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ORIGINAL RESEARCH

Traffic priority based delay-aware and energy efficient path allocation routing protocol for wireless body area network

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Abstract

Wireless body area network (WBAN) is the emerging field in domain of healthcare to monitor vital signs of patients with the support of bio-medical sensors. The design of delay-aware and energy efficient routing protocol based on the traffic prioritization is the key research theme in WBAN. In addition, WBAN has challenging issues of packet loss, temperature rise, delay with retransmission of the lost packets due to which it does not extend the network life time and is not acceptable for life critical data. In this context, this paper proposes traffic priority based delay-aware and energy efficient path allocation routing protocol for wireless body area network (Tripe-EEC), which selects the optimal paths with high residual energy of nodes with minimum temperature rise. Specially, the design of Tripe-EEC routing protocol is mostly divided into four Folds. Firstly, the patient's data is classified into four classes that included normal data, data on-demand, Emergency data of low threshold readings and high threshold readings. These classifications assist in allocation of paths on the priority basis by removing conflicts along with support of an improved equation. Secondly, energy efficient and delay-aware path allocation algorithm is developed for normal data focusing on the selection of optimal and shortest paths with minimum temperature rise (hotspot). Thirdly, data on-demand algorithm is developed for on-demand traffic to transmit immediately to the medical doctor which is usually asked if any criticality or emergency situation happens with patient. Forth, criticalities (abnormal readings of vital signs i.e. low and high threshold values) detection algorithms are developed for measuring criticalities of vital signs and allocation of adaptive and energy efficient paths on the priority basis by removing conflict between them. Extensive simulations are performed in realistic medical environments for comparing performance of the proposed Tripe-EEC protocol with the state-of-the-art protocols.

1 Introduction

World Health Organization (WHO) has issued a report containing an increased death rate in million due to cancer, stroke, diabetic and other chronic diseases (Ullah et al. 2012). To overcome the death rates, we need an advanced technological development to monitor health conditions of patients without bringing them to the hospitals and those people who are living in remote areas and cannot reach to hospitals on time. This new technology to be informed the patients and medical doctors in advance if the patient health condition in life threatening conditions. To achieve

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these goals, wireless body area networks (WBANs) have the potentials to monitor various vital signs of patients and sportsmen wirelessly, included home-based aged people, in travelling, intensive care units (ICUs) and wards of hospitals without involvement efforts of humans (Bates et al. 2014; Feng-Cheng Chang 2016). Moreover, WBAN comprises of tiny Bio-medical sensors (BMSs) to monitor heart beat rate, respiratory rate, blood pressure, temperature, ECG, EEG, EMG (Rahman et al. 2011) of patient as shown in Fig. 1. The sensory (monitored) data of each vital sign is forwarded to the body coordinator and the body coordinator forwards the received sensory information to the medical doctors (Beyond BAN) for optimal treatments via GSM technology (Intra BAN). In addition, there are three methods of deployment of BMSs in monitoring of vital signs of patient as shown in Fig. 1. First method is known as wearable sensors, where different BMSs are sewed in shirt or directly placed on the skin of patient. Examples are ECG sensors and temperature sensors. Second method is the implementation of BMSs inside the patient's body like endoscopy sensor which monitors kidney and lungs conditions. The third method of deployment of sensors are different where various sensors are installed near the patient to monitor physical activities like sleeping duration and positions, sitting positions on sofa, hand shaking (Movassaghi et al. 2014),etc. These three types of deployment of sensors are connected with body coordinator in star and mesh topology based on the strength of the antenna, energy level and transmission of data.

The sensory data is classified into non-emergency data and emergency data (Xia et al. 2013). The non-emergency data contains information of normal reading of blood pressure and normal temperature. While emergency data

