LTE Based E-Health Monitoring System

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***Abstract* –** Recently, the on-line health monitoring have been considered in the research to obtain pragmatic e-health systems with low cost and high efficiency. In this paper, a mobile e-health system is proposed based on an algorithm over long terms evolution (LTE) technology that can be called as fourth generation (4G). This system controls the receiving of the transmitted health data from the patients under supervision and replies the responses of the considered algorithm. The responded signals include the required actions that should be performed by the patient and the hospital. The proposed system utilizes the LTE based mobile networks for the signal transmission to save the consumed cost spent on installing a specific wireless network. In other words, the patients involved in the proposed system are connected to the available mobile networks that cover the area. Additionally, the sensor readings are transmitted either from the patient's mobile device or from other consoles, which have ability to connect and synchronize with the considered mobile network. The simulation results show an efficient performance of the proposed system in terms of data transmission, control signals and decision.

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Keywords – E-health systems, LTE, Wireless communication systems.

1. Introduction

Modern generations of wireless mobile communication systems are employed in the remote electronic-health (e-health) monitoring schemes. This is to support the healthcare of outpatients at any place they might be using the available mobile systems. Therefore, the physical location of the patient under supervision is not restricted, limited and important [1], [2].

The high bit rate broadband of the fourth generation (4G) mobile network based on long terms evolution (LTE) technology can be considered as the most suitable transmission systems for e-health applications. This is to cover the required information size and guarantee the speed in addition to the high accuracy. Moreover, the patient need to install the e-health application on his /her smart mobile console, which has the ability to read data from the sensors, fixed on the body. This can reduce the required complexity and size of the devices rabidly to ease the matter for the patients [1]-[6].

The wireless e-health monitoring systems have been recently considered in the research. In [7], modern telemedicine and telehealth schemes were implemented using an introduced architecture for telecommunication and wireless network. This system is responsible on transferring different types of e-health data, such as voice, image and videos that can facilitate the communication between the patients and professional medical actor. The authors of [8] introduced an efficient fiber based radio system with high broadband facility to guarantee the real-time remote e-health monitoring network. In [9], an overview on wireless mobile systems used for biomedical applications was provided. These systems were structured based on LTE network of mobile cellular. In addition, a biomedical application has been introduced as an example. In [10], a sparkmed data framework for mobile healthcare was proposed. This system benefits from the high capacity of LTE based network to send and receive a huge database of patients, such as hospital information, images and reports. The proposed framework was provided with high resilience against failure of transmission and the designed mobile handled devices can work even with low quality of service. Ten devices worked over WiFi and 3G were utilized to verifying the meeting the objectives of the proposed framework. The author of [11], introduced a talk to discuss and predictions on the coming technology in the future and how the digital signal processing can help to implement these technologies in e-health systems. In [12], several security issues in the e-health monitoring systems were addressed in order to guarantee the secured medical data over mobile broadband. In this work, the authors used the broadband of the LTE based mobile network for data transmission. In [13] and [14], studies on the modern e-health monitoring systems have been introduced. In these studies, deep details of the utilized mobile networks were included.

In this paper, a low cost e-health monitoring system based on a pragmatic algorithm over LTE technology mobile network is proposed. The low cost is the result of utilizing the available mobile network instead of installing a specific professional one. As mentioned earlier, the available mobile networks are utilized to transit the readings of the sensors connected to the patients to the health center using the working mobile signals.

The LTE based communication systems used in considered mobile networks include uplink and downlink transmission types. The uplink transfers the e-health information, which includes the sensors' readings, of different patients to the health center. At the other hand, the downlink is responsible on transmission the control signals and actions from the health center to the independent patients. This can be done using the smart phone of patients or specific consoles that are able to work on mobile signals. Moreover, the health center is considered as a mobile base station, in which any mobile network can transmit and receive its signals.

