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A store-forward method for biosignal acquisition in smart healthcare system utilizing wearable IoT device

Dany Primanita Kartikasari*[1], Apriyanto Tobing[2], Adhitya Bhawiyuga[3], Ari Kusyanti[4], Nuretha Hevy Purwaningtyas[5]
Brawijaya University, Indonesia[1,2,3,4,5]

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*Corresponding author.
Dany Primanita Kartikasari
E-mail address:
dany.jalin@ub.ac.id

Abstract
Smart Healthcare System has been developed massively in the last decade. Internet of Things implementation has accelerated the development of smart health technology. People nowadays have realized the importance of doing independent health monitoring. Supported by more affordable e-health tools, the motivation in using the smart health system is increasing. The availability of cloud as storage services triggers demands to always connect to the Internet. However, there are times when interference occurs, so the measurement results cannot be stored in the cloud database properly. The idea of using a store-forward mechanism to overcome the problem of the disconnected smart healthcare system is proposed in this paper. The temporary storage mechanism is carried out by forming a local database on the smartwatch using the SQLite library to store data that failed to send due to BLE disconnection. Once the connection is made available again, the data will be sent to the gateway, sequentially with the new data recorded by the sensor nodes. From the test results, the data can be sent properly even though disconnected status occurs for 30 minutes. Smartwatch's memory usage has increased 30 percent during temporary storage occupied.

1. Introduction

Internet of Things (IoT) has impacted our daily activity life in all aspects. IoT interconnected various components to communicate using network links and enables them to sense and perform tasks together [1]. IoT architecture consists of smart objects from embedded sensors, actuators, processors, and transceivers to carry out smart systems and automation [2]. IoT Gateway functions as a bridge device to connect local sensor networks and cloud servers [3]. The cloud server is utilized as a storage device and computation component in the IoT paradigm [4].

Meanwhile, in the last two decades, healthcare needs are becoming an interesting matter in the community. People start to demand improvement of life quality and quality of care. This has increased attentiveness in the use of healthcare systems by monitoring physiological functions using non-invasive wearable sensors. In 1996, [5] proposed a wireless body area network as a method of information exchange between the human body and electronics devices using networking capabilities. It started with devices such as personal digital assistants, cellular phones, and pagers. A Wireless Body Area Network (WBAN) is a wireless network of wearable computing devices. It covers the human body with a set of resident sensors or devices. A sensor node in the wireless body area network can sense, process, and communicate one or more vital signs such as heart rate, Blood Pressure, oxygen saturation, activities, or environmental parameters, which include location, temperature, humidity, etc [6].

The Wearable device is a mobile electronic device that can be worn to be an accessory or embedded into other materials near the body. This device is an adoption technology of biosensors and wireless data communication, whereas wearers can access and transmit information in all human endeavor sectors [7]. The enhancement of wearable technology and growing demand from consumers has accelerated the development of wearable device types. One of the leading wearable devices is the smartwatch, which offers one-stop solutions featuring cellular connectivity. Smartwatch devices are expected to grow to 30 percent of the world's population in 2024 [8].

The Wearable IoT concept is an enhancement of IoT to improve the quality of human life, and it becomes a part of the healthcare industry in various ways. Wearable IoT's basic components are wearable body sensor devices that can collect, send, and receive data sensed from the wearer body through the Internet. Architectural elements of wearable IoT is similar to the original concept of IoT. It consists of three elements: wearable body area sensors function data acquisition component, interconnected gateway as data gathering and transferring component and cloud computing with big data support to do data processing and analyzing [9]. Wearable IoT is also applicable for medical applications. Biomedical wearables have been utilized to perform monitoring tasks on the Internet of Things for healthcare purposes. The architectural elements of wearable IoT Healthcare are illustrated in Figure 1.

