ECTI Transactions on Computer and Information Technology
Journal homepage: https://ph01.tci-thaijo.org/index.php/ecticit/
Published by the ECTI Association, Thailand, ISSN: 2286-9131

An Enhancement of Network Reliability for Patient Monitoring System with IoT Rehabilitation Devices

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ABSTRACT

This paper presents a patient monitoring system that can support multiple IoT (Internet of Things) rehabilitation devices. The physicians can plan the treatment for each patient via the Internet connection system with our software which has three sub processes: device configuration, monitoring, as well as feedback. The proposed system has been designed to support multiple devices and various types of rehabilitation devices by using the common HTTP protocol. This allows various IoT platforms to be programed to control various rehabilitation devices and connect to the Internet via WLAN, LAN, or cellular networks. The network connection test reported that the system can support many users' devices sending the measurement data concurrently as well as correctly. Moreover, we propose a network selection algorithm for mobile devices that considers both Wi-Fi and cellular using energy efficiency, packet delay, and UDP success rate as key parameters to enhance network connection reliability. This algorithm is able to make sure that the network connection for transmitting the important data is always the very best in terms of reliability and efficiency. The system reliability test reported approximately 99% success rate for sending data to the servers with a low data rate. Consequently, this system works well in real world applications.

Article information:

Keywords: Rehabilitation, IoT, Patient Monitoring, Network Connection Reliability

Article history:
Received: September 29, 2021
Revised: October 22, 2021
Accepted: November 16, 2021
Published: February 12, 2022 (Online)

DOI: 10.37936/ecti-cit.2022161.245721

1. INTRODUCTION

Rehabilitation through physical therapy is very important for improving the quality of life of elderly people, people with disabilities, and other patients. The main obstacle to effective physical therapy is a lack of regular and consistent participation due to inadequate training by physicians, lack of motivation to practice, inability to track and control the rehabilitation program when a patient leaves the hospital, inconvenience of travel, and finally the number of tools and physicians are insufficient. Therefore, a monitoring system and devices to assist elderly people, people with disabilities and patients in distance therapy through the Internet network, which works without having to go in person to rehab at the hospital every time and allows physicians to monitor the physiotherapy of their patients more effectively, is needed [1]-[5].

A review of the literature related to existing systems allows comparison of the features in the existing solutions. 1) For target patients/diseases, it shows that most patients need physical therapy to manage their muscles. Most of systems serves patients who have had strokes [6]-[11], except cardiovascular disease [12]. 2) For training device/instrument, it shows that most systems lack a variety of training devices. Most have only a single type of device in a system. 3) Goal setting rules set goals for training. For example, how much should the percentage of trained muscles increase? Most systems [7], [8], [10], [11], [12] support manually setting the goals by medical experts. 4) Physicians can schedule physical therapy sessions online and edit prescription amendments. 5) Physicians can adjust their goals if the results are better or worse than their original goals. The adjustable system appears in many papers [7]-[10]. 6) Patient monitoring is important to let the doctor be aware of

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how the patient is able to perform physical therapy. It can be done both online and offline. Some papers [7] [8] [9] [12] describe systems that can monitor the results via text or plot, while others are able to monitor with a GUI [6] or visualization [11]. 7) It is advisable to inform the patient if the physical activity is not accurate or is less than the goal. A physician can give feedback to the patients automatically [7], [12]. 8) Most systems allow communication between physicians /physiotherapists and patients. This is done in a variety of ways such as text [7], [10], [12], web pages [11], and visual/audio files [6].

The existing systems are monolithic systems with a single device in the system. The communication between the physician and the patient is the same as most current online communication systems. To improve this, the proposed patient monitoring system is characterized by a variety of rehabilitation devices developed to meet the needs of users. The proposed patient monitoring system is designed to support multiple IoT rehabilitation devices. In order to connect to the Internet network all the time efficiently, software needs to discover and use the optimal network path. To deal with this issue, there are many papers with research about network selection. Some papers consider the modification of mobile phone firmware, so that all network paths can connect to the Internet simultaneously. Some apply human consideration to weight each parameter for calculation [20], by allowing the users to input the data for working on their method. One paper is using neural networks for wireless network selection [21]. Their algorithms collect the important data and use it in a neural network for training to get the optimized network. Delphi [17] has an algorithm based on a regression tree to select the optimized wireless network by using data such as energy as well as monetary cost in objective functions and weights from user assignment. Furthermore, ASWU [18] uses the Max-Min Fairness Algorithm for dynamic weights and Zero-Sum Game, which is a mathematical model of a situation where after adding to the total gains and subtracting from the total losses of each participant, the summation must be zero, so that the loss or gain of the data of each participant is balanced. Then the device uses weights for calculating the score function to obtain the optimized network. Finally, we studied the network selection scheme in the simulation based on Delphi and ASWU [22]. The proposed algorithm has been tested to verify that it can reach convergence.