The objective of the proposed system is to keep the outpatient in monitoring 24 hours per day by connecting the e-health indicators on-line with the health center, such as hospital. This is achieved by installing a group of different purpose sensors on the patient's body and then collecting the reading data to prepare them for transmission to the health center. The health center applies the proposed algorithm to take action depending on the case state of the patients. This can include calling the emergency, take medicine, ..., etc. The utilizing of LTE based mobile network can offer a high bit rate to exchange the required information in a short time with low number of errors and even low cost. Different case studies have been considered to test the proposed system and the obtained results show a superior performance in terms of data transmission.

The rest of the paper is organized as follows. The proposed system model is described in Section II. In Section III, the proposed algorithm is explained and discussed. In Section IV, simulation results of the adopted case studies are introduced. Finally, conclusions are drawn in Section V.

2. The transmission system model

In this paper, a LTE system is considered as a link for data transmission between the patients and health center [1]. Fig. 1 illustrates the block diagram of such employed system. This system is divided into two main parts as follows.

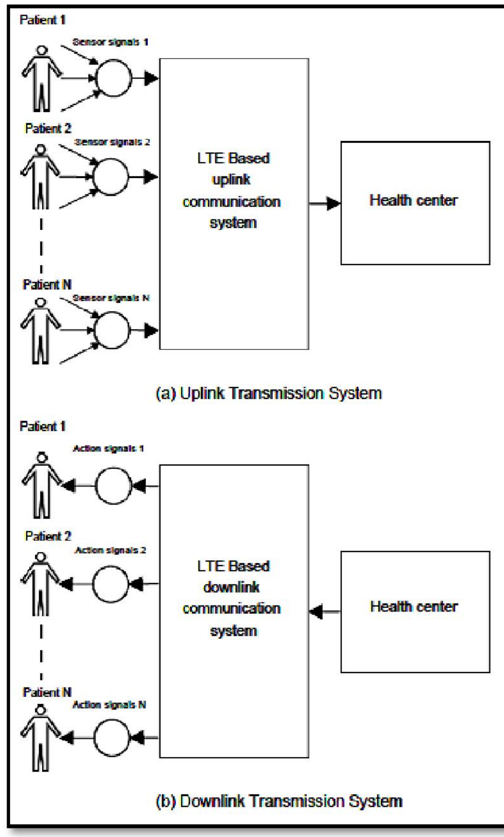

Figure 1. Block Diagram of the LTE Based Transmission System

2.1 Uplink part

At the health center or base station, the e-health information is collected from *N* patients at distinct physical locations. This information is fed to the proposed algorithm to perform the required processes and make the decision and actions that should be done by each patient individually. Based on the concepts of LTE systems the patients, considered as users, reads the data from the sensors fixed on the body and then save them in a temporary buffer in order to send them to the health center [2].

On the other hand, the utilized uplink communication system tackles the problems of information propagation over the Rayleigh fading channels, such as inter symbol interference (ISI) and the channel effects [3]-[6]. In this paper, different ITU channel models are considered to obtain the simulation results [15].

2.2 Downlink part

The health center obtained the required decisions and actions of each patient individually from the proposed algorithm. Then, these decisions are sent to the related patients (users) using the downlink technique of LTE systems. As mentioned earlier, the obtained decisions include two types. The first part can be performed by patients, while the second type is done by emergency department at the nearest hospital [1].

The transmitted downlink frame work involves the information for all included patients. At the receiver of each user, the related data is obtained using the employed communication systems for downlink LTE systems [2]. It is important to highlight that the same channel model is used for downlink, which is ITU channel model [15]. This is to simulate the real-case of mobile channel environment and test the proposed system performance over different conditions [3]-[6].

3. The proposed algorithm

As highlighted above, the health center collects the sensors' signals from the considered patients and then applies the proposed algorithm to obtain the required actions and decisions. The sensors' signals or information are transmitted over wireless channels via the uplink transmission systems, based on LTE technology [1].

