Some tasks required writing statements, such as sign up, reset password, cancel appointments for the nurse, and delay appointments for the nurse, which take between 15 and 25 seconds.

We also asked the users to fill a survey about testing the whole application for its usability and their satisfaction regarding the common application. According to the study, we obtained the following results: performance is 58.3%, the graphical user interface is 83.3%, friendliness is 75%, the easy-to-use application is 100% (which means the system has no difficulties using), and satisfaction is 58.3%.

All in all, UAT showed that the designed App was successful in executing the desired functions. The performance overall reached its goal of providing quality services to the users. Moreover, the application's system faced no crashes. The privacy factor was remarkable too, and no leakages or breaches in privacy were reported to be seen.

5. Conclusion and Future Work

In this paper, a unique, location-aware mobile-based using BLE technology solution was devised and proposed. The main goal for introducing UrNext was to improve the quality of the health sector services by attempting to reduce long waiting times and organizing patients' admission systemically.

The current version of UrNext supports the Android operating system; hence, the future work will be focused on the implementation of UrNext to support all the compatible iOS devices. Furthermore, new features will be added as well, such as support for indoor navigation to the clinic room number and support for more languages, making the

application universal.

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Conflicts of Interest: The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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