The remainder of this paper is organized as follows. Section II introduces the system overview. Section III gives the detailed system design. Section IV explains system reliability analysis and test, respectively. Finally, the conclusion is in section V.

2. SYSTEM OVERVIEW

Fig.1 shows the proposed patient monitoring system overview. In this paper, there are five types of rehabilitation devices: A) image processing devices for measuring the degree of shoulder movement for shoulder rehabilitation, B) image processing devices for measuring of the lung volume for Triflo pulmonary rehabilitation, C) pressure measurement devices for BreatheMAX muscular breathing rehabilitation, D) EMG and angle measurement devices for isotonic knee rehabilitation with sand bag, and E) torque measurement devices for isokinetic knee rehabilitation with NK-Table. Each rehabilitation device communicates with servers at the hospital via the Internet. The proposed patient monitoring system is designed to support various IoT rehabilitation devices.

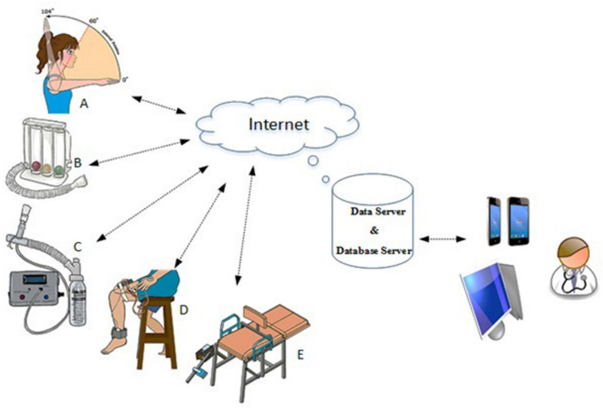

Fig.1: *The proposed patient monitoring system overview.*

There are many possible networks for the proposed patient monitoring system. It has been implemented with support for networks such as LAN, Wi-Fi, and cellular. However, we especially focus on the network system of the device type C), which is an android smartphone attached with the embedded system and a sensor that is connected to the Internet. The most popular wireless communication these days is provided by mobile phones which are very good for using in remote systems [13,14]. Today, smart phones are using wireless networks to connect worldwide. Examples are GSM, LTE, WCDMA, and Wi-Fi. The mobile phone's owner can choose which path to connect to the Internet. Moreover, mobile phones can select the network path by themselves, by trying to connect to Wi-Fi first if this connection is available. If Wi-Fi is not available, mobile phones switch to cellular instead. Nevertheless, the smart phones cannot measure the network performance of each network to connect to the Internet. Therefore, a phone may obtain the worst network connection in network selection. In order to connect securely to the Internet all the time for transmitting the significant data [15,16] such as ECG signals to the hospital as quickly as possible, the device needs to select a suitable network path for data communication with respect to reliability and efficiency.

3. SYSTEM DESIGN

Our system has a database and process design supporting multiple IoT rehabilitation devices. Furthermore, the network and Internet connection design has been created systematically to communicate with the server.

3.1 Database Design

As one of the main functions for this system, the database has been designed and developed to collect the data of various devices for supporting the entire system as shown in Fig.2. The schema is divided into eight tables Device's table collects the device information. Patient's table keeps the important data of patients entering the physical training program using data collected by the patients in the physiotherapy program. PatientHistory's table is a table for gathering all data measured from all devices as a history of the physical therapy of the patient. It will be used for further analysis. Staff's table stores the staff data. This is the information of the physicians or nurses who are responsible for the patients in the physical therapy program. User's table keeps data of all system users such as physicians, system developers, and administrators of the system. It supports separate levels of different system permissions. Threshold's table keeps the threshold data for each device configuration in the physical training program using default setting data. This value is determined by the physician after considering each patient physically. Patient Week's table stores all the data from all tracking and assistive devices for physical therapy through communication networks. Feedback's table collects all information on the recommendations from physicians for patients in the physical training program in order to improve physical therapy for the patients.

3.2 Process Design

This system has two groups of users. The first group is for the patient or disabled person. The doctor or nurse or physiotherapist is in the other group. The first group includes the system users who provide configuration information to the system. The data from the doctors must be identified for the disparate devices and each patient. The patient does the rehabilitation following the physical therapy program. After the patients are investigated and tracked, the doctors will give advice above physical therapy by sending feedback. The method of operation for this system is related to communication between two groups, the physicians and the patients as represented in Fig.3. A physician can use a smart phone or a computer to perform online device configuration, monitoring, and for sending feedback to the patients.