In the proposed algorithm, three sensors types are considered to provide the blood pressure, blood sugar and temperature of each patient. These three health signals give living indicator for each patient to be considered and processed to obtain the important actions and decisions.
Four actions and decisions have been considered by the proposed algorithm as follows:

- No action is required, for normal sensors' readings.
- Take medicine, for up-normal sensors' readings.
- Take a rest, used as assistant to the above actions.
- Emergency call, for high or low ranges sensors' readings.

Depending on the sensors' reading the above actions and decisions have been taken. In some cases, two or more actions can be taken to control the patient's health state.

Fig. 2 illustrates the proposed algorithm as a flowchart. The procedure of this algorithm can be explained as:

1. *Collect ten readings of each sensor for a patient.*
2. *Check the values of the ten readings of each sensor for a patient, consequently. If the readings is out of*

the normal range.. go to step 3. Otherwise go to step 6.

3. *Check the other readings of each sensor. If the values of readings are still out of range..go to step 4. Otherwise go to step 6.*
4. *Take the suitable actions and decision depending on the type of sensors' readings and the values according the assigned normal range. Send copy of the actions and decisions to the supervised doctor to be informed.*
5. *Focus on the next readings of the allocated patients with up-normal readings. (Keep eye on him)*
6. *Take no action decision and continue in sequence monitoring.*

4. Simulation Results

In order to exam the performance of the proposed algorithm, different case studies have been considered. These studies are a list of sensors' readings for distinct patients. Depending on these readings, the proposed algorithm takes the suitable action and decision as shown in Table 1.

Table 1. The Considered Sensors' Reading and the Suitable Decision

Temperature	Blood Pressure	Blood Sugar	Decision
34-35 130/90	100/70-	20-100	No action
> 40	> 200/180	> 500	Call Emergency
30-33 110-	70/30-190/170	480	Take medicine
< 29	< 70/30	< 20	Call Emergency
34-37.5 30-	100/70-135/95	110	Take a Rest

Table 1 explains the ranges of the received sensors' readings from distinct patients and the decisions taken for these ranges. It is important to know that the decision of take a rest can be combined with any of other decisions.

Ten case studies are adopted in this simulation as explained below.

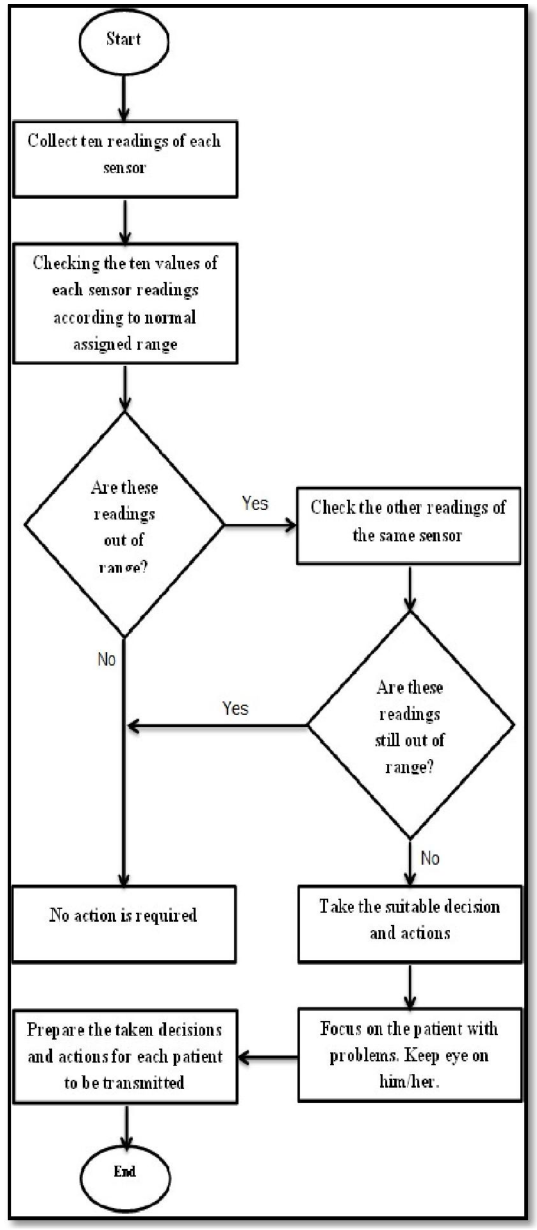

Figure 2. Flow-Chart of the Proposed Algorithm.