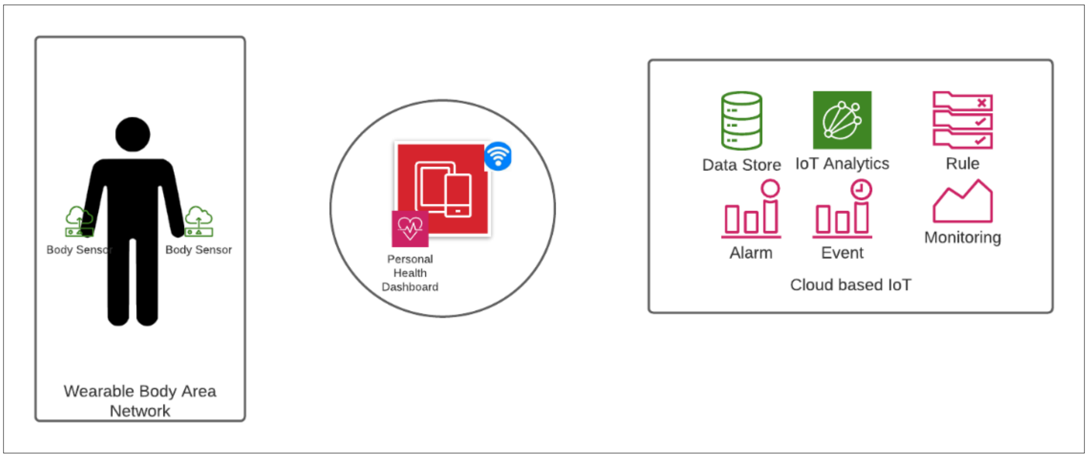


Figure 1. Architectural Elements of Wearable IoT [10]

There are two major types of wearable body sensors in the market. The first type is on-body contact sensors. This type is usually suitable for monitoring and therapeutic application. The second type is a non-contact sensor. This type is usually used for fitness and wellness applications, attitude observation, and rehabilitation [11]. Since healthcare is always an important issue in human life, the application development based on wearable IoT has been summed up [12]. Some of the application is developed for health treatment and rehabilitation. The other type of application is designed for health monitoring, such as published by [13][14].

Smartwatch devices commonly use low-power wireless communication such as Bluetooth Low Energy (BLE) to overcome power constraints and node's lifetime. These devices require an application layer gateway to translate data from a low-power link to the Internet at a global network to connect to the Internet. A Smartphone can act as a useful gateway because it has a near-constant Internet connection, mobility, and ubiquity. Connecting to a smartphone seems to be an ideal method to provide data connectivity on a smartwatch. But problems arise when the paired smartphone connection is ceased [15]. Bluetooth Low Energy (BLE) is a protocol between two devices or more, designed to provide significantly lower power consumption. In the BLE communication mechanism, devices interact with specific roles and responsibilities. A device may act as a central in master mode, and the other devices are in slave mode. The master device scans to look for advertisements. Meanwhile, the slave mode transits periodic beacons, termed advertisement packets, to notify nearby central nodes of their presence. After establishing a connection, both master and slave devices start to transfer GATT metadata to one another. BLE system can reduce the consumed energy through fast neighbor discovery by only using three special channels as the advertising channel during the neighbor discovery process. It also uses periodic sleeping during connection. A pair of master-slave connection state changes to sleep if two consecutive packet transmission failures are detected. It may experience a high bit error rate (BER) as interference results from other nodes. Signal interference from other nodes causes transmission failure and turns the node state to sleep. This greatly affects the performance of BLE. Kaala's paper [16] has observed environmental conditions that cause interference with BLE. The success rate of sending depends on the selection of available channel data. If the selected data channel is in an environment with interference, it will result in unsuccessful data transmission.

Health-related data can be obtained by utilizing IoT technology, even though the patient and medical staff are not in the same location. Telemedicine and telehealth concepts have made it possible for medical diagnoses to be made based on data obtained from real-time monitoring [17]. Wearable IoT technology is one of the choices for individual vital sign monitoring devices. This smart personal healthcare system can monitor, and record information related to individual physical conditions and motor activities without disturbing their daily activities. This vital sign data must be obtained completely so that the connecting network's reliability must also be ascertained. Wearable devices require a gateway device that can connect storage. Among the choices of devices that can function as gateways, smartphones are the right choice. Smartphones are mobile, so they can always be carried by the monitored individual. Smartphones have an Internet connection connected to data storage in the cloud environment, using either wifi or a telco connection. Meanwhile, both smartwatches and smartphones are equipped with the BLE communication protocol. As stated in prior studies, BLE communication devices are susceptible to interference, resulting in the loss of data transmission packets. Meanwhile, to monitor data related to a person's health, a high-reliability connection is needed to ensure that no data is lost. This study suggests a method to ensure that the data that has been acquired by the sensor on the smartwatch can still be sent even though there is a disconnection in BLE communication with the smartphone gateway. This study's main contribution proposes the store-and-forward mechanism in the data acquisition phase using the BLE connection and measures the performance of our proposed scheme. The rest of the paper is organized as follows. Section 2 describes the proposed system. Section 3 describes the performance evaluation. Finally, this paper is concluded in section 4.