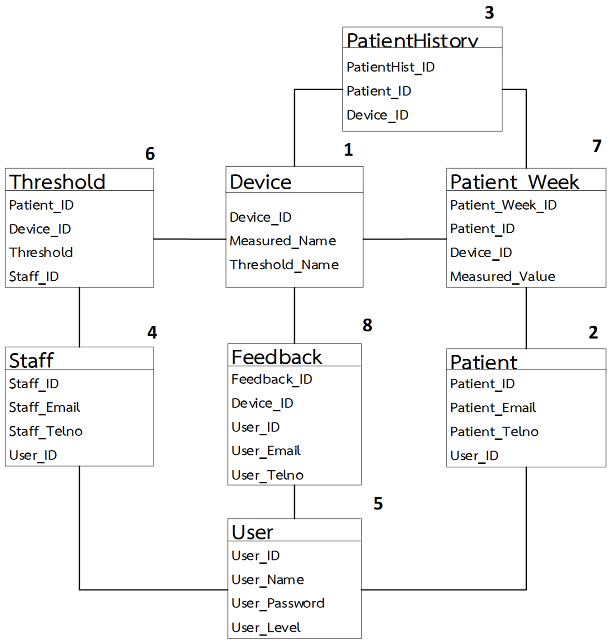

Fig.2: The relationship between all the tables in the system design of the database.

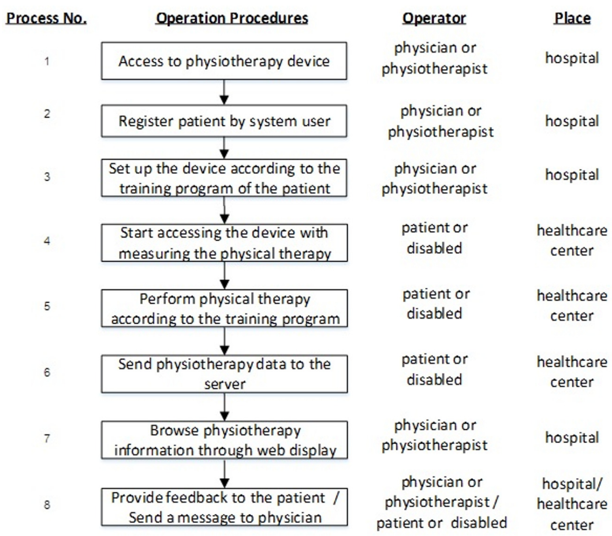

Fig.3: Overview process of the proposed system.

3.3 Network and Internet Connection Design

From the overview of the operation in the proposed system, the network and Internet connection system has been designed using sub processes. It is divided into three steps as follows:

Step1. This sets up the system for tracking and assistive devices for physical therapy through communication networks. This process develops a program on the server that is responsible for receiving values from the doctor for endpoint devices that uses the

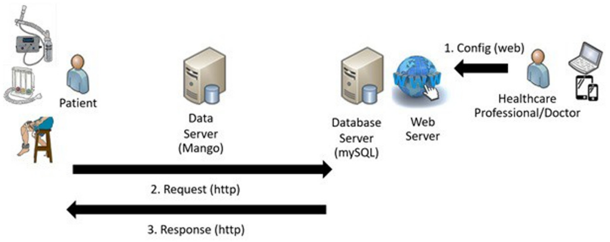

Fig.4: *System settings for tracking and assistive devices for physical therapy through communication networks.*

threshold information for each different device and each person. The physiotherapy device of the patient must request information from the server as demonstrated in Fig.4. The physician designs a program to help the patient practice physiotherapy. The server then sends the configuration to the destination device in XML message format. The configuration server is built using Netbean in the form of a web application. In this service, it receives the data from the destination device in the form of HTTP GET. After that, the server will access the data that the destination device wants to retrieve from the database. It will find the data with the highest value of Threshold ID received from the destination device, because the maximum value is the value of the newest data. This information is then converted to XML data before being returned to the destination device. An example of the requesting command for the configuration of the Patient ID 58666666 with Device ID 5 must be sent via URL as follows.

nbtcrehab.eng.psu.ac.th:8080/*ConfigurationServer/webresources/database*?*Patient ID* =58666666&*DeviceID* =5

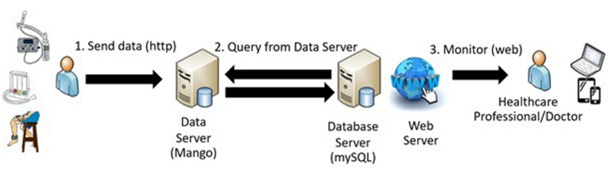

Fig.5: *The process reports the measurement results from the tracking and assistive devices for physical therapy through the communication network.*

Step 2. This is about a monitoring system for the measurement results from the tracking and assistive devices for physical therapy through the communication network. This approach reports the measured value of all devices which are related to the physical therapy program as shown in the overview of this method in Fig.5. The users of this system are physicians. They have to select the patient to be able to monitor his/her physical therapy via a webpage. The system can manage both old and new registration of the patient to follow up. It then selects the different types of devices for the patients who want to see the measurement results as shown in the sample output in Fig.6.

