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REGULAR ARTICLE

Development of an Energy-Efficient Patient Monitoring System Using RSSI-Based Wireless Sensor Network with AODV and ZigBee Technology

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The AODV (Ad-hoc On-demand Distance Vector) scheme delivers reliable transmission in wireless ad-hoc networks, with loop-free operation, self-starting behavior, and scalability. It streamlines transmission by automatically finding the closest data receiver in an anycast group, minimizing latency. It also enhances path recovery efficiency by initiating restoration from intermediate routers along the original path. Leveraging these capabilities makes AODV highly effective for monitoring elderly patients and those with disabilities. The proposed system integrates Wireless Sensor Nodes (WSNs) to monitor the patient's position using a triaxial accelerometer for fall detection, along with ECG monitoring. These components are integrated into a ZigBee network architecture. The patient's position is relayed to nearby emergency centers via the ZigBee network, utilizing the Received Signal Strength Indicator (RSSI) parameter to identify and designate the nearest center as the destination. Experimental findings using an ARM7 Microcontroller (ARM LPC2148) with a ZigBee transceiver (CC2530) illustrate the system's effectiveness in measuring RSSI values and accurately identifying and transmitting data to the nearest emergency center, showcasing its potential for real-world healthcare monitoring application.

Keywords: Wireless sensor network, RSSI, ECG, Energy efficiency, AODV, ZigBee.

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1. INTRODUCTION

The aging global population is leading to increased demand for patient monitoring and caregiving systems, especially in developing countries with low fertility rates [1]. Monitoring vital signs like body temperature, blood pressure, and blood sugar levels through biological sensors can reduce staffing needs in care homes and hospitals. These vital signs need to be wirelessly transmitted, categorized as emergency data requiring immediate transmission or regularly collected data that can be periodically stored and sent. For indoor transmission, wireless mesh networks (WMNs) like ZigBee offer a convenient multi-hop topology that can self-configure without prior setup [3, 4]. ZigBee devices are low-power, low-cost, with small size - advantageous for this application. ZigBee's mesh networking enables high reliability and extended range [6] Integrating ZigBee with wireless wide area networks (WWANs) can create a seamless wireless patient monitoring platform. However, current ZigBee standards do not ensure reliable message transmission over multi-hop networks, which is critical for emergency vital sign data used to diagnose illnesses and determine urgency. A reliable anycast routing protocol is proposed for transmitting emergency data over ZigBee networks [2]. Multiple data sinks are deployed, utilizing anycast to locate and transmit data to the nearest available sink. If the original sink path fails, the protocol automatically rebuilds the path from the last node before the failure to a new sink. This approach enables faster recovery compared to unicast's full source rebuilds, while also generating less overhead than multicast/broadcast methods. This paper is organized as follows Section II describes AODV based transmission protocol Section III explains the system architecture for patient monitoring system Section IV confers the system transmission Section V presents the experimental setup with results and Eventually, Section VI concludes with future enhancement of this work.

2. RELATED WORK

Several researchers have proposed solutions for reliable data transmission in wireless sensor networks for patient monitoring applications. Huang et al. [7] developed a priority-based delay-tolerant protocol for monitoring vital signs in wireless body area networks. Their protocol categorizes data into different priority levels and uses different transmission mechanisms

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accordingly to ensure reliable delivery while minimizing energy consumption. Gao et al. [8] proposed a cooperative relay transmission scheme for wireless patient monitoring systems. Their approach employs relay nodes to improve the reliability of data transmission, especially in scenarios with obstacles or long distances between the patient and the monitoring center. In [9], the authors present a reliable and energy-efficient routing protocol for wireless body area networks used in patient monitoring. Their protocol, called REERP, uses a multi-objective optimization approach to balance energy efficiency and reliability while considering the criticality of different types of data. Tan et al. [10] developed a context-aware adaptive routing protocol for wireless patient monitoring systems. Their protocol adapts the routing strategy based on the patient's context, such as their mobility pattern and the criticality of the monitored data, to improve reliability and energy efficiency.

These works highlight the importance of reliable data transmission in wireless patient monitoring systems and propose various techniques to address this challenge, considering factors such as data prioritization, relay-assisted transmission, multi-objective optimization, and context-awareness.