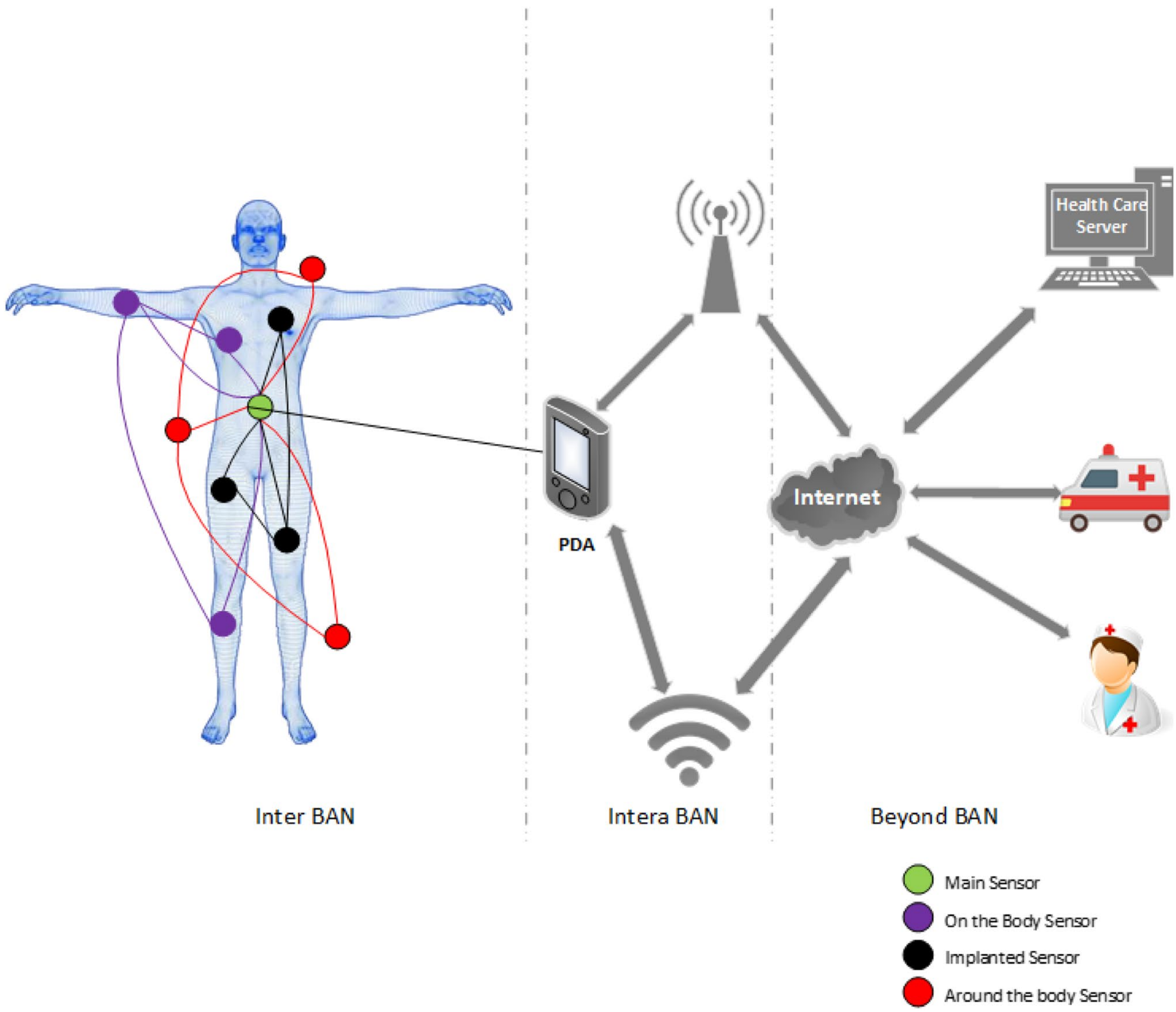


Fig. 1 Typical deployment of BMSs and monitoring health of a patient

comprises of abnormal reading of vital signs which requires a high attention to transmit on priority basis without delay by consuming a minimum energy of the selected paths. However, the existing classification of patient's data is insufficient and does not fulfill the requirement of patients according to the medical doctors. In addition, the existing research cannot resolve the conflict of path allocation if the same types of emergency data (i.e. low and high thresholds reading) are detected. Furthermore, Vetale and Vidhate (2017) and Karmakar et al. (2017) tries to select a high quality paths with low temperature rise and handles the path loss issues but the suggested protocols do not consider reliability and energy consumption issues which may reduce the performance in terms of higher delay, low throughput with high energy consumption. In Smail et al. (2016), if there is any invalid path information found in the routing table, then it broadcasts route request messages (RRM) in the network. If a path is engaged by other nodes, then the designated nodes must wait till path released from nodes. The same challenging issues has faced as mentioned in Vetale and Vidhate (2017) and Karmakar et al. (2017) which is not suitable for readings of low and high threshold values of vital signs. Djenouri and Balasingham (2009) has introduced an idea of using two sinks which reduces reliability in terms of delay by accepting which data packets. This type of decision brings delay in accepting packets which may interrupt the transmission of emergency data. Razzaque et al. (2011) and Khan et al. (2015) has provided different services for handling patient's as well as delay, energy and other performance parameters but the suggested protocol creates overheads in terms of congestion which causes a higher delay in transmission with high energy consumption. Nadeem et al. (2013) uses cost function to calculate the residual energy of sensor nodes for selection of an appropriate path. However, this protocol does not consider a mechanism for retransmission of the dropped/lost data.

The aforementioned challenging problems are motivated to design a novel traffic priority based delay-aware and energy efficient path allocation routing (Tripe-EEC) protocol. The proposed protocol classifies the patient's data into normal data (ND), data on demand (DOD) and emergency data (ED). Further, ED is divided into readings of low and high threshold values of vital signs. The purpose of these classified data is to allocate channel according to the severities of data, accordingly. Specifically, the main contributions are the proposed techniques summarized into four folds:

- Firstly, classification of patient data into four classes that included ND, DOD, ED_low (low threshold readings) and ED_high (high threshold readings). These classifications assist in allocation of paths on the priority basis by removing conflict along with support of an improved equation which is the traffic prioritization.
- Secondly, an optimal path allocation algorithm is developed for normal data focusing on longest paths, shortest paths, energy efficient, minimum temperature rise (hotspot) and delay-aware performance parameters.
- Thirdly, data on-demand algorithm is developed for on-demand traffic to transmit immediately to the medical doctor which is usually asked if any criticality or emergency situation happens with patient.
- Forth, criticalities (abnormal readings of vital signs i.e. low and high threshold values) detection algorithms are developed for measuring criticalities of vital signs and transmission of emergency data is performed on basis of priority by removing conflict between them.

Simulations are performed in realistic medical environments for comparing performance of the proposed techniques with the state-of-the-art techniques.

This paper is constructed as follows: the extensive literature on the routing protocol is presented in Sect. 2. Section 3 presents the proposed Tripe-EEC protocol including classification of patient's data, network model, paths selection procedures with scenarios and different proposed algorithms for non-emergency data, on-demand data and emergency data for allocation of energy efficient and delay-aware paths. Section 4 presents performance of the proposed protocol and comparison with existing protocols. Finally, the paper is concluded in Sect. 5.

2 Related work

This section briefly discusses the existing literatures that focus on transmission of all types of patient's data with prioritization by considering delay, throughput, packet drop and energy consumption. The delay tolerant energy efficient protocol for Inter-BAN transmission (Sangwan and Bhattacharya 2018) concentrates on energy consumption issues while monitoring the vital-data transmission is to sink. Furthermore, the cluster concept selects an energy efficient path with effective energy for vital-data transmission between sensor or cluster-head and sink. However, frequent topology-change occurs transmission overhead among sensor and sink, which results higher energy consumption, while patient's data is kept unconsidered. The hybrid data-centric routing protocol (HDRP) (Vetale and Vidhate 2017) select high quality paths with low temperature rise and handles path-loss in transmission of sensitive data. Relay node is used for transmission of data between sensors and base-station (BS). However, the energy consumption and reliability is not considered which results higher delay, maximum energy consumption, throughput and low performance. The suggested mobility handling routing protocol (MHRP) (Karmakar et al. 2017) deals with postural movement issues reported in Vetale and Vidhate (2017). As the transmission of emergency data is direct while normal data is sent via relay node to the sink. However, the energy consumption is higher in direct transmission which increase delay and decrease throughput. The mathematical mobility model (Sandhu et al. 2014) handles postural movements by using multi-hop- forward techniques for transmission of data among sensor and BS. However, the selected routes consume high energy of nodes for assigned tasks which is not suitable to transmit emergency data critical situations.