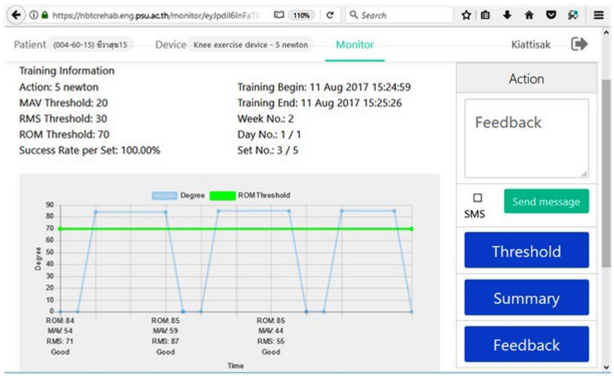

Fig.6: *Web page displays feedback function for knee exercise device in the system.*

Step 3. This is about a system which sends advice from physicians to the patients in physical therapy through communication networks. The overview of this process demonstrated in Fig. 7 also shows that a physician can give a comment as shown in Fig. 6 similar to the monitoring system. In this method, doctor's advice has been sent in a message to the patient via email and via SMS. On the other hand, the patient can communicate with the doctor via email/SMS with the same method through this system.

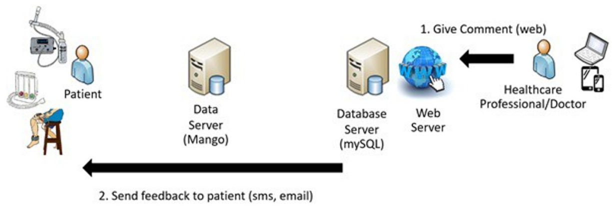

Fig.7: *The system of counselling by physicians or physical therapists for the disabled and patients in physical therapy.*

4. NETWORK RELIABILITY ENHANCEMENT

We furthermore propose network selection to enhance network reliability for our patient monitoring system in IoT rehabilitation devices using max-min fairness with dynamic weights. For wireless network selection, the algorithm collects the important data and uses it to find the best network. Our proposed network selection is based on the same main three functions as Delphi [17], and it also uses game theory for dynamic weights like ASWU [18]. Due to the wide variety of different payment methods for Internet usage, like a buffet per month of each mobile company, in this paper we propose wireless network selection for mobile devices without considering monetary cost for Internet usage. Instead, it focuses on data throughput. This parameter can also determine what the performance of a network is for comparison in network selection. Nevertheless, our scheme considers the energy efficiency with regard to the power model like PowerTutor [19] for estimating the battery usage of the application. However, we still use an approach based on dynamic weights from a game theory algorithm for our proposed mobile network selection.

The proposed network selection algorithm considers both Wi-Fi and cellular. We use delay, data rate, as well as energy efficiency for our proposed wireless network selection via mobile devices. The three important procedures to choose an optimal network are used data collection, weight calculation, and then network selection. First, the device needs to obtain the configuration data of all available Radio Access Networks (RANs). Then the algorithm uses dynamic weights [18] to indicate the important factors of each parameter based on game theory. Finally, the algorithm calculates score functions to compare each network for optimized network selection using weights from the prior procedures.

The data collection is the first step. It is a process of the important data for gathering our algorithm. The essential data consists of delay, UDP success rate, and energy efficiency. In ASWU, they employ three key parameters: delay, monetary cost, as well as energy remaining. However, we are interested in UDP success rate instead of monetary cost with regard to the success ratio of network path. The other reason we chose this parameter is because it supports the HTTP protocol which we utilize in the patient monitoring system with IoT rehabilitation devices. All three types of data: delay, UDP success rate, as well as energy efficiency, are from our measurement. For delay, ping round trip times (RTT) have been transmitted to our server for measuring the delay. Before using this value, the raw data has to be passed through equation (1) to acquire the normalized data, which is delay of RAN i (n_i) between 0 and 1. D_i is the received delay, while i indicates the RAN number and T_{max} is the delay threshold that indicates the maximum delay which the network can exhibit from our experimental results in each possible network. For UDP success rate, data has been calculated by sending two-thousand packets to our server. Then, the device receives the packet count from the server. Last, energy efficiency data has been used from battery usage information within the settings menu of Android smart phones. The battery usage is separated into energy usage of each application. So, our energy efficiency is equal to one minus energy usage of ping round trip time application and UDP success rate application.

$$n_i = |\min(0, (\{D_i\} - T_{max})/T_{max})| \quad (1)$$

In the next process, the device finds the dynamic weights using the methodology shown in Fig.8. Furthermore, the algorithm computes all possible game outcomes by adding the data from the Zero Sum Game to the given data in each path. The weight of the energy efficiency and UDP success rate become higher when one of the parameters is increased, but delay becomes lower when the delay parameter is increased. As a result, the weight calculations are applied to equations (2) to (4) to get the outcomes of data. Then we apply those payoffs to Zero-sum game branches in Fig.8. In our example, applying that data to equations (5), (6), and (7) we get current weights of possible outcome 1.