2. Proposed Method

In a smart healthcare system, data acquisition is a mandatory function to gain complete information about the user's body information and state [18]. To ensure complete data availability, the system must confirm the availability of the link connection to the cloud network. This work focuses on a method to postpone data delivery to the next host using a buffering management method implemented on a delay tolerant network [19] to solve the problem of end-to-end disconnection on the Internet network. The store-and-forward mechanism [20] on the delay-tolerant network requires buffer space to hold data until the network connection is restored. The data arrangement in the buffer uses an ascending order of array index. The proposed system utilizes an additional module to keep the data temporary during the inspection phase of network availability. The stored data will be forwarded following the regular transmission procedure after the connection is reinstated. The architecture of the proposed method is represented in Figure 2.

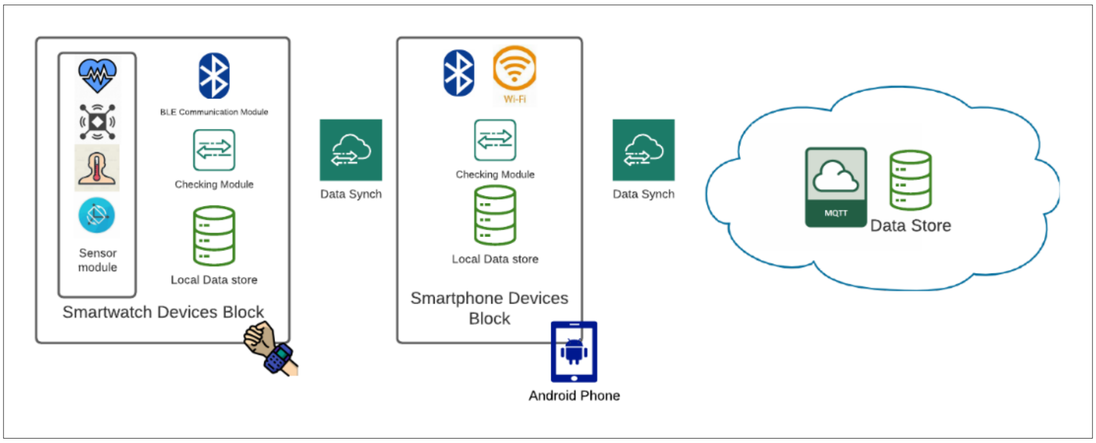


Figure 2. The Architecture of the Proposed Method

This design aims to ensure the availability of measurement data by utilizing temporary storage to ensure connection to the next node. On the first step, the initialization module begins with recognizing body signal characteristics to verify that the smartwatch is applied to the human body. This is a necessary decision to retrench power consumption when off body status is detected. Sensing modules start to run afterward by defining sensor type and periodic time interval needed for the reading phase. Managed by the main sensor manager function in the initialization module, the sensor manager begins to load the sensor module and set the sensor's sampling period in the activating sensor phase. In this e-health system, the data sensor is read using API provided by the Android operating system. After sensors begin to read, they send the data to local storage in smartwatch memory within an interval of 10 seconds. A thread handler is utilized to ensure the store process takes place in exactly ten-second intervals. The storing process is scheduled four times in one second. Each data is saved in an array with four indexes to accommodate updating data at a high rate.

Meanwhile, the communication module is checking the BLE connection from pairing devices activity. If the connection status is available, then the system database helper function starts to read data from the smartwatch's local database. The data will be forwarded to the gateway module on the smartphone. After sending data, the database module will delete the data from the smartwatch's local storage. When the system is offline, the sensors' measured data will be stored in the local database. The local database on the smartwatch is formed by utilizing the Sqlite library in the android application. The data saving interval on Sqlite is 10 seconds. The storage process pays attention to the usage indication parameters and the available BLE connections. If the value returned by the Offbody Latency sensor and the RegisterDevices variable is null, then the storage process from the DatabaseHelpder class will be executed. This storage process is carried out four times, based on accelerated data, which stores four data in one second. Each acceleration data is stored in an array with four indexes. This design uses time variables to ensure that no duplicate data is stored in the gateway's temporary database and storage module. For data with the same time variable value, it will be ignored when it reaches the gateway. The structure of the local database is shown in Table 1.

