Collaborative Remote Patient Monitoring System Using IEEE 802.15.4 Wireless Body Area Networks

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Abstract: In IEEE 802.15.4 Wireless Body Area Networks, the existing remote patient monitoring rarely address the joint issues of power consumption, reliability and mobility. Generally, there is a tradeoff between reliability and power consumption since, increasing the reliability may result in increased power consumption. Moreover, when the patient moves from one location to another, it may affect the accuracy of results and leads to increased delay, due to poor channel conditions. To solve the identified problems, in this paper, we propose a Collaborative Remote Patient Monitoring System using IEEE 802.15.4 Wireless Body Area Networks. The proposed architecture consists of clusters of local sensors situated on various parts of the body. Each cluster head communicates with a wireless local gateway (WLG) which lies within the patient's premises. The WLG in turn communicates with a remote hospital gateway (HG) such that the collected data from WLG is transmitted to the corresponding destination in the HG. The HG applies fuzzy logic decision model based on the input variables patient age, heartbeat, body temperature, percentage of the blood oxygen saturation and blood pressure and determines the criticality condition of patient. By simulation results, we show that the proposed module provides accurate estimation of patient condition.

Key words: Wireless body area networks, remote patient monitor, wireless local gateway, fuzzification, sensors, gateway.

1. Introduction

Patient health care monitoring is seen as an effective method of providing immediate care as it allows for continuous as well as emergency transmission of patient information to the doctor or healthcare providers. Patient monitoring will not only redefine hospital care but also work, home, and recreational activities. These new technologies enable us to monitor patients on a regular basis, replacing the need to frequently visit the local doctor for a recurring illness [1]. Wireless body area networks (WBANs) constitute an active field of research and development as it offers the potential of great improvement in the delivery and monitoring of healthcare. WBANs consist of a number of heterogeneous biological sensors. These sensors are placed in different parts of the body and can be wearable or implanted under the user skin.

Each of them has specific requirements and is used for different missions. These devices are used for measuring changes in a patient's vital signs and detecting emotions or human statuses, such as fear, stress, happiness, etc. WBAN can provide continuous measurements of the physiological parameters and allow better revealing organ failures and faster detecting emergency situations. Such remote monitoring system will be safer, more convenient and cheaper [2].

In past years, at remote rural areas the peoples die, due to lack of treatments and lack of availability of health monitoring devices and doctors, most of the countries in the world facing this type of problems. There are numbers of the system which can provide remote health care services but there has some limitation such as very costly, lack of patient data security and highly communicational and computational overhead.

Today's healthcare systems in most countries are struggling with increased number of patients and increased costs of patient care per patient. This situation is aggravated by the current trends of unhealthy lifestyle habits, including stress and physical inactivity, which increasingly leads to chronic illnesses such as obesity, diabetes and heart disease, even in younger population. For such cases, early treatment, including physical exercise, could prevent negative outcomes as population ages. Such a treatment would be more likely to succeed if the healthcare system had access to facilities for continuous monitoring of the individual's physical fitness level, because it would allow monitoring compliance and providing feedback. Such facilities would ideally consist of simple, inexpensive and readily available equipment.

Patients suffering from heart diseases, low blood pressure, diabetes etc. need continuous monitoring of health conditions, even after the treatment in hospitals. It will be expensive for them to continuously stay as inpatients in hospitals. So, by means of arranging a nurse or physically measuring the health conditions will be again expensive. Moreover, it is not possible for the patients residing at remote rural areas to get health assistance in case of emergency, because of lack of infrastructure and communication facilities. Hence remote health care system or remote patient monitoring system will be more useful in these circumstances.

1.1. Problem Formulation

Some of the challenges of remote patient monitoring related to power consumption, reliability, security, and mobility are as follows: Low-power consumption is considered to be one of the most important and challenging requirements of remote patient monitoring in WBAN systems. Devices in WBAN systems mainly consume energy during sensing vital information, wireless communication and data processing. However, compared to sensing information and data computation, wireless communication consumes a significant amount of energy. Thus, reducing the energy consumption of data transmission during communication can conserve considerable amounts of the energy reserves [3].

Data transmission reliability is an extremely important factor in patient monitoring applications. High reliability of data transfer ensures that real time data is successfully transmitted and is immediately accessible to healthcare providers. Reliability directly influences the quality of patient monitoring. It can be life-saving in many situations and in case of worst-case event. It can be disastrous when a life-threatening incident has not been observed or detected. In order to achieve optimal reliability and network efficiency, appropriate MAC layer protocols are required to be designed to fulfil the particular needs of specific applications [3].