$$w_e^+ = (1 - E_b) \cdot w_e^{t-1} \quad (2)$$
$$w_s^+ = (1 - S_b) \cdot w_s^{t-1} \quad (3)$$
$$w_d^+ = n_b \cdot w_d^{t-1} \quad (4)$$

At the beginning, all three of the allocated weights, namely payoffs, such as energy weight (w_e^+), UDP success weight (w_s^+), and delay weight (w_d^+), are equal to 1/3 to prepare the initialization phase to be fair. Meanwhile the selected data from the normalized parameter values in data collection, selected energy efficiency (E_b), as well as selected UDP success rate (S_b), are equal to 1, in spite of selected delay (n_b) being equal to 0, to assume the finest data in the algorithm for Game Theory Algorithm. In each iteration (t) and possible outcome(j), the weights are represented by w_{ej}^t , w_{sj}^t and w_{dj}^t for the current energy, UDP success rate, and delay weight respectively.

$$w_{ej}^t = w_e^{t-1} + w_e^+ \quad (5)$$
$$w_{sj}^t = w_s^{t-1} + w_s^+ \quad (6)$$
$$w_{dj}^t = w_d^{t-1} + w_d^+ \quad (7)$$

The total of all weights in each Zero-Sum game outcome is equal to one. In addition, if the path has at least one weight that is less than zero, the outcome of that path can be pruned. To determine the utility function, the algorithm uses equation (8) to obtain the data that should be used in the next process by selecting the network that has the highest score. The next step uses the network from the previous process in equation (9) for all possible game outcomes. Then, the algorithm uses the calculated data for the maximin processes by selecting the minimum of possible outcomes O_1 to O_5, O_6, O_7, O_8, and O_9 to O_{10}. This process gives five results to the algorithm. Next, the algorithm selects the maximum number from these five results to get only one result, which is the set of selected weights and data.

$$U_i^t = w_e^{t-1} \cdot E_i + w_s^{t-1} \cdot S_i + w_d^{t-1} \cdot n_{i'} \quad (8)$$

$$O_{ij}^t = w_{ej}^{t-1} \cdot E_i + w_{sj}^t \cdot S_i + w_{dj}^t \cdot n_{i'} \quad (9)$$

Next, the algorithm assigns weights, depending on the selected outcome and selected data, to E_b, S_b, as well as n_b which depend on the RAN of that selected outcome from energy efficiency of RAN i (E_i), UDP success rate of RAN i (S_i), and delay of RAN i (n_i). After initialization, the algorithm continues these processes until convergence occurs or it reaches the maximum iteration count, which is equal to nine-thousand.

After weight calculation, the algorithm uses the weights from the selected result in a calculation process to apply the utility function for each of the RANs in equation (10). After receiving the scores from the utility function of all network paths, the algorithm compares the scores for each RAN to select the highest score data.

$$U_i = w_e \cdot E_i + w_s \cdot S_i + w_d \cdot n_{i'} \quad (10)$$

The algorithm initializes the data every time that the system triggers to profile the active measurement parameters. The algorithm does the repetition of the process for dynamic weight calculation until Max-Min Fairness reaches the condition of the end process. Then, the algorithm calculates scores to select the best network.

5. EXPERIMENTAL RESULT

After we have implemented support for all devices, they could communicate with the server via network and Internet connection system. The system was validated for both the correctness and reliability using both network and system tests.

5.1 Network and Internet Connection Test

We have tested the reception of configuration commands with the Taurus tool, an open source test automation framework. Taurus tool version 1.8.1 is supported by BlazeMeter to test our website performance. We built a load test scenario to send the data for testing the execution of the rehabilitation monitoring system. The simulated data in a variety of formats is generated for this test. The test results are given in Table 4. From this table, we found the requesting command for configuration for each device in the system can be transmitted simultaneously without data error. The packet delay for response to a command call is less than 4.5 seconds. We also tested the measurement results in the monitoring system from all devices via the communication network by simulating the data in a variety of formats to perform this experiment. The report for this test is shown in Table 5. The packet delay to respond HTTP 200 OK from sending data to the server is not more than 2 milliseconds. From the report, it is clear that the system can support many user's devices sending measurement data concurrently.

5.2 Network Reliability Test

Our algorithm was implemented on real hardware with the Android smart phone (Quad-core, 4x2.5 GHz, Hybrid Dual SIM, Wi-Fi 802.11 a/b/g/n/ac, dual-band). We set up a smartphone with Wi-Fi enabled and connected it to the LTE network. We were able to utilize the mobile network selection algorithm on the Android platform. Although LTE has encountered the QoS demand through the use of new RANs and resource management including handover decision algorithm, our scheme was able to enhance the connectivity. For the experimental environment, we had three smartphones in the same place together, two in airplane mode with Wi-Fi enabled in different frequencies (2.4 and 5 GHz), as well as another with Wi-Fi disabled using only LTE. The reason we implemented the two Wi-Fis is so that we can show the network performance in the possible different network paths which we can use in the real-world implementation for the best network selection.