Table 1. Database Attribute

Table	Attribute	Data Type	Length
data_vital	Time	LONG	8 bytes
	heart_rate	FLOAT	4 bytes
	step_counter	INTEGER	4 bytes
data_activity,	Time	LONG	8 bytes
	acc_x	FLOAT	4 bytes
	acc_y	FLOAT	4 bytes
	acc_z	FLOAT	4 bytes
	gyro_x	FLOAT	4 bytes
	gyro_y	FLOAT	4 bytes
	gyro_z	FLOAT	4 bytes

BLE is designed for periodic transfers of very small amounts of data [21]. In this study, the data transmission intervals are performed every 5 seconds and operating in a fully asynchronous mode as the scanner device listens asynchronously, waiting for a packet from an advertiser. Gateway device receives data from smartwatch after BLE pairing is connected. On the initial process, data from the smartwatch contains information about Sensor's MAC address and UUID for each service, characteristic, and descriptor provided by the BLE sensor node. Bluetooth adapter API is used to define variables needed for the initiation phase. After the connection is settled, the gateway module starts to receive data from the smartwatch using changes in the value of the service characteristics that occur. Data is received in the gateway module in hexadecimal form. Hexa data is converted to array format using the ByteBuffer function to fit in required format data in the processing phase. The Forwarding step in the gateway device begins after sensor data is received completely. The sensor's originated data is sent to the cloud utilizing communication method in paho MQTT platform and registered in system's database according to its UUID and topics that have been defined by parameter and instance of MQTT service.

3. Performance evaluation

The proposed method has been implemented in The Smart Healthcare System. The application is developed and tested for consumer-grade smartwatches produce by Mobvoi [22]. It provides several built-in sensors such as accelerometers, gyroscope, and heart rate. A smartwatch device's operating system is WearOS [23], which provides APIs to read raw sensor data. Smartwatch applications can display measuring results in a single choice user interface. The user interface on the smartwatch application is shown in Figure 3.

Figure 3. Single Choice User Interface

The android smartphone used as a gateway device works with the Android 6.0 operating system [24]. This operating system runs API level 23 and can support the BLE communication module. Meanwhile, to run the publisher function on the gateway, the gateway device is installed with the paho MQTT library [24]. The gateway publishes the data and sends it to an existing broker. This study using a hosted message broker for IoT provided by cloud MQTT [25].

To evaluate system performance, some experimental procedures have been conducted with configurations listed below:

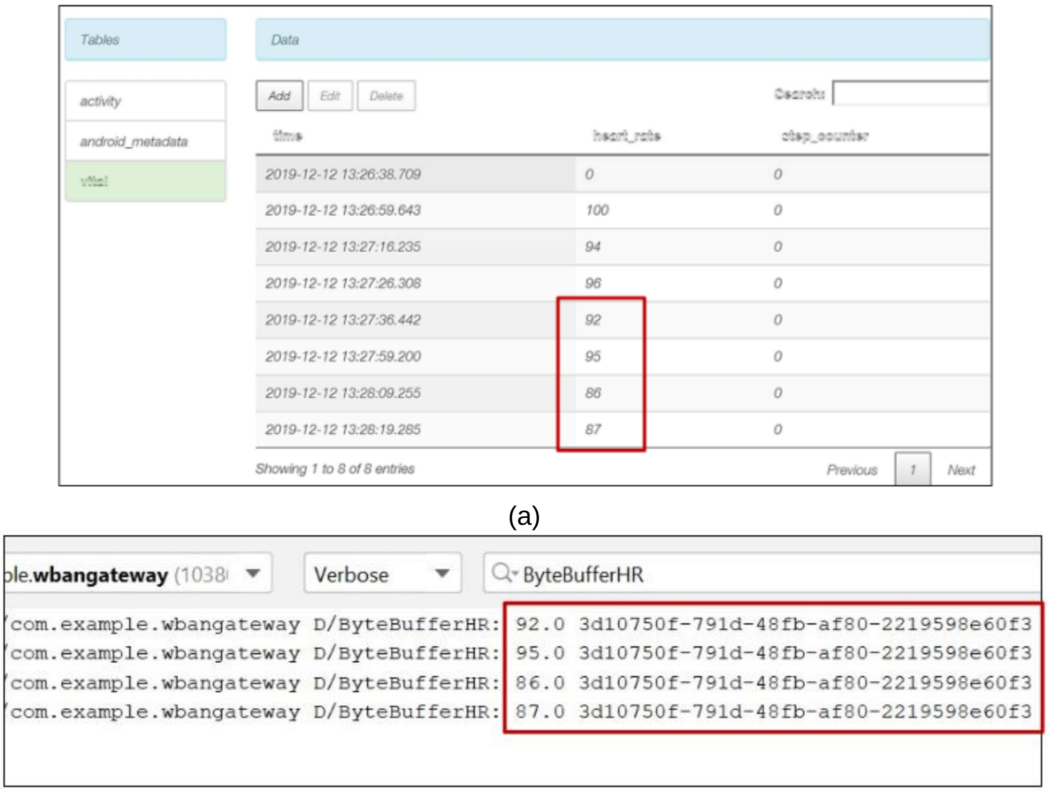
- reading validity of built-in sensors
- storing validity of smartwatch local database
- store and forward implementation