The scheme proposed has adopted TDMA approach to sort time in different channel for data transmission (Johnson and Maltz 1996). Parent node select path via routing table and a node has specific time-span to get active for data transmission while another node remain de-active till transmission completion. In case of critical-data transmission on priority basis, then the transmission is suspended, routing table rebuilt, new topology initiate and schedule-table is refreshed. However, sudden setup-change for emergency data causes transmission-delay and high energy consumption. In data transmission, the source node verifies the established path from routing table (Smail et al. 2016) while for any invalid-path a Route Request Messages (RRM) is broadcasted within the network. If path is engaged then the elected nodes must wait until path is released. However, broadcast of RRM within network causes high energy consumption while locating path which is not suitable for emergency data. The Localized multi-objective routing for biomedical networks (LOCALMOR) (Djenouri and Balasingham 2009) proposes modular scheme including (a) the power-efficiency module deals with regular packets (b) the reliability-sensitive module uses primary and secondary sinks for routing packets. (c) The delay-sensitive module routes assist in transmission of packets. However, transmission of duplicate messages to sinks reduces reliability which causes transmission-delay and interrupt emergency data. The cooperative link aware and energy protocol for body area network (Co-LAEEBA) (Ahmed et al. 2015) relies on the cooperative routing, assures maximum throughput by identifying cooperative nodes using shortest path route algorithm. The emergency data is transmitted directly while normal data is sent via multi-hops whereas source node avail single link at a time. Cost function analyzes residual energy by subtracting utilized energy from initial energy. However, the protocol uses multiple decision parameters which causes low throughput with high delay in network. The suggested protocol (Roy et al. 2017) transmits different sensors data to designed sensor and onwards to Base-station by adopting zigbee technologies. The scheme checks connectivity with designated sensor, once connection is acknowledged, then the sensor-energy, temperature and threshold value is check before transmission. However, sensory-data types, alternate path for data and critical data transmission is not considered. The suggested scheme in Chaudhary and Gupta (2018) combines single and multi-hop in multi-hop transmission. A cost function is adopted to elect a node as parent/forwarder node. This scheme is better for packet delivery. However, Energy consumption is high due to path loss and delay in re-establishment.

The suggested meta-UI system is for establishing a familiar relationship between human and intelligent systems to facilitate ambient living lifestyle especially for old age people who are unable to pay frequent visits to their concerned doctors and hospitals (Mostafazadeh et al. 2018). The proposed system is composed of different behavioral schemes which are revitalized to re-configure the UI. However, there is a lack of adding human postural dynamic behaviors. The auto downloading and re-configuration of new behaviors from cloud to system and PDA is not considered. The proposed citizen data management system is an enhanced component for H2020 City4Age project with an objective to facilitate senior age living with latest technological life style and prior determination of risks to avoid any intrusions and expand better living environment (Mulero et al. 2018). The statistical data generated from the system is published to cloud through SPARQL and RDP nodes by adopting IOT. The IMD is assumed to deliver analytical data to caretakers of the users/patients for early risks detections and its required preventions. However, there is no such mechanism suggested to read the user data by caretaker locally in case of transmission interruption from cloud. Moreover, a wearable pattern system with measuring system is proposed for utilizing 9DoF sensor boards attached to WSN spots (Sarcevic et al. 2019). A new classification algorithm suggested use two wrist-worn sensor spots for detection of various arm movements while in static and moveable state which eases the process of deployed unit controller. The proposed system consumes low energy other than existing systems. However, the suggested system consumes more energy if the moments are rapid and fast. The dynamic and un-expected moments of arms has been ignored which may cause high energy consumption. The proposed online distribution resource aware (ODRA) algorithm which gives an accurate condition of the patients so as to inform the status to physician whenever immediate attention is required (Tambe and Gajre 2018).

The data-centric multi-objective QoS-based routing protocol (DMQoS) (Razzaque et al. 2011) has presented modular architecture including dynamic packet classifier, energy aware geographic forwarder, reliability control, delay control and QoS-aware. However, congestion occurs due to overhead which causes a high delay, maximum energy consumption which is not suitable for emergency data. QoS-aware Peering Routing Protocol for delay-sensitive Data, (QPRD) (Khan et al. 2015) protocol assists in identifying better route for data transmission with respect to QoS requirement and the same modular approach (Razzaque et al. 2011) is used. However, high energy consumption occurs due to high traffic load and no capability for reliable transmission. The Energy-Balanced Rate Assignment and Routing Protocol (EBRAR) (Ababneh et al. 2012) protocols uses topology discovery, routing tree, data assignment for transmission, and state transition processes which supports nodes in paths selection and run time topology creation during data transmission. However, the scheme has same issues mentioned in Razzaque et al. (2011) and Khan et al. (2015). The global dynamic routing protocol select sensors based on their energy levels (Argade and Tsouri 2013). The energy consumption is better but cause overheads in alteration of the harvested energy when apply on sensor nodes. The thermal-aware multi-constrained intra-body QoS (TMQoS) (Monowar et al. 2014) support multi-constrained QoS requirements and maintain sensor temperature to avoid thermal damages and provide high reliability with low delay. However, the balanced power consumption between consistent sensors is ignored and end-to-end delay is not assure in hop-by-hop. The RE-ATTEMPT (Ahmad et al. 2014) protocol extra network life time for reliable data transmission. The (1) Sensor nodes transmit Hello packets for updating routing table, (2) The emergency data is transmitted directly while ordinary data is sent via multi-hops. (3) Time-span is allocated for transmission of the sensory-data. (4) Transmission succeed if completed within time-slot. However, No method for managing emergency data in terms of reliability-sensitive and delay-sensitive. No mechanism to resolve conflict of path and similar priorities. The balanced energy consumption (BEC) (Sahndhu et al. 2015) uses cost function of Ahmed et al. (2015) to determine residual energy of nodes before path selection. If there is a distant node with an emergency data from BS the data is forwarded via relay nodes which store information of the node till successful transmission. Similar parameters of Adhikary et al. (2016) are used i.e. identity, location and residual energy. The protocol extends the network life time. However, consumes higher energy in transmission.

3 Traffic priority based delay-aware and energy efficient path allocation routing protocol

This section presents the detailed working mechanism of the novel and proposed traffic priority based delay-aware and energy efficient path allocation routing protocol for wireless body area network (Tripe-EEC) by focusing on the classification of patient's data, prioritization based transmission of the detected readings of vital signs with the support of designing main topology. Further, the priority based transmission requires efficient path selection process with optimal energy consumption and handling critical data. Section 4.2 describes the brief overview of the proposed protocol while in Sect. 4.3 presents the designing of different proposed algorithms for dissemination of the classified data.

3.1 Classification of vital signs

The proposed Tripe-EEC protocol classifies the patient's data into three categories that are normal data (ND), data on-demand (DOD) and emergency data (ED). ND represents normal reading of vital signs like normal blood pressure as shown in Table 1 and is represented as regular healthy values. DOD is the required data when the medical doctor accesses reading of the deployed sensors for checking against any ED in emergency situation. Moreover, ED is categorized into critical data (CD) and delay sensitive data (DSD). CD is the life critical data which requires a high attention to transmit on the priority basis without delay and loss such as low reading of heartbeat rate, as depicted in Table 1. DSD accepts delay for specify very short spin of time and contains readings of high threshold values as discussed in Table 1. These four vital signs have been confirmed from medical doctors for survival of normal life of person, as described in Ullah et al. (2017). Therefore, these data require dedicated and high reliable paths for transmission on the priority-basis without delay, loss and must consume a minimum energy of network.