The significant data for network selection is divided into two categories: the passive network parameters, and the active network parameters. The passive indicators are the triggers of the system, such as RSSI, link speed, and AP Count. RSSI expresses the received signal strength indicator for Wi-Fi as well as signal strength for cellular. Link speed represents the data rate of each network type for both Wi-Fi and LTE. AP count indicates the number of RANs the mobile device can detect at that time. We can read these passive parameters without transmitting any packet to check network performance. The active network parameters are the indicators enumerated in the part of the data collection in this section. Whenever some of these passive indicators change their values, then the system will be triggered for collecting the active network parameters. Examples of active parameters include energy efficiency, data rate, as well as delay from each RANs. We need to transmit packet data for assessing the performance of each available RANs.

Also, the algorithm needs to measure energy efficiency, UDP success rate, and delay of each RAN. Due to using JAVA language to implement this algorithm, the code can be applied to an Android application directly without modification. Therefore, the network selection algorithm can be used for network selection in the real world on Android smart devices. For this experiment, we have collected the results from each active parameter for three days running to collect statistical data to analyze for our proposed algorithm. We investigated the interesting differences between the network connections of cellular

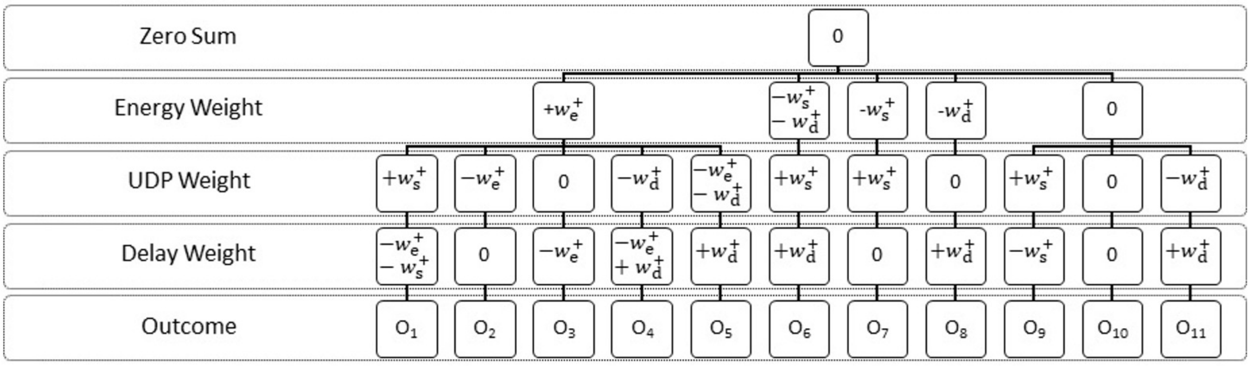

Fig.8: *Zero-Sum Game.*

and Wi-Fi. Even though the expected delay or RTT for sending the packets of cellular is higher at 131.40 ms than Wi-Fi at 37.11 ms for 5GHz in average, the data rate is also higher and the energy efficiency is lower on average for our measured data.

Delay is the first parameter which can be used to explicitly measure the network performance. If the indicator's value is very high, the network efficiency is too low as well, so that network path would not be best for network path selection. We sent an ICMP echo request packet 10 times consecutively in the experiment.

Table 1: *Packet delay measurement.*

Delay Ping RTT (ms)	**2.4G**	**5G**	**LTE**
Minimum	1.94	1.76	64.92
Average	41.71	37.11	131.40
Maximum	122.58	115.51	167.63

Each packet has a size of 32 bytes like the standard ICMP protocol. The Ping RTT application was used for measuring the delay of the network connection. After sending the ICMP request and checking the ICMP reply message, we can get the maximum, minimum as well as average delay for every request packet in milliseconds. In Table 1, the results are presented for the different network types to evaluate the network delay. The expected delay for cellular increased dramatically on average when comparing with both Wi-Fi types. The delay time with LTE connected is almost three times more than the delay with Wi-Fi enabled. Wi-Fi 5G is the best network selection in terms of the expected delay.

The next indicator refers to the UDP data rate. We measure how many data packets can be sent from mobile devices to a server without any packet error. The experiment sent two thousand UDP packets consecutively within a period of time. The total length for each data packet is 54 bytes including overhead

The minimum, average, and maximum UDP data rates for the various network types are given in Table 2. We found that a cellular connection can provide practically more bandwidth on average than either of

Table 2: *UDP success rate measurement.*

UDP Data Rate (Kbps)	**2.4G**	**5G**	**LTE**
Minimum	69.81	71.11	55.64
Average	102.90	102.66	112.19
Maximum	123.21	130.55	145.58

the Wi-Fi frequencies. Wi-Fi connection is not always the best network path to send the data packet when we consider that the data communication takes place all of the time. In term of the bandwidth we should select the cellular connection for data transmission. For this reason, the network selection must measure all possible network paths to find the best way for transmitting the medical data.