Deploying new technologies in healthcare applications without considering security makes patient privacy vulnerable. Moreover, the physiological data of an individual are highly sensitive. Therefore, security is a paramount requirement of healthcare applications, especially in the case of patient privacy, if the patient has an embarrassing disease. Traditional security mechanisms needed unlimited resources, so they cannot be directly applied to the extremely resource-constrained sensor nodes [4]. Since professional equipment always requires operational skills and limits the patient's mobility, it is unsuitable for daily monitoring of sub-health or chronic disease patients. Such situations bring challenges for continuous monitoring and mobile health. Hence, mobility should be considered while designing remote patient monitoring.

But existing systems on remote health care monitoring [5]-[7] rarely address the joint issues of power consumption, reliability and mobility. Generally, there is a trade-off between reliability and power consumption since, increasing the reliability may result in increased power consumption. Moreover, when the patient moves from one location to another, it may affect the accuracy of results and leads to increased delay, due to poor channel conditions. In order to solve the identified problems, the following objectives should be met: To design a patient monitoring system using Fuzzy based decision module provide accurate estimation of patient condition.

2. Proposed Solution

2.1. Overview

In this paper, we propose a Collaborative Remote Patient Monitoring System using IEEE 802.15.4 Wireless Body Area Networks. The proposed architecture consists of clusters of local sensors situated on various parts of the body. Each cluster head communicates with a wireless local gateway (WLG) which lies within the patient's premises. The WLG in turn communicates with a remote hospital gateway (HG) such that the collected data from WLG is transmitted to the corresponding destination in the HG. The HG applies fuzzy logic decision model based on the input variables patient age, heartbeat, body temperature, percentage of the blood oxygen saturation and blood pressure and determines the criticality condition of patient. By simulation results, we show that the proposed module provides accurate estimation of patient condition.

2.2. System Model

The proposed architecture shown in Fig. 1 consists of clusters of local sensors situated on various parts of the body. The sensor within a cluster collects data and transmits it to their respective cluster head. Each cluster head communicates with a wireless local gateway (WLG) which lies within the patient's premises. The WLG in turn communicates with a remote hospital gateway (HG) such that the collected data from WLG is transmitted to the corresponding destination in the HG. The destination refers to the nurse or doctor authorized to monitor the patient's health condition. Note that at HG, the patient personal information such as name, age, previous case history is already stored.

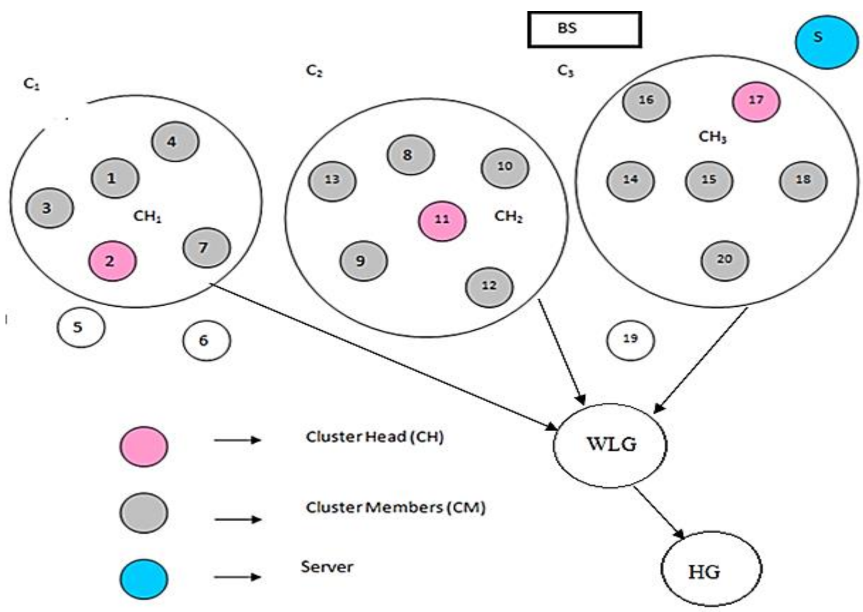

Fig. 1. Proposed system model.

2.3. Patient Monitoring Module

The body sensors deal with the measurements of basic body functions like heart rate, blood pressure, body temperature and blood oxygen saturation level. The reading of these sensors helps in patient health monitoring, diagnostics of diseases and other clinical studies.

Let H, T, O and B represent the heartbeat, body temperature, blood oxygen saturation level and Blood pressure sensors respectively

Let PS be the power supply

Let TX and RX be the RF transceiver and receiver respectively.