3.2 Network model

The sensory data is sent from sensors to main sensor (S_{Main}). The S_{Main} is the designated sensor which sends and receives data from deployed sensors and transmit it to body coordinator (BC), as shown in Fig. 1. The deployed topology is mesh network. The sensory data is classified into ND, NOD and ED. In addition, ED is divided into low and high threshold readings of vital signs. These types of data are further sent to health care system (HCS) whereas doctor prescribes treatment. Therefore, we have proposed different algorithms for transmission of these sensory data with checking an optimal

Table 1 Classification of ranges of threshold values

Vital sign	Criticalities of vital sign		Regular healthy values
	Low threshold (L)	High threshold (H)	
Heartbeat rate (HR)	0–50 beats/min	51–140 beats/min	51–119 beats/min
Respiratory rate (RR)	0–11 breaths/min	12–40 breaths/min	12–49 breaths/min
Blood pressure (BP) (mmHg)	70–90	140–190	90–120
BP Diastolic (mmHg)	40–60	90–100	60–80
Temperature	–	40 °C & >	37 °C

path selection and energy level by avoiding hotspot nodes along with priority basis transmission, which are discussed below.

3.3 Path selection

The sensory data of the source node is transmitted directly to the body coordinator via main-sensor using shortest path. Normally, this path is selected when a node has high priority data and needs to transmit it without delay, path loss and data packet drop. Figure 2 shows different paths for data transmission to connect with main-sensor. For Path 1, we have to use X, J and K nodes reach to main-sensor. Similarly, path 2 comprises of X and K which are the shortest path for reaching to main-sensor. Like other paths are 4 and 5 have shown in Fig. 2 which are the longest paths for data transmission. Moreover, the shortest path (i.e. path 2 and 3) will be selected on the priority basis for transmission of emergency data when all paths are engaged by other nodes for data transmission. The continuous transmission over the same path of sensors having sufficient energy but the regular transmission over the same sensors decreases energy level and hence sensors become overheated. The overheated sensors damage human's tissues and skin which is not acceptable to hurt the patient.

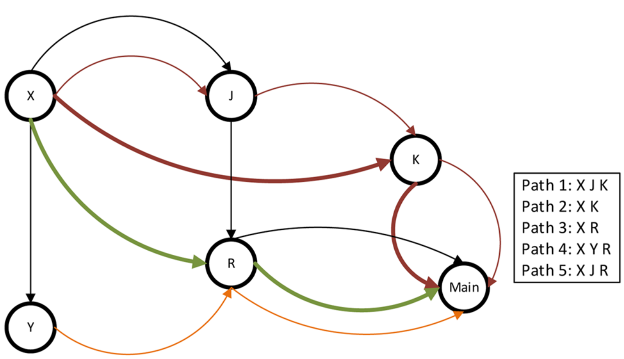
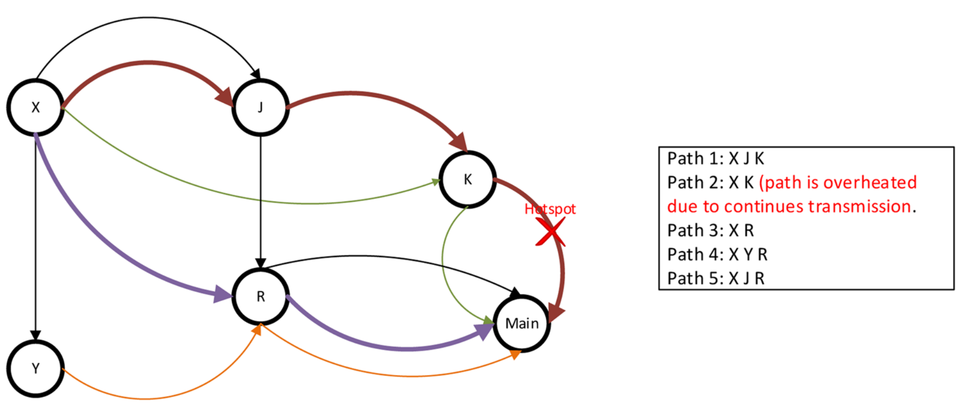


Fig. 2 Shortest path selection without hotspot

The ND is on the regular basis while DoD is requested by medical consultant to compare it if there is an emergency situation. The emergency data is considered to be transmitted on the priority basis and all possible channels or paths are allocated. The transmission of data over the same paths causes in decreasing energy level of sensors which become hotspots. Figure 2 shows that the sensor-x is transmitting the reading of vital signs to body coordinator over path-2. The path-2 is composed of two sensors i.e. sensor-x and sensor-k and it is the shortest path. The transmission of vital-data over path-2 increases temperature high which becomes hotspot and exceeds the drop ratio of packets. The hotspot diverts the transmission of data to alternate path as shown in Fig. 3. The second alternate is path-3, which is another shortest path to reach main-sensor. The sensor-x transmission will start over path-3. If the same situation occurs with this path-3 as occurred to path-2 then the transmission will divert and continue on other paths as shown in Fig. 3. However, before selecting the alternate path for transmission, the shortest path is preferred and if there is no shortest path then any alternate path will be selected and the communication of sensory data will be continue till its completion.

Similarly, if there is any request received from medical consultant for reading of vital sign from patient's body. Then the same mechanism is followed for transmission of data as aforementioned. However, there will be alternate paths selected on the priority basis for transmission of DoD. In case of emergency data, the shortest available paths are checked first. If all sensors and paths are engaged and there is no path available then direct connection or path will be established with main-sensor by stopping transmission of ND or if there is no direct connectivity or any alternate route then a time-slot will be requested from main-sensor using alert signal, as shown in Fig. 4. The main-sensor will allocate time-slot for transmission of emergency vital-data based on TDMA scheduling scheme.