3. TRANSMISSION PROTOCOL

The AODV routing protocol, a reactive approach, establishes routes between nodes only when necessary for data transmission. It utilizes two main packet types: route request (RREQ) and route reply (RREP). When a source node lacks a route entry to a destination, it triggers route discovery by broadcasting an RREQ message to neighbors. Intermediate nodes update their routing tables with a reverse route entry back to the source and propagate the RREQ. Upon reaching either the destination node or an intermediate node with a valid route, a unicast RREP is sent back towards the source. As the RREP travels hop-by-hop, nodes create forward route entries to the destination. Upon receipt of the RREP, the source can commence sending data packets to the destination over the newly discovered multi-hop route.

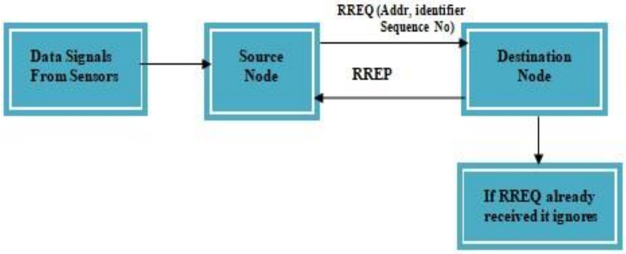


Fig. 1 – AODV Scheme

AODV uses sequence numbers to ensure route freshness and notifies the source of link failures via route error (RERR) messages to reinitiate discovery. While AODV is loop-free, self-starting, and scalable [11], it cannot ensure reliable data transmission. The proposed system enhances AODV reliability by introducing anycast routing capability. It deploys multiple data receivers, allowing the source to communicate with the nearest one using a hybrid anycast/reliable transmission approach for efficient route recovery.

4. SYSTEM ARCHITECTURE

The proposed system architecture for the patient monitoring system is represented in Fig. 2. It consists of source node and destination node. The source node continuously monitors the ECG and position of the patient and also informs the destination for abnormal condition of the patient.

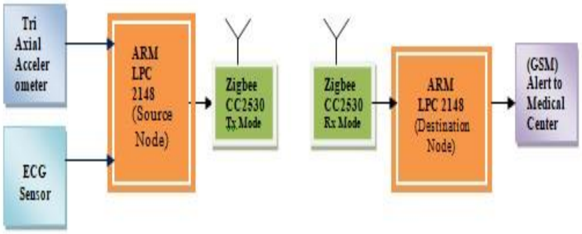


Fig. 2 – System Architecture for patient monitoring system

A ZigBee-based monitoring device has been developed to ensure reliable wireless transmission, particularly for fall detection and electrocardiogram (ECG) monitoring among elderly individuals. Central to this device is a triaxial accelerometer capable of detecting falls. Upon sensing a fall, the system promptly dispatches the patient's current location coordinates to a designated emergency response center through a ZigBee wireless mesh network.

In addition to fall detection, the device continuously monitors and transmits the patient's ECG data, providing crucial insights into their health status. Any anomalies detected in the ECG readings or sudden changes in the patient's position indicative of a potential fall trigger the wireless transmission of sensor data in real-time via the integrated ZigBee transceiver. This ensures that emergency responders receive prompt and comprehensive information, enabling them to assess the situation swiftly and deliver timely assistance as required.

4.1 Source Node

The monitoring system described in this study employs a source node equipped with a triaxial accelerometer and an ECG sensor to monitor patients' activity and vital signs. Triaxial accelerometers, such as the MMA7361L MEMS sensor used in this system, enable simultaneous measurement of vibration in three perpendicular axes, providing detailed information on the patient's movement and orientation. This sensor features low power consumption, temperature compensation, and self-test capabilities, making it suitable for continuous monitoring applications.

The ECG sensor can determine the ECG (electro-cardio graph) of a patient and can find the heartbeat. The

ECG sensor basically made of an instrumentation amplifier and consists of 3 electrodes placed on both the arms and a leg as reference. In this setup, the reference electrode is designated with a green color. positioned on the left arm is the blue electrode, while the red electrode is situated on the right arm. The voltage difference between these two electrodes is fed into an instrumentation amplifier configured with a gain of approximately 2000. Subsequently, the amplified signal undergoes filtering through a band-pass filter with a frequency range spanning from 60 to 200 Hz. and given input to the ADC of the microcontroller. The Internal circuit for ECG sensor is shown in Fig. 3.