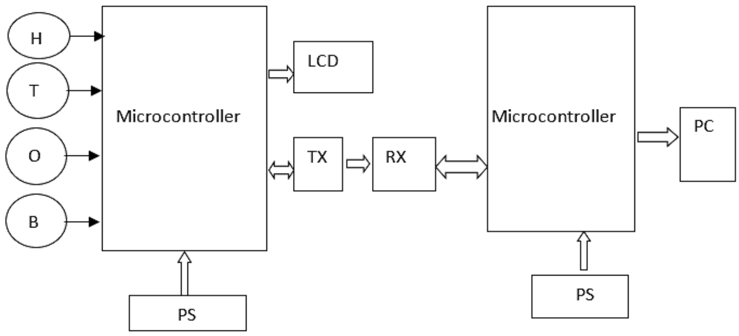

Fig. 2. Illustrates the patient monitoring system.

It contained four sensors (heartbeat, body temperature, blood oxygen saturation level and Blood pressure sensors), microcontroller, nRF transceiver, LCD and power supply for each node. Note that the microcontroller is used to interface sensors and nRF transceiver shown in Fig. 2.

The steps involved in this monitoring system are as follows:

The sensors will transmit the pulse signal to microcontroller which is then converted it to machine language.

Microcontroller receives data from sensors and then nRF transceiver sends these data by the radio. The base station will receive the transmitted digitized signal, and forward it to MCU, MCU will establish a connection to PC, PC will display the body condition of the patient in visual studio.

2.4. Fuzzy Based Decision Module

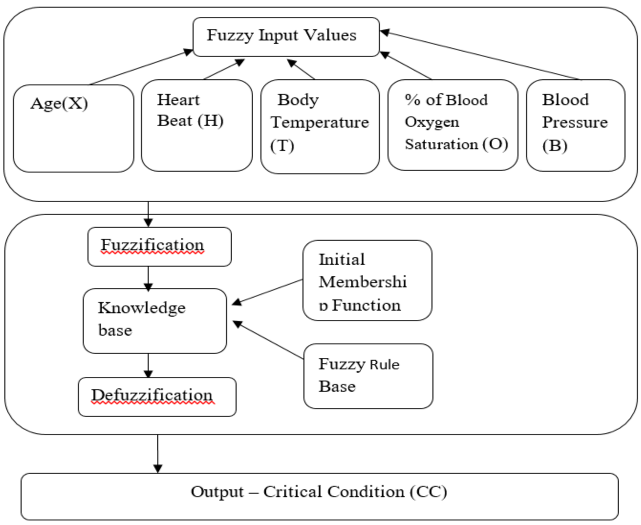

Fig. 3. Fuzzy interference system.

The HG applies fuzzy logic decision model based on the input variables patient age, heartbeat, body temperature, percentage of the blood oxygen saturation and blood pressure and determines the criticality of data as Less, Moderate and High.

The steps that determine the fuzzy rule-based interference are Fuzzification: This involves obtaining the crisp inputs from the selected input variables and estimating the degree to which the inputs belong to each of the suitable fuzzy set. Rule Evaluation: The fuzzified inputs are taken and applied to the antecedents of the fuzzy rules. It is then applied to the consequent membership function. Aggregation of the rule outputs: This involves merging of the output of all rules.

Defuzzification: The merged output of the aggregate output fuzzy set is the input for the defuzzification process and a single crisp number is obtained as output. The fuzzy inference system is illustrated in Fig. 3.

2.5. Fuzzification

This involves fuzzification of input variables such as Age (X), Heart Beat (H), Body Temperature (T), Percentage of The Blood Oxygen Saturation (O) and Blood Pressure (B) (collected in Patient Monitoring System explained in the previous section). And these inputs are given a degree to appropriate fuzzy sets. The crisp inputs are combination of X, H, T, O and B. We take three possibilities, low and high for X, H, T, O and B. Fig. 4-9 shows the membership function for the input and output variables. Due to the computational efficiency and uncomplicated formulas, the triangulation functions are utilized which are widely utilized in real-time applications. Also, a positive impact is offered by this design of membership function.

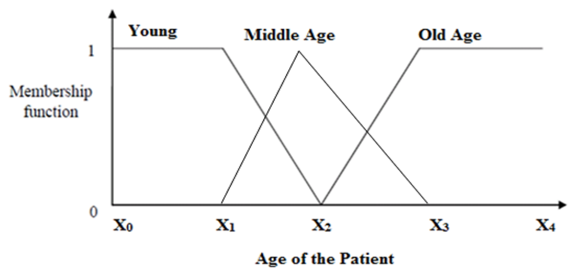

Fig. 4. Membership function of age of patient.