For data processing purposes, each test process will store information in a log file placed in each section. The log files are formatted with a special tag to distinguish each type of transmission to specified test results. The tag format used in the log file is shown in Table 2.

Table 2. Tag Format in Data Transmission Log File

Source	Format
Database	[TAG: ActivityDB] | [ByteArray Accelerometer] | [ByteArray Gyroscope]
Database	[TAG: VitalDB] | [ByteArray Heartrate] | [ByteArray Pedometer]
Sensor Module	[TAG: HeartSensor] | [ByteArray Heartrate]
Sensor Module	[TAG: StepSensor] | [ByteArray Pedometer]
Sensor Module	[TAG: Activity] | ["Accelerometer: " ByteArray Accelerometer]
Sensor Module	[TAG: Activity] | ["Gyroscope: " ByteArray Gyroscope]

During testing the store-forward method, this is done by disconnecting the BLE connection for 5 seconds. To ensure the store-forward mechanism is running well, the test has been done checking the data stored in the local database and the data sent to the gateway. The test results of the store-forward mechanism on the system are shown in Figure 4.



(b)

Figure 4. Heartrate Data Stored in local database (a) and Forwarded to Gateway(b)

This proposed method is designed to improve data availability in the Smart Healthcare System Framework. To evaluate the improvement level gained from this work, we conducted two experiments to certify that research goals are achieved. The first test is calculating the data transmission success ratio. To ensure data received on the cloud server, data were sent from sensor nodes in various characteristics and topics simultaneously. Data tested were heart rate, footstep, acceleration, and gyroscope 3D. The sensors were disconnected from BLE for three duration lengths: 5, 15, and 30 minutes. Data were recorded in the smartwatch's local database. Success ratio can be computed by Equation 1.

$$\text{Success Ratio(SR)} = \text{Total Data Transmitted} / \text{Total Data Received} \tag{1}$$

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The result exposed that applying the store-forward mechanism, the smartwatch's data has arrived completely at the gateway device. The proposed method has been implemented successfully to save temporary data with a BLE disconnection duration of up to 30 minutes. But in a certain condition, there was a loss of data when data is supposed to arrive at cloud storage. MQTT connection between gateway and MQTT broker is provided by the public Internet provider, and this uncontrollable traffic condition is inevitable. Figure 5 visualize experiment result in success ratio for all sensors.