Fig. 3 Shortest path selection with one hotspot path



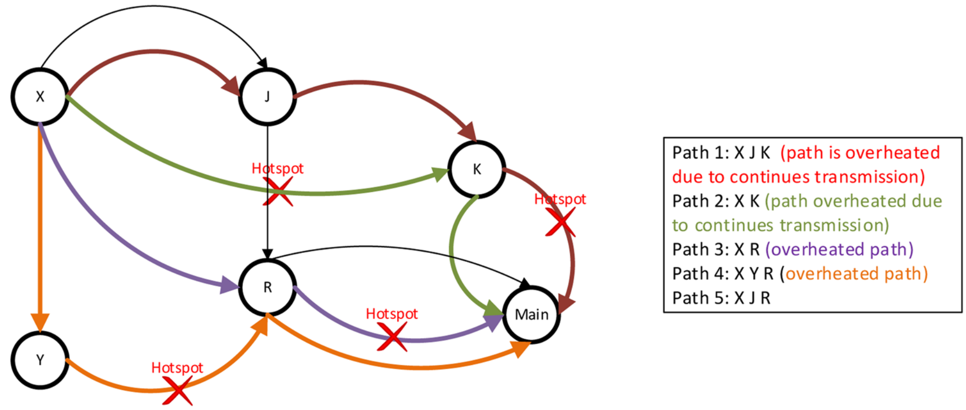


Fig. 4 Shortest path selection with more than one hotspot paths

Table 2 Some commonly used keywords and its narration

Terms	Description
$Sen_{i, j, k, r, x, y}$	Planted in/on the body sensors or nodes in WBAN
D_N	Normal data of sensor
D_{OD}	Data on demand by doctor/health care system
$D_{Emgy\text{-}L/H}$	Emergency data (low or high)
S_{Main}	Main sensor to which all other nodes are connected
$Ergy_{L\ or\ H}$	Energy L indicates Low energy and H shows High energy
TH_{value}	Threshold value
TH_{Heat}	Threshold head of the sensor
$SETUP_{RQ}$	Setup request for connection establishment to S_M
$SETUP_{RP}$	Setup response received from the body main Sensor S_M
Ack_{ST}	Acknowledgment upon successful transmission
TTL	Time to live in mille seconds i.e. 250 ms
C_{conn}	Connectivity with S_{Main}
Gen_{Rate}	Generation rate for emergency data
C_{conn_Ack}	Connectivity with S_{Main} acknowledged
F_{Max}	Sensor maximum fitness
Ʀ	Request made from doctor/health care system
SAR	Specific absorption ration
Alt_{Route}	Alternate route

3.4 The proposed algorithm for transmission of normal data

The ND based sensor generates data and transmits to Main Sensor (S_{Main}) and the S_{Main} forwards the same data to body coordinator (BC). Table 2 describes commonly used keywords and their meanings in the proposed algorithms. The Normal Data D_N is generated from Sen_x and the Sen_x wants to transmit to the Sen_main. The proposed algorithm for transmission of N_D states that when the data is received then initially the connectivity between Sen_x and Sen_main is checked. In case if the sensor has neither direct connectivity with the Sen_main nor received any connectivity acknowledgment from Sen_main. In this situation, the Sen_x will send setup request ($SETUP_{RQ}$) to Sen_main, as shown in the proposed algorithm 1. When the request is received from Sen_x then the energy level of Sen_x is checked. The main purpose of checking energy level of Sen_x is that either it has sufficient energy for transmission of data. If the energy level is greater than or equal to threshold value (TH_{value}) then the node has sufficient energy for transmission of data to Sen_main.

Moreover, if the calculated energy of Sen_x is greater than specific absorption ratio (SAR) (Tang et al. 2005) then the Sen_x energy is insufficient for data transmission. SAR is the term indicating heat which is produced by the sensor during communication, if the SAR of Sen_x is greater than threshold heat (TH_{Heat}) then it transmits data of the sensor but it will also damage the tissues of patient's body and it is considered as overheated sensor. If such sort of situation occurs then the transmission must be stopped as to avoid tissues thermal damages. It is worth mentioned that SAR of any sensor must be less than TH_{Heat}. The SAR of sensor can be calculated using standard (Tang et al. 2005) as expressed in Eq. 1.

$$SAR = \frac{\sigma|E|^2}{\rho}\ (\mathrm{W/kg}). \tag{1}$$

E is convinced electric pitch by radiation, tissue-density is denoted by ρ and σ is the tissue-electrical conductivity. Different regions and officialdoms keep stern criteria for topmost standards for SAR. Some tryouts revels that SAR value 8 W/kg if in any gram of tissue specifically in head or trunk or chest for 15 min is censoriously injurious for tissue. Sen_x will either retry for connectivity or its request will be stored in buffer state till its TTL expire i.e. 250 ms.

Algorithm 1 : Transmission of Normal Data

1. **Start:**
2. **If** (data-i) receive (Sen_x) **AND**
3. **If** (data-i) $\leftarrow D_N$
4. **AND**
5. **If** (!C_{conn} _S_{Main} OR !receive Ack_S_{Main}) **THEN**

If (data $\leftarrow D_N$) **THEN**
If (Sen_j Ergy $\geq TH_{value}$ (p)) **THEN**
If (Sen_j **SAR** < TH_{Heat} using eq-1) **THEN**
Send (**SETUP**$_{RQ}$_D_N) $\rightrightarrows S_{Main}$
If receive (**SETUP**$_{RP}$) S_{Main} **THEN**
C_{conn}_$S_{Main} \underset{=}{\leftrightarrow}$ Allowed
$S_{Main} \leftleftarrows$ data-i
$Ack_{ST} \rightrightarrows D_N$

6. **Else**

Wait or Re-try for Sen_j_Store (buffer) == TTL (a)

7. **End**

Output: Sen_x sent sensory-normal-data to Sen_main. The Sen-main has allowed the sensor to send its data.

If the Sen_x_SAR value is according to required value then Sen_x will send request to Sen_main for connection establishment and the Sen_main will send response as well as acknowledgment for the connectivity request. The Sen_main is then allowed Sen_x for transmission. When the Sen_x data is received by Sen_main then it will send back a successful transmission acknowledgment Ack_{ST} to Sen_x. The Ack_{ST} indicates that the sensory-data sent from Sen_x is received successfully. Once the connection between Sen_x and Sen_main is established then it will be remain established till transmission completion. The same procedure will be adopted by any other sensor for creation of connection with Sen_main.

3.5 The proposed algorithm for handling transmission of on-demand data

The transmission of N_D is easier as compared to on-demand data (D_{OD}) because N_D communication is continuous process while transmission of D_{OD} is an immediate request which is also termed as data on call. The doctor at hospital or a consultant at clinic needs a sensory data of a patient regarding patient's heartbeat. The doctor will send request (℞) for the specific sensory data of patient. This sort of request for sensory-data is called as data on-demand. Moreover, the body coordinator receives a request from doctor regarding heartbeat or sugar level or blood pressure (BP) and further it is forwarded to concerned sensor for gathering of the required data. The concerned sensor engenders the requisite data and sends it to Sen_main which forwards the same data by succeeding the similar request-cycle that was created by a doctor/consultant, as shown in Algorithm 2. Furthermore, it is to be mentioned that the broadcasting process of N_D is in progress. The associated Sen_x will first check its direct connectivity with Sen_main if the Sen_x has direct connectivity with Sen_main then the data will be sent without any delay and interruption, as described in Algorithm 2. However, if the Sen_x has no direct connection established with Sen_main then it will send request to its neighbor sensors i.e. Sen_J or K or R which have direct link connectivity with Sen_x. Sen_J or K or R will send connection acknowledgement to Sen_x. The neighbor sensors in this case will act like relay-sensor for transmitting data of Sen_x to Sen_main. Before transferring data, Sen_x will calculate the energy level and TH_{Heat} of the neighbor-Sen_j,k,r. If the required values of energy is less than TH_{value} and SAR value is greater than TH_{Heat} then the Sen_x request will be put into retry-state or it will be stored in buffer state till TTL session terminates. Similarly, if the energy is greater or equal and TH_{Heat} is less than Sen_x_SAR value then the concerned sensor will send the requested data to the nearest Sen_J or K or R and in response the Sen_J or K or R will send an Ack_{ST} to Sen_x ensuring that the data has been sent to the requesting location positively.