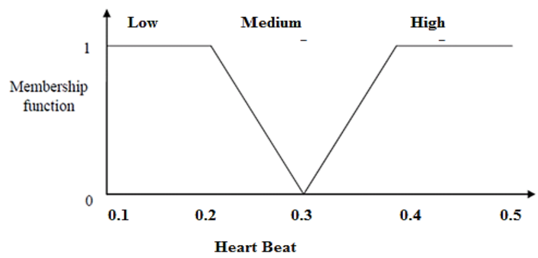

Fig. 5. Membership function of heart beat.

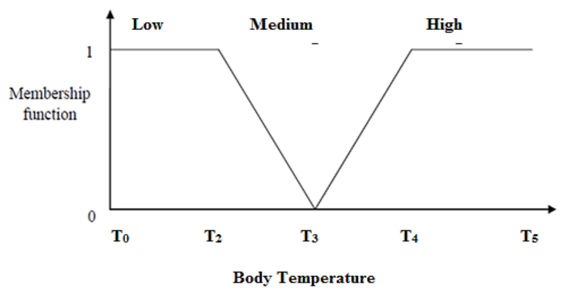

Fig. 6. Membership function of body temperature.

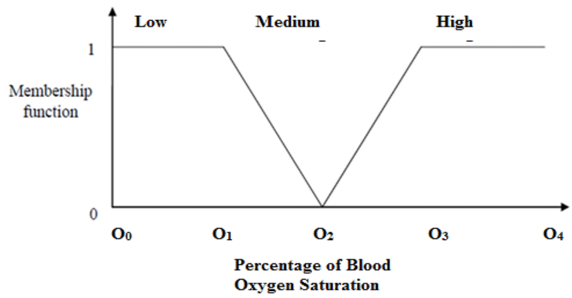

Fig. 7. Membership function of percentage of the blood oxygen saturation.

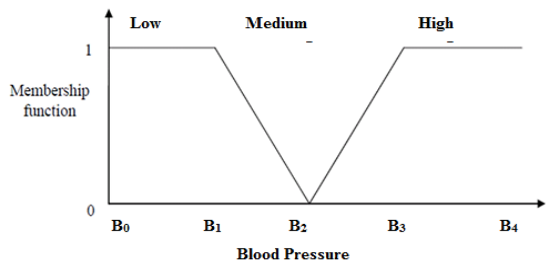

Fig. 8. Membership function of blood pressure.

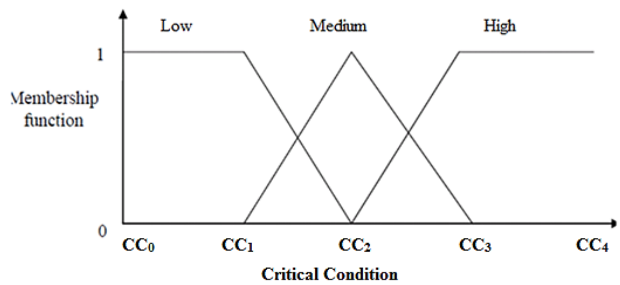

Fig. 9. Membership function of combined score.

Table 1 demonstrates the designed fuzzy inference system. This illustrates the function of the inference engine and method by which the outputs of each rule are combined to generate the fuzzy decision.

For example Let us consider Rule 14, If (ET, BL, AB and LQ = High) & (D = low)

Then CC = High

Critical warning message will be broadcasted to respective doctors.

End if

Table 1. A, H, T, O and B Are Given as Inputs and the Output Represents the Critical Condition. The Fuzzy Sets Are Defined with the Combinations Presented in Table 2.

S.No	A (High)	H(High)	T (high)	O (Minimum)	B (High)	CC
1	Low	Low	Low	Low	Low	Less
2	Low	Low	Low	Low	High	Less
3	Low	Low	Low	High	Low	Less
4	Low	Low	Low	High	High	Less
5	Low	Low	High	Low	Low	Less
6	Low	Low	High	Low	High	Less
7	Low	Low	High	High	Low	Less
8	Low	Low	High	High	High	Less
9	Low	High	Low	Low	Low	Less
10	Low	High	Low	Low	High	Less
11	Low	High	Low	High	Low	Less
12	Low	High	Low	High	High	Moderate
13	Low	High	High	Low	Low	Less
14	Low	High	High	Low	High	Moderate
15	Low	High	High	High	Low	Less
16	Low	High	High	High	High	Moderate
17	High	Low	Low	Low	Low	Less
18	High	Low	Low	Low	High	Less
19	High	Low	Low	High	Low	Less
20	High	Low	Low	High	High	Less
21	High	Low	High	Low	Low	Less
22	High	Low	High	Low	High	Moderate
23	High	Low	High	High	Low	Less
24	High	Low	High	High	High	Moderate
25	High	High	Low	Low	Low	Less
26	High	High	Low	Low	High	Less
27	High	High	Low	High	Low	Less
28	High	High	Low	High	High	Moderate
29	High	High	High	Low	Low	Moderate
30	High	High	High	Low	High	High
31	High	High	High	High	Low	Moderate
32	High	High	High	High	High	Moderate