Energy consumption for an Android application is the last indicator used in network selection. The experiment acquired the results from accessing PowerTutor [19] with our algorithm to determine the energy consumption in Joules for packet delay measurement and UDP success rate measurement. It has been categorized into three parts for calculating the power consumption in a general smartphone: transmitting data, CPU processing, and LCD displaying. The power estimation is shown in Table 3 for the different network types. The energy model was created using a library function of PowerTutor called directly from our program as part of our proposed algorithm. The values for minimum, average, and maximum energy efficiency of the cellular connection are less than the values for Wi-Fi. This emphasizes that we should consider all network paths for data transmission. A mobile phone is not only Wi-Fi enabled, but it is also LTE connected as well.

Table 3: *Energy efficiency measurement.*

Energy Efficiency (J)	**2.4G**	**5G**	**LTE**
Minimum	1.42	1.41	1.04
Average	1.97	1.96	1.81
Maximum	3.59	3.72	3.63

All active indicators have an effect on the network performance with regard to the different network types. Consequently, the mobile network selection needs to analyse every parameter in a real world implementation. This subsection explained the whole function of our proposed algorithm considering all of the related parameters used in the mobile network selection. We have discussed the experiment in the different areas to study the characteristics of the network selection. First of all, we tested in three different locations using fixed smartphones with the same hardware platform. Our system needs to connect to the Internet anywhere not just from a fixed location. The testing environment was a big hospital which has many buildings and floors. Some areas prevented connectivity to the network because of obstacles. Some positions in an area may have weakness of the signal strength where the mobile device is quite far from the last hop (access point).

From Fig. 9 and 10, we measured three locations for collecting the results of the throughput as well as packet error rate. The experiment tested the transmission of the medical data without using our proposed network selection scheme between only LTE connected (cellular connection) and only Wi-Fi enabled (Wi-Fi) as well as using our proposed network selection. The medical data has been implemented on UDP protocols. A UDP data packet has less overhead than a TCP packet. Also, we measured the active indicators in the network with UDP success rates, and verified UDP packets are suitable for transmitting the medical data. For the first location (LOC1), we placed all three smartphones at the same place together on the seventh floor of a high building. Next location, LOC2 is a small room near the side of a flat building. Whereas, the last station named LOC3 is a big research lab room which is in the center of the same flat building. There are many Wi-Fi access points in different places in these two buildings.

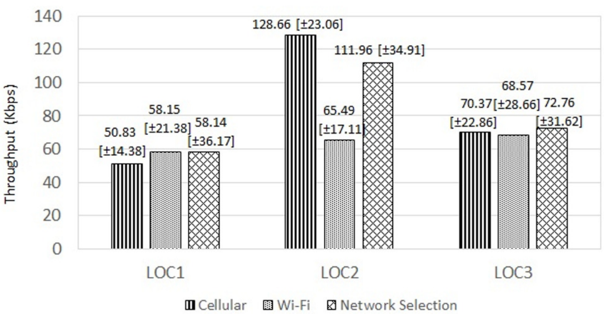

Fig. 9: *The histogram shows the average values and standard deviation in the bracket for the throughput in different locations.*

The results from Fig. 9 show that the throughput between these various locations with the different approaches of the network connection have obtained similar results except for LOC2. This demonstrates that our proposed algorithm works efficiently in the real-world implementation for the android smartphone when the speeds of transmission over WLAN and LTE are very different. Moreover, in case where the throughput of cellular is much higher than the Wi-Fi's case, we found that the throughput of selected network is also very high according to the cellular's case. When the throughputs of Wi-Fi and cellular are similar, the throughput of the selected network will be related to a higher one.

On the other network performance, we measured the packet error rate as shown in Fig. 10 for transmitting UDP data packets. The results demonstrate that the packet error rate with network selection is as good as using only Wi-Fi enabled on average. While the packet error rate of cellular is very high in two areas (LOC1 and LOC3), the packet error rate for the case of network selection does vary for the case of Wi-Fi enabled. This also demonstrated that our proposed scheme obtains the lower packet error rate when this value is highly dissimilar between Wi-Fi and cellular. All the error rates are not more than 2.2% for our network selection scheme.