Algorithm 2: for handling transmission of Data-On Demand to the medical doctor

If (data-i $\leftarrow D_{OD}$) AND (R_Sen_x)
  If (Sen_j Ergy $\geq TH_{value}$ (p)) **THEN**
    If ($Sen_{J\ or\ K\ or\ R}$ SAR < TH_{Heat} using Eq1) **THEN**
      Send (**$SETUP_{RQ}$**_D_{OD}) $\rightrightarrows S_{main}$
        If !receive (**$SETUP_{RP}$**) S_{Main} **THEN**
          Find (**Alt_{Route}**_D_{OD})
            If ($C_{conn}\_S_{Main}$) $Sen_{j\ or\ k\ or\ r}$ $\underset{=}{\leftrightarrow}$Allowed **THEN**
              Receive (C_{conn}_Ack_ $Sen_{j\ or\ k\ or\ r}$) $\rightrightarrows D_{OD}$-i
              $Sen_{j\ or\ k\ or\ r}$ $\leftleftarrows$ data-i
              $Ack_{ST} \rightrightarrows D_{OD}$
Else
  Wait or Re-try for Sen_j_Store (buffer) == TTL (a)
End

OUTPUT: On demand data is sent to main sensor via alternate route

3.6 The proposed algorithm for transmission of emergency data

The sensory data is emergency data containing low or high threshold readings of vital signs which is important to be sent on priority basis. The emergency data is denoted as D_{Emgy} which is further classified into two major types that included emergency data-low (D_{Emgy-L}) and emergency data-high (D_{Emgy-H}). Table 1 shows various ranges of criticalities of vital signs which have been used for simulation to compare the proposed algorithms with the state-of-the-art schemes. Further, the proposed algorithms will transmit emergency data (i.e. low and high threshold values) of vital signs on the priority basis without delay and packet loss by avoiding conflict of channel allocation which is expressed in Eq. 2.

$$\text{Patient's Traffic Prioritization} = \frac{Sen_x\_\text{Threshold readings}}{\text{Time of Generation} * \text{packet\_capacity}}, \tag{2}$$

where Senx_Threshold readings is concerned with detection of threshold values that can be low or high reading. The time of Generation means timing of data when it was generated like it was generated earlier as compared to the second value that was generated recently and the packet size must be greater than zero bytes. Equation 2 assists in removing conflict of allocation of resources to sensor nodes.

The transmission of emergency data is further classified in four different cases. First: Low threshold reading of *Seni_x* and Low threshold reading of *Sen_y*, second: low and high readings of two vital signs, third: high and low readings of two vital signs and, Four: high threshold reading of *Seni_x* and high threshold reading of *Sen_y*. Therefore, there are four different algorithms have proposed as shown below from Algorithm 3 to Algorithm 6 to support four different cases as aforementioned. The Algorithm 3 has proposed for first case where Sen_x and Sen_y produce low threshold based data. The Sen_x data is received earlier while Sen_y data is received recently. As mentioned in Table 1 that the emergency data of the heartbeat is high critical when it is low because the low heartbeat rate has 95% chances of death. Therefore, it will be transmitted first as compared to Sen_y. If Sen_x and y data is low and their generation time is earlier. In this situation, the Sen_x data will be sent first and then Sen_y data will be sent later. Similarly, Sen_x has low reading of data received recently while Sen_y has high reading of data received earlier, as shown in the proposed algorithm 4. In this case, the Sen_x data will be transmitted before Sen_y. If the Sen_x_has low reading of data received earlier and Sen_y has high reading of data received recently then low will be transmitted before high. The proposed Algorithm 5 shows the transmission of high and low readings of threshold are similar as the transmission of low and high readings of threshold data. The data which is low and received either earlier or recent will be communicated first and high data which is produced earlier or recent will be transmitted later. The proposed Algorithm 6 shows if two Sen_x and y generate high data, then high data of any sensor which is received earlier will be first transferred as compared to the sensory data received recently. Moreover, the emergency data which is to be sent prior has been briefly discussed in the above four different cases of algorithms. In the proposed algorithms, the sensory data is received and compared. Then, in next step the Generation-rate denoted by Gen_{Rate} is performed to check that which vital-data is received earlier and recent. After the analysis of earlier and recent parameters, the sensor energy is checked with TH_{value}. If the energy level of sensor is less than TH_{value}, the sensor will try again or will wait in buffer state or the sensor must wait till its TTL value is equals to 0 whereas the default value for TTL is 250 ms.

On the other hand, if the node energy level is greater or equals to TH_{value} then the sensor will check SAR value which is the TH_{heat} value, as shown in the proposed algorithms 4–6. If the SAR value of that node is greater than the required TH_{heat} value then the sensor will retry for connection, but if the SAR value of that node is less than the required TH_{heat} value then the node will send direct *setup-request* for connectivity to the main corresponding node, as described in the proposed Algorithms 4–6. If that sensor does not receive direct connection response from the main-sensor then that node will check alternate paths of neighbor nodes. The neighbor nodes have direct connectivity with the main-sensor. If the source node receives acknowledgment from the neighbor nodes for their direct connection with main-sensor then that node will send its emergency-data to the nearest nodes. The nearest nodes will then send ACK_{ST} to that node for its successful data transmission to the main corresponding sensor, as described in the proposed Algorithms 4–6. But before sending data via neighbor nodes, the emergency based node will also check fitness level of the neighbor node. If the fitness level is greater or equal to required fitness value (F_{Max}) then the neighbor node will send connection request for data transmission. In other case, if the emergency based node does not receive any response from neighbor nodes then *sensor-x* or y will send direct request for allocation of timeslot for instant transmission of emergency data, as discussed in the proposed algorithms 4–6. Once the response from $Sensor_{Main}$ is received to *sensor-x* then the node will send its data to main-sensor without any delay. The emergency data transmission is performed in three phases. In the first phase, the direct connection is checked. In the second phase, the connectivity with neighbor nodes is checked while in the third phase, the time slot from $Sensor_{Main}$ is requested.

The proposed Algorithms 3–6 have suggested for ND, DoD and D-emgy, respectively, whereas they follow the similar mechanism for transmission of data to the body coordinator and further communication to Doctor. The transmission of data which is received earlier is kept prior than data received recently.