2.6. Defuzzification

The technique by which a crisp value is extracted from a fuzzy set as a representation value is referred to as defuzzification. The centroid of area scheme is taken into consideration for defuzzification during fuzzy decision-making process. The formula (1) describes the defuzzifier method.

$$\text{Fuzzy cost} = [\sum_{allrules} f_i * \psi \ \text{(fi)}] / [\ \sum_{allrules} \psi(f_i)] \quad (1)$$

where fuzzy cost is used to specify the degree of decision making, fi is the fuzzy all rules, and variable and $\psi\ (f_i)$ is its membership function. The output of the fuzzy cost function is modified to crisp value as per this defuzzification method.

3. Simulation Results

3.1. Simulation Parameters

The proposed Collaborative Remote Patient Monitoring System (CRPMS) is simulated in NS2 and compared with Fuzzy Inference System for Remote Health Monitoring (FIHRHM). The simulation settings are shown in Table 2. In this simulation experiment, the on-body area communications surrounding everyday activity of long periods using multiple small body-mounted radios as Transmitters and Receivers are considered as shown in Table 3 and Table 4.

We consider two experimental scenarios to investigate the temporal variations in the channel quality.

Scenario 1: The subject is static and sitting on a chair

Scenario 2: The subject is slowly moving.

Table 2. Simulation Parameters

Number of Nodes	13
Area	1000 X 1000 m
MAC Protocol	802.15.4
Simulation Time	20,40,60,80 and 100 sec
Traffic Source	Poisson traffic
Propagation	Two Ray Ground
Antenna	Omni Antenna
Initial Energy	12.1 Joules
Transmission Power	0.5 watts
Receiving Power	0.3 watts
Packet size	512 bytes

Table 3. Range of Values for Temperature for Various Age Groups

Body Temperature Range				
Location	0-2 Years	3-10 Years	11-65 Years	65 years and Above
Oral	-	35.5C-37.5C	36.4C-37.6C	35.8C-36.9C
Rectal	36.6C-37.3C	36.6C-38.0C	37.0C-38.1C	36.2C-37.3C
Axillary	34.7C-37.3C	35.9C-36.7C	35.2C-36.9C	35.6C-36.3C
Ear	36.4C-38.0C	36.1C-37.8C	35.9C-37.6C	35.8C-37.5C
Core	36.4C-37.8C	36.4C-37.8C	36.8C-37.9C	35.9C-37.1C

Table 4. Statistical Data of Patients for Various Age Groups

S. No	Parameter	Age	Heart Rate	Blood Pressure	Temperature
1	Minimum	25	62	67/45	32.5
2	Maximum	66	120	190/106	36.6
3	Range	41	93	123/61	4.1
4	Standard Deviation	13.5	16.5	21.5/13/5	0.3
5	Median	37	96.5	126/68	36.5
6	Mode	49	84	124/68	36.6

3.2. Results & Analysis

3.2.1. Scenario 1: The subject is static and sitting on a chair

Fig. 10 shows the simulation topology of scenario-1. In this figure, the patient body is surrounded by 10 biological sensors. A local gateway (LG) is deployed within the premises of the patient and a remote gateway (RG) has been deployed in a remote location.

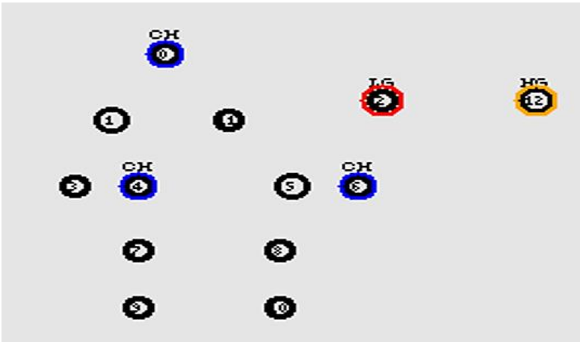

Fig. 10. Simulation topology for scenario -1.

Fig. 11 shows the transmission delay occurred while transmitting the information to HG. As we can see from the figure, the transmission delay of CRPMS increases from 0.82 to 4.17 seconds and the delay of FIHRHM increases from 2.3 to 8.1 seconds. Hence we conclude that our proposed CRPMS has 59% lower delay than FIHRHM.