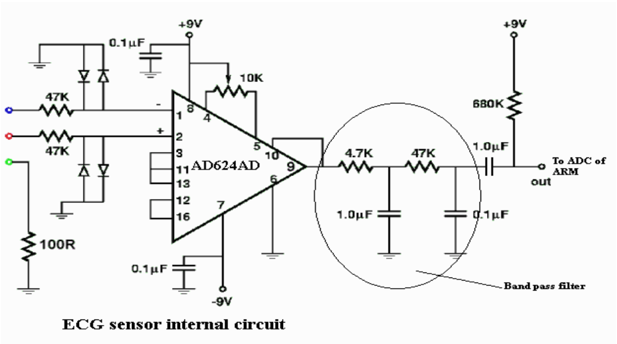


Fig. 3 – ECG sensor

These sensors would monitor the patient's activity all through the day. When the patient is about to fall and ECG rate is becoming abnormal the sensors would transmit the data through the zigbee transceiver used. The transmitter will send the data to the destination. The selection of nearest destination is done in order to reduce the latency and control overhead. Hence the number of destinations present will depend upon the requirement where the system is going to be applied. The analog sensor data is converted into digital format using the ARM microcontroller's built-in ADCs before being transmitted over the ZigBee network. This is the stage where the initial broadcast happens and further the data would be transmitted to the selected anycast transmission node. The selection of the node is done through the AODV protocol. This helps to alert the medical centre and to provide an immediate recovery to the patient under a critical or in an abnormal condition in case of any emergency. The data that is transmitted to the destination will be analyzed in the section 4.2.

4.2 Destination Node

The destination node functions as a receiver for patient data, which is then analyzed using a software-defined system. Multiple destination nodes may be available, with the most suitable one chosen based on the RSSI value obtained from the Zigbee module. Each destination node comprises a Zigbee transceiver for data reception and a microcontroller for data analysis via software. In cases of abnormal data, the microcontroller can activate an alarm and notify the nearby medical center. The data received includes readings from the MEMS accelerometer and ECG sensor, both of which are subject to analysis. Heartbeat detection from the ECG sensor involves initiating an ADC count during programming, with the count over a specific duration yielding the heart rate, typically measured over 30 or 60 seconds. The standard human heartbeat rate is known to be 72 beats per minute.

5. SYSTEM TRANSMISSION

The source node has the ability to send data to the closest available destination node by utilizing the RSSI value retrieved from the Zigbee modules installed across various destination nodes. RSSI, an abbreviation for Received Signal Strength Indicator, quantifies the strength of a received radio signal [13].

$$RSSI = 10\log_{10} P_{RX} \tag{1}$$

The Friis transmission equation outlines the principles governing radio communication propagation, establishing a connection between transmission distance (D) and received power (P_{RX}). In this Eq. 2, P_{TX} represents the transmission power, G_T stands for the transmitting antenna gain, G_R denotes the receiving antenna gain, and λ signifies the wavelength of the *RF* (radio frequency) signal.

$$P_{RX} = \frac{P_{TX}G_T G_R \lambda^2}{(4\pi)^2 D^2} \tag{2}$$

End-users typically observe an RSSI value while assessing the signal strength of a wireless network using monitoring tools. This RSSI value typically ranges from 0 to 255 dBm, although it may vary among manufacturers. A higher RSSI value indicates a stronger signal, suggesting that the node is in closer proximity to the source compared to other nodes. Consequently, further transmission can be directed towards the destination with the highest RSSI value. A higher RSSI value (or less negative value in some devices) indicates a stronger signal strength.

When a patient is at risk of falling, the MEMS accelerometer value and ECG data are transmitted through the following steps:

1. Sensors affixed to the patient continuously monitor and record various physiological and movement data.
2. The data is sent to the ARM microcontroller, which digitizes the values.
3. The controller then instructs the Zigbee module to transmit the data to the nearest destination.
4. The nearest destination is determined using the RSSI signal from the Zigbee.
5. Upon detection of an abnormality, an alert is triggered, and analysis can be performed using the software-based system.

The MEMS and ECG sensor data are transmitted to this destination, enabling a rapid alert setup to aid patient recovery.

6. EXPERIMENTAL SETUP AND RESULTS

The experimental setup for the real time measurement of RSSI with complete hardware setup is shown in Fig. 4. The receiver node is fixed to the system through the serial port. The transmitter section is placed at different distances and the values of RSSI are obtained for that distance. There are about eight such values taken for each distance by changing the angle but with constant distance value. The mean of the eight values are taken and this mean value for each distance is taken as the final signal strength for the particular distance through which the graph is plotted. A hardware platform consists of ARM7 Microcontroller (ARM LPC2148) and CC2530 as RF Transceiver has been developed for the measurement of RSSI value. The CC2530 has builtin RSSI and gives analogue output signal at the RSSI pin [12]. The program was written for ARM LPC2148 Microcontroller to get the RSSI values and received RSSI value was displayed with command prompt. This experiment was conducted in an open space with good line of sight. The Table 1 shows the RSSI value for each distance obtained with different step angle and Fig. 5 Graphicaly represented the mean value of RSSI versus distance.