Algorithm 3: For Transmission of Low threshold readings of vital signs

Start

1. **If** Data $\leftarrow D_{Emgy}$ && Single Sensor Data **THEN**
2. **If** (Sen $_{J\ or\ K\ or\ R}$ Energy ≥ TH_{value} (p)) **THEN**
3. **If** (Sen $_{\mathbf{J\ or\ K\ or\ R}}$ **SAR**<TH_{Heat}) **THEN**
4. Send (**SETUP**$_{\mathbf{RQ}}$_$D_{Emgy)}$ $\Longrightarrow S_{Main}$
5. **If** !receive ($SETUP_{RP}$) S_{Main} **THEN**
6. Find (Alt_{Route}_D_{Emgy})
7. **If** (C_{Conn}_Sen $_{J\ or\ K\ or\ R}$ $\leftrightarrows$Allowed **THEN**
8. Receive (C_{conn_Ack}_Sen $_{J\ Or\ K\ Or\ R}$) D_{Emgy}
9. Sen $_{J\ Or\ K\ Or\ K}$ $\leftleftarrows$ D_{Emgy}
10. Ack_{ST} $\rightrightarrows D_{Emgy}$
11. **END**
12. **Else**
13. **If** !receive (**SETUP**$_{\mathbf{RP}}$) Sen $_{\mathbf{j\ or\ k\ or\ r}}$ **THEN**
14. Sen_x_**R** (**T**$_{\mathbf{Slot}}$**_S**$_{\mathbf{Main}}$**)**
15. **If** (T_{Slot}_S_{Main}) $\leftarrow$Allocated **THEN**
16. Receive (C_{conn_Ack}_ Sen $_{J\ Or\ K\ Or\ R}$) D_{Emgy}
17. Sen $_{J\ Or\ K\ Or\ R}$ $\leftleftarrows D_{Emgy}$
18. ACK_{ST} $\rightrightarrows D_{Emgy}$
19. **END**
20. **Else**
21. **If** (Sen-i$\leftarrow D_{Emgy}$ && G_{Rate}_Ea && Sen-j $\leftarrow D_{Emgy}$ && G_{Rate}_Re) **THEN**
22. **If** (Sen $_{J\ or\ K\ or\ R}$ Energy ≥ TH_{value} (p)) **THEN**
23. **If** (Sen $_{\mathbf{J\ or\ K\ or\ R}}$ **SAR**<TH_{Heat}) **THEN**
24. **CALL Steps 4 to 18**
25. **END**
26. **Else**
27. **If** (Sen-i $\leftarrow D_{Emgy\_L}$ && G_{Rate}_Ea && Sen-j $\leftarrow D_{Emgy\_L}$ && G_{Rate}_Ea) **THEN**

    OR

28. **If** (Sen-i $\leftarrow D_{Emgy\_L}$ && G_{Rate}_Ea && Sen-j $\leftarrow D_{Emgy\_L}$ && G_{Rate}_Re) **THEN**

    OR

29. **If** (Sen-i $\leftarrow D_{Emgy\_L}$ && G_{Rate}_Re && Sen-j $\leftarrow D_{Emgy\_L}$ && G_{Rate}_Re) **THEN**
30. **If** (Sen $_{J\ Or\ K\ Or\ R}$ Energy ≥ TH_{value} (p)) **THEN**
31. **If** (Sen $_{J\ Or\ K\ Or\ R}$ SAR<TH_{Heat}) **THEN**
32. **CALL Steps 4 to 18**
33. **END**
34. **Else**
35. **If** (Sen-i $\leftarrow D_{Emgy\_L}$ && G_{Rate}_Re && Sen-j $\leftarrow D_{Emgy\_L}$ && G_{Rate}_Ea) **THEN**
36. **If** (Sen $_{J\ Or\ K\ Or\ R}$ Energy ≥ TH_{value} (p)) **THEN**
37. **If** (Sen $_{J\ Or\ K\ Or\ R}$ SAR<TH_{Heat}) **THEN**
38. **CALL Steps 4 to 18**
39. **END**
40. **END**

Algorithm 4: For transmission of High threshold readings of vital signs

1. **If** (Sen-i $\leftarrow D_{Emgy\_H}$ && G_{Rate}_Ea && Sen-j $\leftarrow D_{Emgy\_H}$ && G_{Rate}_Ea) **THEN**
OR
2. **If** (Sen-i $\leftarrow D_{Emgy\_H}$ && G_{Rate}_Ea && Sen-j $\leftarrow D_{Emgy\_H}$ && G_{Rate}_Re) **THEN**
OR
3. **If** (Sen-i $\leftarrow D_{Emgy\_H}$ && G_{Rate}_Re && Sen-j $\leftarrow D_{Emgy\_H}$ && G_{Rate}_Re) **THEN**
4. **If** ($Sen_{J\ Or\ K\ Or\ R}$ Energy $\geq TH_{value}$ (p)) **THEN**
5. **If** ($Sen_{J\ Or\ K\ Or\ R}$ SAR<TH_{Heat}) **THEN**
6. Send (**$SETUP_{RQ}$**_D_{Emgy}) $\Longrightarrow S_{Main}$
7. **If** !receive ($SETUP_{RP}$) S_{Main} **THEN**
8. Find (Alt_{Route}_D_{Emgy})
9. **If** (C_{Conn}_$Sen_{J\ or\ K\ or\ R}$ $\leftrightarrows$Allowed **THEN**
10. Receive (C_{conn_Ack}_$Sen_{J\ Or\ K\ Or\ R}$) D_{Emgy}
11. $Sen_{J\ Or\ K\ Or\ K}$ $\leftleftarrows D_{Emgy}$
12. Ack_{ST} $\rightrightarrows D_{Emgy}$
13. **END**
14. **Else**
15. **If** !receive (**$SETUP_{RP}$**) $Sen_{j\ or\ k\ or\ r}$ **THEN**
16. Sen_x_**Ʀ (T_{Slot}_S_{Main})**
17. **If** (T_{Slot}_S_{Main}) $\leftarrow$Allocated **THEN**
18. Receive ($C_{conn\_Ack\_}$ $Sen_{J\ Or\ K\ Or\ R}$) D_{Emgy}
19. $Sen_{J\ Or\ K\ Or\ R}$ $\leftrightarrows D_{Emgy}$
20. ACK_{ST} $\rightrightarrows D_{Emgy}$
21. **END**
22. **Else**
23. **If** (Sen-i $\leftarrow D_{Emgy\_H}$ && G_{Rate}_Re && Sen-j $\leftarrow D_{Emgy\_H}$ && G_{Rate}_Ea) **THEN**
24. **If** ($Sen_{J\ Or\ K\ Or\ R}$ Energy $\geq TH_{value}$ (p)) **THEN**
25. **If** ($Sen_{J\ Or\ K\ Or\ R}$ SAR<TH_{Heat}) **THEN**
26. **CALL Steps 6 to 20**
27. **END**
28. **END**