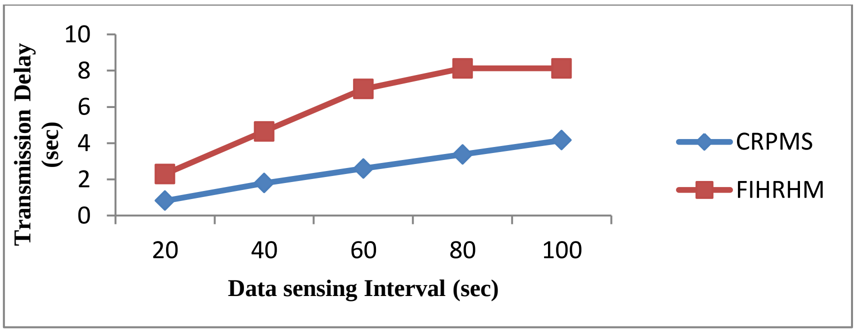

Fig. 11. Transmission delay for various intervals.

The transmission success rate denotes the number of successful transmissions made from the patient body to the HG. Fig. 12 shows the transmission success rate measured for CRPMS and FIHRHM. As we can see from the figure, the transmission success rate of CRPMS decreases from 0.97 to 0.94 and the transmission success rate of FIHRHM decreases from 0.95 to 0.88. Hence we conclude that proposed

CRPMS has 4% higher success rate than FIHRHM.

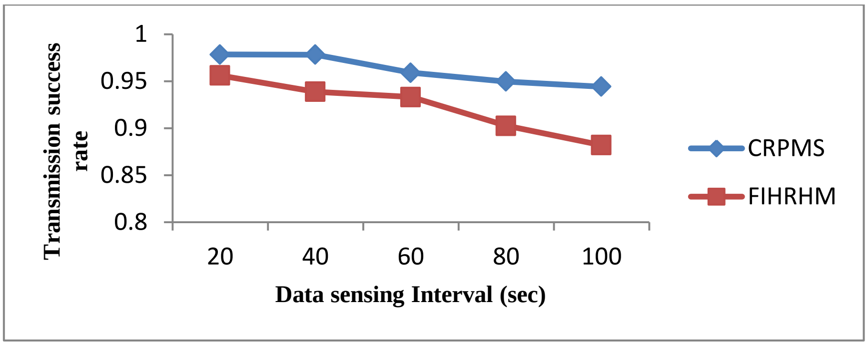

Fig. 12. Transmission success rate for various intervals.

Fig. 13 shows the percentage of critical warning message transmitted from the patients as per the fuzzy decision output. As we can see from the figure, the percentage of critical warning message of CRPMS decreases from 97% to 84% and for FIHRHM it decreases from 91% to 71%. Hence we conclude that the proposed CRPMS has 10% higher percentage of warning messages, when compared to FIHRHM.

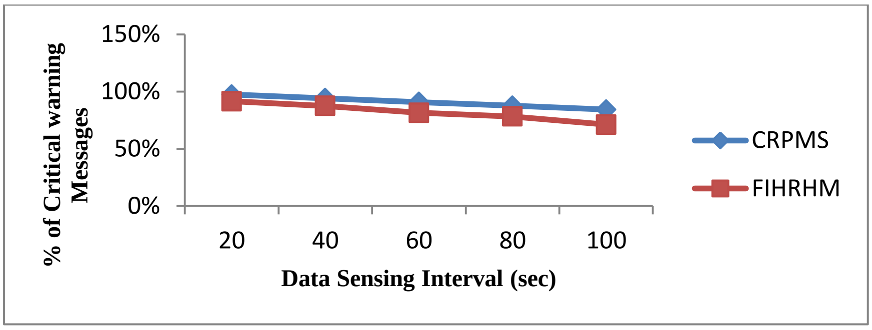

Fig. 13. Percentage of critical warning message for various intervals.

The communication cost denotes the amount of data transferred between the LG and HG. Fig. 14 shows the communication cost measured for CRPMS and FIHRHM. As we can see from the figure, the communication cost of CRPMS increases from 38.2 to 79.52 KB and the communication cost of FIHRHM increases from 59.12 to 136.65 KB. Hence we conclude that the proposed CRPMS has 42% reduced cost when compared to FIHRHM.