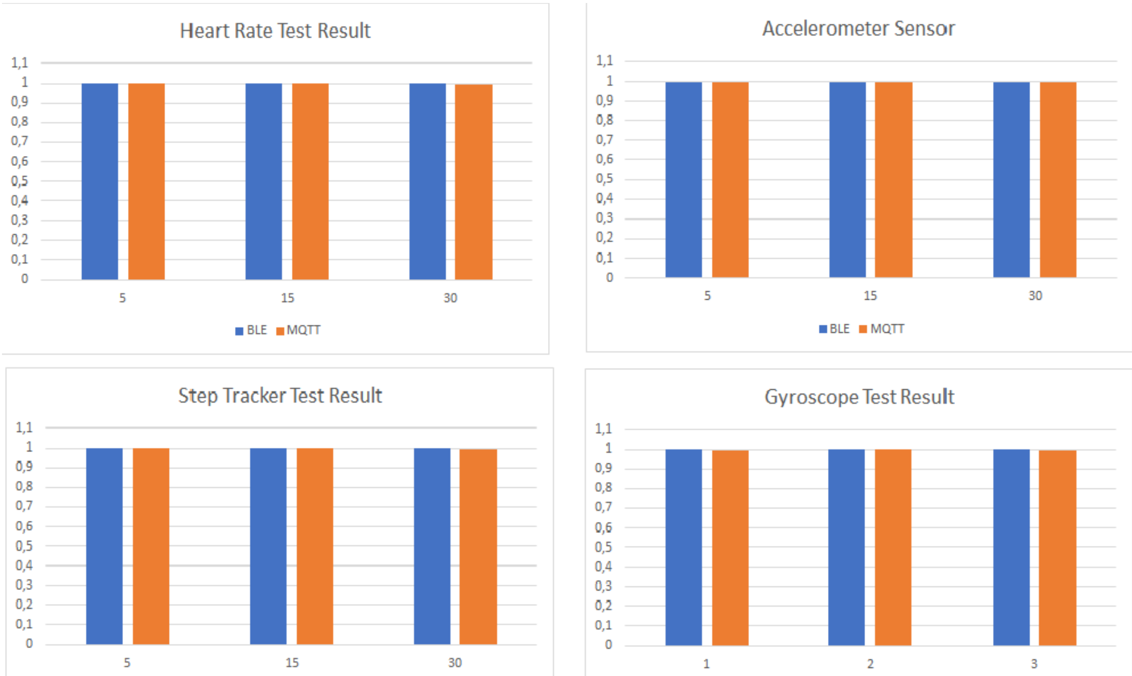

Figure 5. Success Ratio Testing Result

In the second test, we experimented with the memory usage during the store-forward method with the local SQLite database. The amount of data stored corresponds to the network's duration disconnection in the first test. The stored duration is 5 minutes, 15 minutes, and 30 minutes. The testing result of memory usage shows that in normal condition, sensor devices activity uses 4KB of file size in the local database and occupies 16,38 KB memory size. Every five minutes of additional time to disconnected network, the local database's temporary data increases about 30%, as shown in Figure 6.

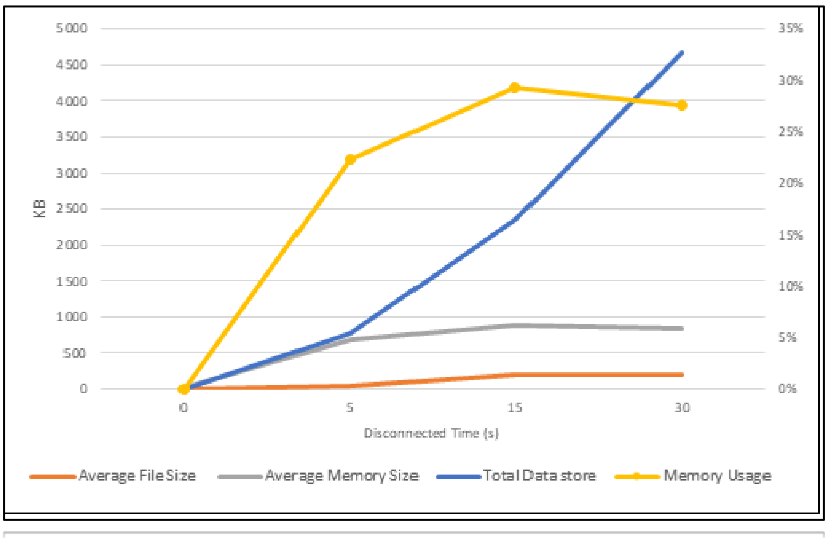

Figure 6. Memory Usage Testing Result

4. Conclusions

In this research work, the store-and-forward mechanism has been implemented in the Smart Healthcare system. This design aims to improve the monitoring data reliability when the system is disconnected from the networks utilizing temporary storage at the smartwatch. The proposed method has been implemented successfully to store temporary data with a BLE disconnection duration of up to 30 minutes. Using the locally store-and-forward method, system memory has increased 30 percent from normal usage during the tested disconnected time.

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