4.1 Case study 1

The readings of health sensors transmitted from the first patient, considered as a case study 1, are shown in Table 1.

This case study, expressed in Table 2, refers to a diabetic patient, who suffers from rabidly increasing in the blood sugar. The other e-health readings are normal with some minor increment in the blood pressure that is required some rest.

The increment in the blood sugar is allocated within the range of take medicine action, therefore the decision, taken by the proposed algorithm, is *Take medicine and Take a Rest* established on Table 1.

Table 2. The Considered Sensors' Reading for Case Study 1.

Temperature	Blood Pressure	Blood Sugar
37	120/80	200
37	120/80	210
37	120/90	220
37	130/90	250
37	130/90	250
37	130/80	250
37	120/80	300
37	120/80	300
37	120/80	300
37	120/80	300
Taken Decision is (Take medicine and take a rest)		

4.2 Case study 2

Table 1 shows the health readings of the sensors fixed on the second patient. This is a diabetic patient suffers from high blood sugar and increment in body temperature in addition to slightly increasing in the blood pressure.

The ranges of blood sugar and temperature increasing force the patient to take medicine and take a rest. Therefore, the taken decision is *Take Medicine and Take a Rest* based on Table 1.

Table 3. The Considered Sensors' Reading for Case Study 2.

Temperature	Blood Pressure	Blood Sugar
38	130/90	400
38	130/90	420
38	130/90	420
38	130/90	420
38	120/80	420
38	120/80	400
38	120/80	400
38	120/80	400
38	120/80	400
38	120/70	400
Taken Decision is (Take medicine and take a rest)		

4.3 Case study 3

The third case study is belonging to a patient with diabetic and high blood pressure. Table 3 lists the readings of the health parameters of the third patient.
Based on the reading ranges of the blood pressure and blood sugar that shows high levels, the patient should take medicine and take a rest as a decision depending on Table 1.

Table 4. The Considered Sensors' Reading for Case Study 3.

Temperature	Blood Pressure	Blood Sugar
37	140/100	400
37	140/100	400
37	140/100	400
37	160/110	400
37	160/110	410
37	160/110	410
37	160/110	410
37	160/110	420
37	150/110	420
37	150/110	420
Taken Decision is (Take medicine and take a rest)		

4.4 Case study 4

In case study 4, the considered patient suffers from high blood pressure and sugar. Table 5 shows the health indicators of this patient.

The health indicators, represented by the sensors' readings shown in Table 5, express that the patient need to take a rest. This is because these readings fall in the normal ranges with slight minor increasing in the blood pressure and sugar as explained in Table 1.

Table 5. The Considered Sensors' Reading for Case Study 4.

Temperature	Blood Pressure	Blood Sugar
37	140/90	110
37	130/85	110
37	130/80	105
37	130/80	100
37	130/80	100
37	130/80	100
37	130/80	100
37	130/80	100
37	130/80	100
37	130/80	100
Taken Decision is (Take a rest)		

4.5 Case study 5

This case study considers the fifth patient, who suffers from high temperature. The health readings of this patient are included in Table 6.

According to the temperature ranges shown in Table 1, the patient with health readings of Table 6 should go to the hospital directly as he/she got dangerous high temperature.

Table 6. The Considered Sensors' Reading for Case Study 5.