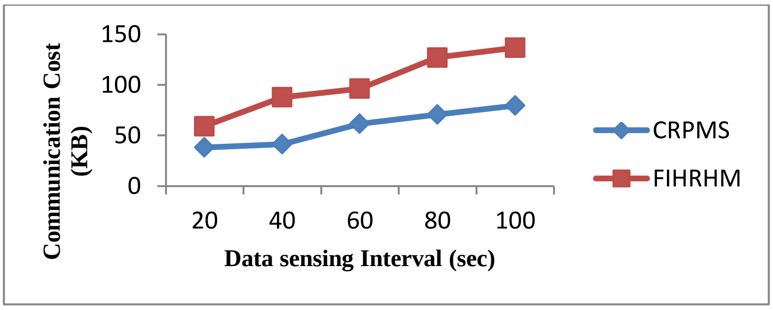

Fig. 14. Communication cost for various intervals.

Fig. 15 shows the average residual energy of LG and HG measured for CRPMS and FIHRHM. As we can see from the figure, the residual energy of CRPMS decreases from 11.2 to 8.6 joules and the residual energy of FIHRHM decreases from 10.4 to 7.0 joules. Hence we conclude that the proposed CRPMS has 15% higher residual energy than FIHRHM.

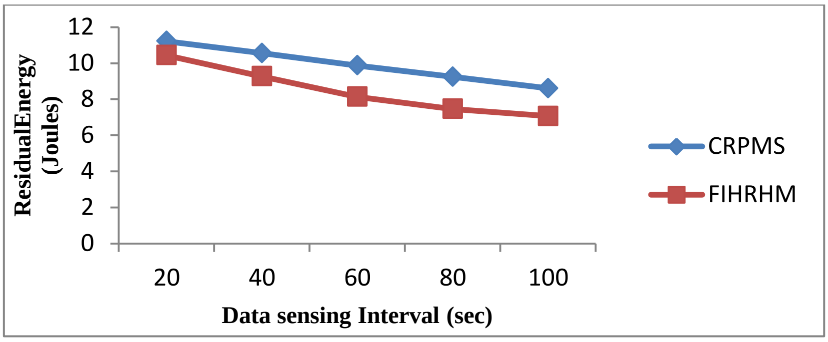

Fig. 15. Residual energy for various intervals.

3.2.2. Scenario 2: The subject is moving

Fig. 16 shows the simulation topology of scenario-2. In this figure, the patient is moving towards the LG.

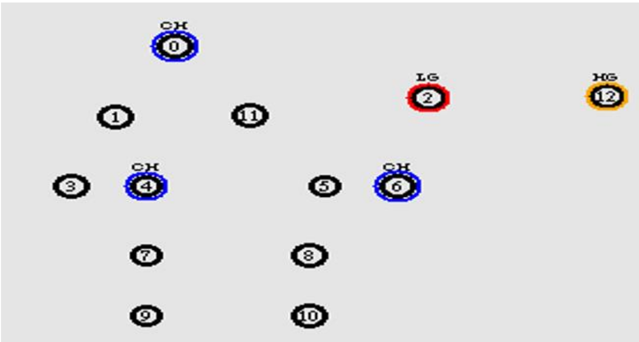

Fig. 16. Simulation topology of scenario-2.

Fig. 17 shows the transmission delay occurred while transmitting the information to HG. As we can see from the figure, the transmission delay of CRPMS increases from 0.9 to 5.8 seconds and the transmission delay of FIHRHM increases from 2.4 to 8.8 seconds. Hence we conclude that the proposed CRPMS has 54% reduced delay than FIHRHM.

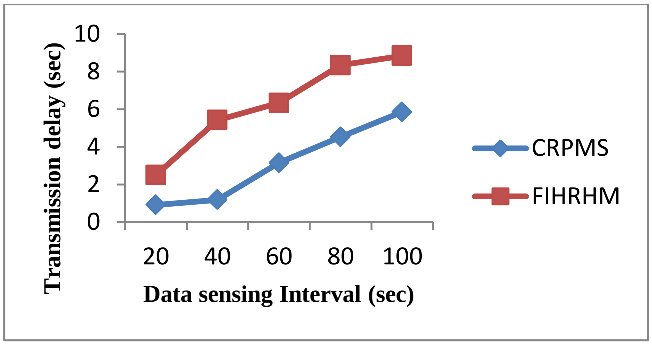

Fig. 17. Transmission delay for various intervals.

Fig. 18 shows the transmission success rate measured for CRPMS and FIHRHM. As we can see from the figure, the transmission success rate of CRPMS decreases from 0.99 to 0.96 and the transmission success rate of FIHRHM decreases from 0.98 to 0.94. Hence we conclude that the proposed CRPMS has 1.3% higher success rate than FIHRHM.