Fig. 4 – Experimental Setup

Table 1 – RSSI Measurement for various distance with different step angles

Step angle	RSSI (dbm)									
	0.5 m	1 m	1.5 m	2 m	2.5 m	3 m	3.5 m	4 m	4.5 m	5 m
45°	15.12	13.97	11.82	10.92	9.24	8.92	7.07	4.7	2.29	2.13
90°	15.076	14.087	12.7	10.86	9.12	8.6	7.13	4.35	2.98	1.65
135°	14.95	14.26	12.32	10.35	9.18	8.63	6.69	4.62	2.63	1.58
180°	14.87	13.98	12.93	10.59	9.34	8.76	6.57	4.09	2.79	1.49
225°	14.86	13.86	12.57	10.74	9.46	9.01	6.43	5.21	3.18	1.66
270°	14.91	13.71	12.91	10.77	10.18	8.87	6.19	5.38	3.82	1.96
315°	14.93	13.91	11.92	11.09	9.53	8.65	6.89	4.79	3.46	1.39
360°	14.85	13.99	11.81	11.14	10.08	8.79	6.28	4.38	3.64	1.23
Mean (RSSI)	14.94	13.97	12.37	10.80	9.51	8.77	6.65	4.69	3.09	1.63

The RSSI value, represented as an 8-bit hexadecimal number, can be obtained from the RSSI status register [12]. According to the manufacturer of CC2530, the actual RSSI value is derived as the two's complement of the RSSI register value. To convert this RSSI value to an absolute power level (RSSI_dBm), the following procedure is employed:

1) While the CC2530 is in receiving mode, retrieve the RSSI value from the RSSI status register.

2) Convert the hexadecimal reading to a decimal number (RSSI_dec).

3) If RSSI_dec is greater than or equal to 128:

$$\text{RSSI\_dBm} = (\text{RSSI\_dec} - 256) / 2 - \text{RSSI\_offset};$$

4) If RSSI_dec is less than 128:

$$\text{RSSI\_dBm} = (\text{RSSI\_dec}) / 2 - \text{RSSI\_offset};$$

Here, RSSI_offset represents a typical value corresponding to the data rate provided by the manufacturer. Since the CC2530 is configured to operate at 250 kb/s, RSSI_offset is set to 72 [12].

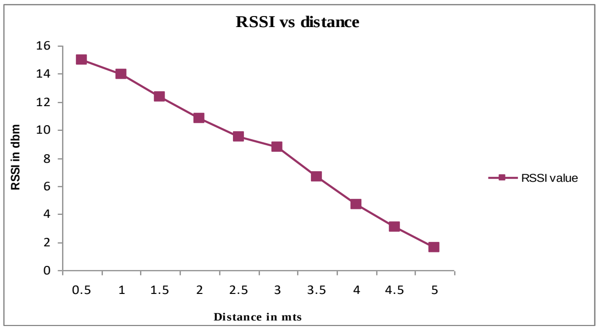
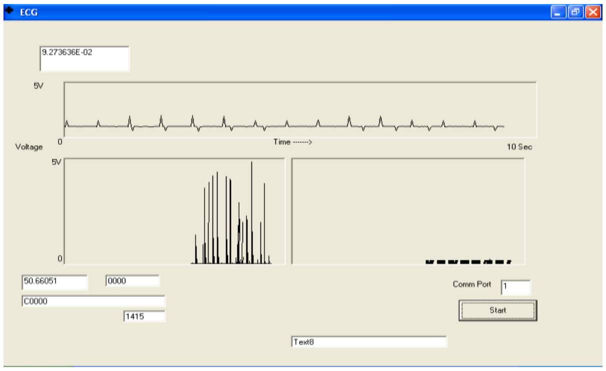


Fig. 5 – RSSI Vs distances (Receiver Node)