Temperature	Blood Pressure	Blood Sugar
38.5	120/80	90
38	125/80	90
38.5	130/80	95
39	125/80	100
39	120/90	85
40	130/90	90
40	120/80	95
41	120/80	90
41	120/80	90
41	120/80	90
Taken Decision is (Call emergency)		

4.6 Case study 6

The readings of different sensors of the sixth patient have been included in Table 7. This patient got diabetic with low blood sugar.

Based on the listed readings in Table 7, this patient has to go to the emergency department at the hospital due to low blood sugar level according to the considered ranges in Table 1.

Table 7. The Considered Sensors' Reading for Case Study 6

Temperature	Blood Pressure	Blood Sugar
36	120/80	10
36.5	125/80	10
37	130/80	5
37	125/80	5
37	120/90	5
36.5	130/90	5
37	120/80	10
37	120/80	10
37	120/80	10
37	120/80	10
Taken Decision is (Call emergency)		

4.7 Case study 7

The seventh case study adopts the health indicators listed in Table 8.

The blood pressure is considered as one of the most dangerous diseases that might affect the death. Therefore, the high or low levels readings should be considered as a high priority.

The entitled readings of blood pressure sensor indicate that this patient should be transferred to the hospital immediately.

Table 8. The Considered Sensors' Reading for Case Study 7.

Temperature	Blood Pressure	Blood Sugar
30	120/80	90
29	125/80	90
29	130/80	95
29	125/80	100
28.5	120/90	85
28.5	130/90	90
29	120/80	95
28	120/80	90
28	120/80	90
28	120/80	90
Taken Decision is (Call emergency)		

4.8 Case study 8

This case study exams different sensor' readings transmitted from the eighth patient as shown in Table 9. It is noticed that this patient suffers from high blood pressure and therefore he/she should be entered as emergency case to the hospital as fast as can.

By making a simple comparison with the considered ranges of Table 1, it is concluded that the decision of this case is *Call emergency*.

Table 9. The Considered Sensors' Reading for Case Study 8

Temperature	Blood Pressure	Blood Sugar
37	200/180	70
37	210/180	75
37	220/190	75
37	220/200	75
37	230/200	75
37	230/210	75
37	230/210	80
37	220/200	80
37	220/200	80
37	220/200	80
Taken Decision is (Call emergency)		

4.9 Case study 9

In the ninth case study, the blood pressure sensor registers low readings for this patient as included in Table 10. The proposed algorithm decides that this patient should be entered in emergency at the assigned hospital.

Table 10. The Considered Sensors' Reading for Case Study 9.

Temperature	Blood Pressure	Blood Sugar
37	70/30	70
37	65/30	75
37	65/25	75
37	60/20	75
37	60/20	75
37	60/20	75
37	65/20	80
37	70/20	80
37	65/20	80
37	65/20	80
Taken Decision is (Call emergency)		

4.10 Case study 10

The decision of this case study is *No action* as the received health sensors' readings indicate that this patient does not need any action according to Table 11.

Table 11. The Considered Sensors' Reading for Case Study 10.

Temperature	Blood Pressure	Blood Sugar
37	120/80	90
37	120/80	90
37	120/80	90
37	110/80	90
37	115/75	95
37	120/80	95
37	120/80	95
37	120/80	95
37	120/80	90
37	120/80	90
Taken Decision is (Call emergency)		

5. Conclusions

A low cost LTE based e-health system has been introduced. This system included a proposed algorithm that considered health readings from different sensors fixed on the body of patients. Based on these readings, different decisions and actions have been taken by the proposed algorithm.

The low cost system came from employing of the 4G mobile network, which considered the LTE technology, instead of installing a new network for transmission the information. The transmitted information exchanged between the patients and the health center.

The simulation results have been produced. In the simulation, ten case studies of different classifications of patients were adopted to test the proposed algorithm performance. Throughout the introduced resulted tables, it is observed that the proposed algorithm is performing perfectly. In addition, the underlying e-health system proved its ability to monitor the considered patients efficiently.

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