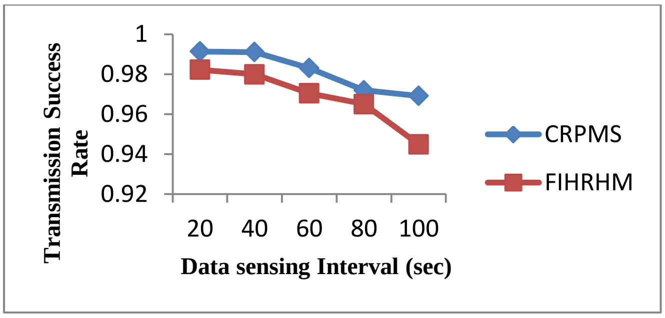

Fig. 18. Transmission success rate for various intervals.

Fig. 19 shows the critical warning message measured transmitted from the patients as per the fuzzy decision output. As we can see from the figure, the percentage of warning message of CRPMS decreases from 97% to 87% and for FIHRHM, it decreases from 92% to 80%. Hence we conclude that the proposed CRPMS transmits 6% higher warning messages when compared to FIHRHM.

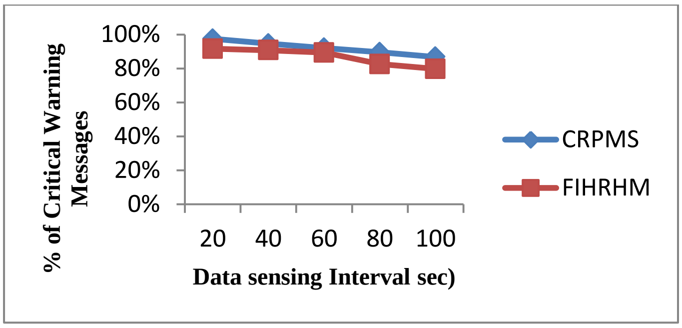

Fig. 19. Critical warning message for various intervals.

Fig. 20 shows the communication cost measured for CRPMS and FIHRHM. As we can see from the figure, the communication cost of CRPMS increases from 18.12 to 126.08 KB and the communication cost of FIHRHM increases from 88.21 to 317.08 KB. Hence we conclude that the proposed CRPMS attains 70% reduces cost when compared to FIHRHM.

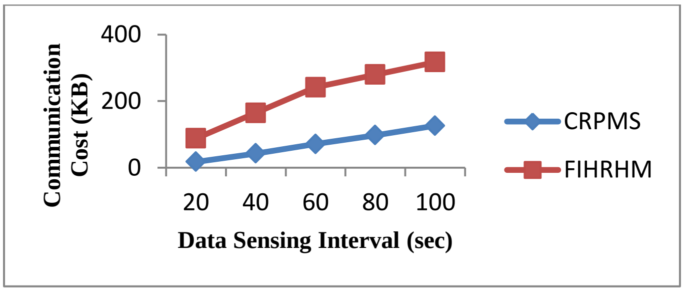

Fig. 20. Communication cost for various intervals.

Fig. 21 shows the average residual energy measured of LG and HG for CRPMS and FIHRHM. As we can see from the figure, the residual energy of CRPMS decreases from 11.2 to 8.0 joules and the residual energy of FIHRHM decreases from 10.2 to 6.0 joules. Hence, we conclude that the proposed CRPMS has 22% higher residual energy than FIHRHM.

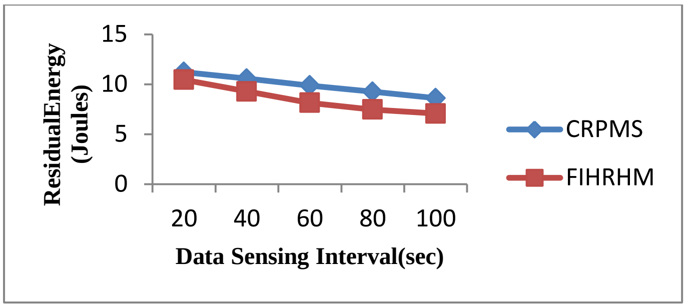

Fig. 21. Residual energy for various intervals.

4. Conclusion

In this paper, we have proposed a Collaborative Remote Patient Monitoring System using IEEE 802.15.4 Wireless Body Area Networks. The proposed architecture consists of clusters of local sensors situated on various parts of the body. Each cluster head communicates with a wireless local gateway (WLG) which lies within the patient's premises. The WLG in turn communicates with a remote hospital gateway (HG) such that the collected data from WLG is transmitted to the corresponding destination in the HG. The HG applies fuzzy logic decision model based on the input variables patient age, heartbeat, body temperature, percentage of the blood oxygen saturation and blood pressure and determines the criticality condition of patient. By simulation results, we have shown that CRPMS has increased transmission success rate with reduced transmission delay and energy consumption.

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