9.273636E-02

50.66051

0000

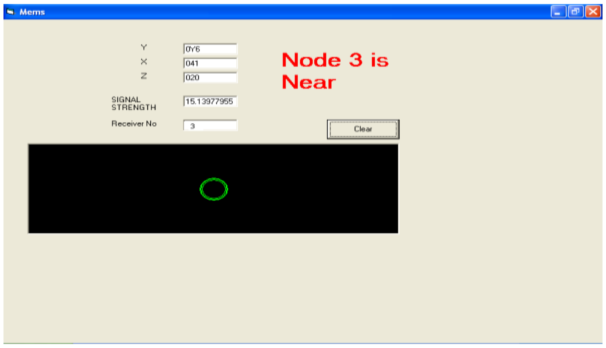
C0000

1415

Comm Port 1

Text8

Fig. 6 – ECG Waveform



Y 0Y6

X 041

Z 020

SIGNAL STRENGTH 15.13977955

Receiver No 3

Node 3 is Near

Fig. 7 – MEMS and signal strength values

The Fig. 6 shows the output of the ECG waveform obtained in the visual basic platform. The first wave is the original ECG PQRST wave obtained from the sensor. The remaining waveforms are the raw data that are obtained. The receiver is connected to the system supported by Visual basic through serial port and hence the data is obtained when the communication port 1 is selected. The ECG count value is also obtained here which can be used to determine the heartbeat of the patient under monitoring.

The Fig. 7 shows the output of the MEMS sensor which is the triaxial accelerometer. The *X*, *Y* and *Z* are the MEMS values which depict the motion of the patient along the forward or backward, sideward and circular directions. The RSSI value is indicated by the signal strength. The receiver number will indicate which of the given receiver is getting the values. Further the concentric circles below show the distance measures. The values of the signal strength can be obtained for different distances and finally the nearest receiver having highest signal strength could be selected for short distance communication. This helps to alert the medical centre and to provide an immediate recovery to the patient under a critical or in an abnormal condition in case of any emergency.

7. CONCLUSION

This study introduces an innovative approach to monitor the well-being of elderly and differently abled individuals. The system incorporates sensors like MEMS and ECG sensors to detect falls and monitor the patient's electrocardiogram (ECG) data. In the event of a fall or detection of abnormal ECG readings, the system promptly transmits the data to the nearest emergency center via Zigbee transceivers, enabling rapid intervention. Node selection for data transmission is facilitated by evaluating Received Signal Strength Indication (RSSI) values to identify the closest available node, optimizing transmission efficiency. Moreover, the protocol incorporates mechanisms for swift rerouting, ensuring minimal disruption in data transmission pathways and upholding the reliability of vital sign data transmission. To address potential future enhancements, considerations may include augmenting privacy and security measures. Integration of advanced encryption and authentication protocols can fortify the system against unauthorized access, thereby safeguarding sensitive patient information and ensuring compliance with privacy regulations.

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Розробка енергоефективної системи моніторингу пацієнтів із використанням бездротової сенсорної мережі на основі RSSI з технологією AODV і ZigBee

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Схема AODV (Ad-hoc On-Demand Distance Vector) забезпечує надійну передачу в бездротових ad-hoc мережах, без циклів, самозапуском і масштабованістю. Він спрощує передачу, автоматично знаходячи найближчого одержувача даних у групі будь-адреси, мінімізуючи затримку. Він також підвищує ефективність відновлення шляху, ініціюючи відновлення з проміжних маршрутизаторів уздовж початкового шляху. Використання цих можливостей робить AODV дуже ефективним для моніторингу пацієнтів похилого віку та людей з обмеженими можливостями. Запропонована система інтегрує бездротові сенсорні вузли (WSN) для моніторингу положення пацієнта за допомогою тривісного акселерометра для виявлення падіння разом із моніторингом ЕКГ. Ці компоненти інтегровані в мережеву архітектуру ZigBee. Місцезнаходження пацієнта передається в найближчі центри екстреної допомоги через мережу ZigBee, використовуючи параметр індикатора потужності отриманого сигналу (RSSI), щоб ідентифікувати та призначити найближчий центр як пункт призначення. Експериментальні результати з використанням мікроконтролера ARM7 (ARM LPC2148) із трансивером ZigBee (CC2530) ілюструють ефективність системи у вимірюванні значень RSSI та точному визначенні та передачі даних до найближчого центру екстреної допомоги, демонструючи її потенціал для застосування в реальному світі моніторингу охорони здоров'я.

Ключові слова: Бездротова сенсорна мережа, RSSI, ECG, Енергоефективність, AODV, ZigBee.