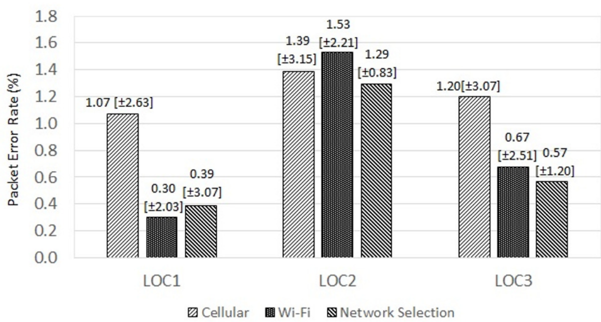

Fig. 10: *The histogram shows the average values and standard deviation in the bracket for the packet error rate in different locations.*

5.3 System Reliability Test

The proposed system has been tested in three places: a hospital, a health promotion center, and a laboratory. Devices A), B), and C) were tested at the hospital because they are suitable for postoperative patients. Device D) was tested at the health promotion center because it is light weight, portable, and suitable for knee exercise. Device E) was tested in the laboratory because of its big size and heavy weight. There were some obstacles to moving this device for volunteers. The test aims to analyze the reliability in the use of each device and the connection to the servers. At the hospital, there were ten volunteers and the tests were repeated for six days. Devices A), B), and C) were tested totally 471, 1082, and 219 times, respectively. This variation is because the usage behavior of each device is different. At the health promotion center, which represents the place that is far from any big hospital, but near patient homes, there were 16 volunteers on the first day and 24 volunteers on the second day. Totally, device D)

Table 4: *Acceptance test of configuration command.*

Test Case	Description	Result	Status
1) Packet Loss	Simulate calls simultaneously 100 times	Server responds to 100 calls.	Pass
2) Packet Delay	Response to a call less than 10 seconds.	The response time is 4.372 seconds.	Pass
3) Unexpected Value	The value is in the text.	Value is not available.	Pass
	Parameter not complete	Value is not available.	Pass
	Parameter exceeded.	Ignore excess parameters.	Pass
	Wrong parameter name	Value is not available.	Pass

Table 5: *Publisher testing from mango to MySQL.*

Test Case	Description	Result	Status
1) Packet Loss	Simulate calls simultaneously 100 times.	Server responds to 100 calls.	Pass
2) Packet Delay	Response to a call less than 10 seconds	The response time is 2 milliseconds.	Pass
3) Unexpected Value	Add parameter	Response: 200 OK.	Pass

was tested only 40 times because most volunteers are really the disabled and elderly people. At the laboratory, device E) was tested 21 times. Fig.11 shows the success rate of sending data of all devices in various test places. Almost all devices successfully sent the rehabilitation data to the server. The problems with devices D and E were from an Internet connection problem. However, the data is stored at the devices and is sent again when they can connect to the Internet.

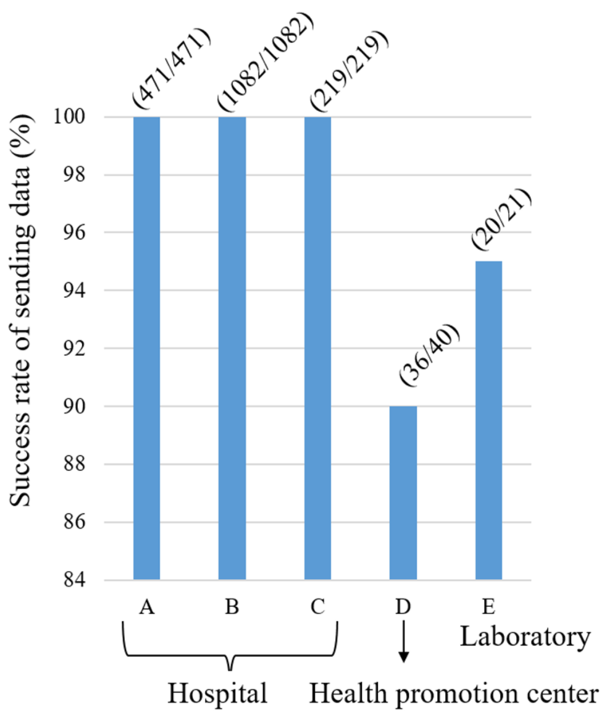

Fig.11: *Success rate of sending data of all devices in various test places.*

6. CONCLUSION

A patient monitoring system designed to support multiple IoT devices has been presented. Physicians can plan the treatment for each patient via our network and Internet connection system. The system has three sub processes: device configuration, monitoring, and feedback. The function of each device and the way it connects to the Internet can be different. The proposed system can support multiple rehabilitation devices of various types by using the common HTTP protocol. The network and Internet connection test reported that the system can support many user's devices sending measurement data concurrently without errors. The system reliability test reported an approximately 99% success rate for sending data to the servers at low data rates. Moreover, our network selection process can also help obtain a reliable network path for data transmission. After collecting the network data, an algorithm is applied for dynamic weight calculation based on game theory and compared score results from an evaluation function for each network path to select the best path. This algorithm can be applied to mobile applications directly without firmware modification. Furthermore, all the error rates on average are not more than 1.29% for this scheme. In future work, the proposed systems will be promoted to be widely used in more health centers. When more devices are used maintaining the network reliability and security, including big data management, will be the challenge.

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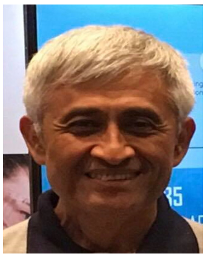

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