Algorithm 5: For transmission of Low & High threshold readings of vital signs

1. **If** (Sen-i $\leftarrow D_{Emgy\_L}$ && $G_{Rate_}$Ea && Sen-j $\leftarrow D_{Emgy\_H}$ && $G_{Rate_}$Ea) **THEN**

   OR

2. **If** (Sen-i $\leftarrow D_{Emgy\_L}$ && $G_{Rate_}$Ea && Sen-j $\leftarrow D_{Emgy\_H}$ && $G_{Rate_}$Re) **THEN**

   OR

3. **If** (Sen-i $\leftarrow D_{Emgy\_L}$ && $G_{Rate_}$Re && Sen-j $\leftarrow D_{Emgy\_H}$ && $G_{Rate_}$Re) **THEN**
4.   **If** ($Sen_{J\ Or\ K\ Or\ R}$ Energy $\geq TH_{value}$ (p)) **THEN**
5.   **If** ($Sen_{J\ Or\ K\ Or\ R}$ SAR<TH_{Heat}) **THEN**
6.   Send (**$SETUP_{RQ}$**_D_{Emgy}) $\Longrightarrow S_{Main}$
7.   **If** !receive ($SETUP_{RP}$) S_{Main} **THEN**
8.   Find (Alt_{Route}_D_{Emgy})
9.   **If** (C_{Conn}_$Sen_{J\ or\ K\ or\ R}$ $\leftrightarrows$ Allowed **THEN**
10.   Receive (C_{conn_Ack}_$Sen_{J\ Or\ K\ Or\ R}$) D_{Emgy}
11. $Sen_{J\ Or\ K\ Or\ K}$ $\leftleftarrows D_{Emgy}$
12. Ack_{ST} $\rightrightarrows D_{Emgy}$
13. **END**
14. **Else**
15.   **If** !receive (**$SETUP_{RP}$**) $Sen_{j\ or\ k\ or\ r}$ **THEN**
16. Sen_x**_R (T_{Slot}_S_{Main})**
17.   **If** (T_{Slot}_S_{Main}) $\leftarrow$Allocated **THEN**
18.   Receive ($C_{conn\_Ack\_}$ $Sen_{J\ Or\ K\ Or\ R}$) D_{Emgy}
19. $Sen_{J\ Or\ K\ Or\ R}$ $\leftleftarrows D_{Emgy}$
20. ACK_{ST} $\rightrightarrows D_{Emgy}$
21. **END**
22. **Else**
23. **If** (Sen-i $\leftarrow D_{Emgy\_L}$ && $G_{Rate_}$Re && Sen-j $\leftarrow D_{Emgy\_H}$ && $G_{Rate_}$Ea) **THEN**
24.   **If** ($Sen_{J\ Or\ K\ Or\ R}$ Energy $\geq TH_{value}$ (p)) **THEN**
25.   **If** ($Sen_{J\ Or\ K\ Or\ R}$ SAR<TH_{Heat}) **THEN**
26.   **CALL Steps 6 to 20**
27.   **END**
28. **END**

Table 3 NS-2 parameters used in simulation

Parameter	Value	Parameter	Value
Channel rate	250 kbps	Type of Traffic	CBR
Data transmission rate	20 kbps and 40 kbps	Power consumption during Transmission	25–210 mW
Number of nodes	14	Cycle between turning-ON/OFF radio signal	0.5 ms
Body coordinator/sink	1	Energy consumption in sleep	0.0049 mW
Buffer size of body coordinator	1800 bytes	Energy consumption in receiving mode	1.69 mW
Buffer size of node	1500 bytes	Simulation coverage area	2.5×3 m^2
Max PHY packet size	127 bytes	Simulation Time (s)	300
CCA time	8 symbols	Scheduling algorithm	TDMA and CSMA/CA

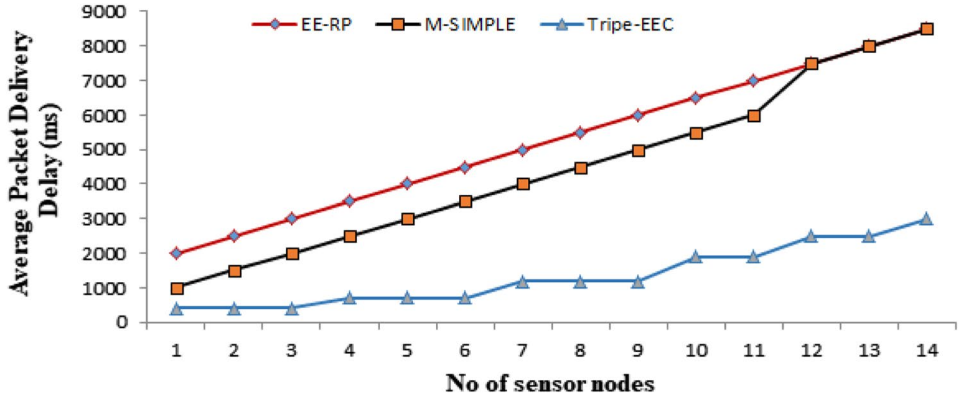


Fig. 5 Average packet delivery delay vs No. of sensor nodes with data rate 20 kbps

Algorithm 6: For transmission of High & Low threshold readings of vital signs

1. **If** (Sen-i ← D_{Emgy_H} && G_{Rate}_Ea && Sen-j ← D_{Emgy_L} && G_{Rate}_Ea) **THEN**
OR
2. **If** (Sen-i ← D_{Emgy_H} && G_{Rate}_Ea && Sen-j ← D_{Emgy_L} && G_{Rate}_Re) **THEN**
OR
3. **If** (Sen-i ← D_{Emgy_H} && G_{Rate}_Re && Sen-j ← D_{Emgy_L} && G_{Rate}_Re) **THEN**
4. **If** (Sen $_{J\ Or\ K\ Or\ R}$ Energy ≥ TH_{value} (p)) **THEN**
5. **If** (Sen $_{J\ Or\ K\ Or\ R}$ SAR<TH_{Heat}) **THEN**
6. Send (**$SETUP_{RQ}$**_D_{Emgy}) ⟹ S_{Main}
7. **If** !receive ($SETUP_{RP}$) S_{Main} **THEN**
8. Find (Alt_{Route}_D_{Emgy})
9. **If** (C_{Conn}_Sen $_{J\ or\ K\ or\ R}$ ⇆ Allowed **THEN**
10. Receive (C_{conn_Ack}_Sen $_{J\ Or\ K\ Or\ R}$) D_{Emgy}
11. Sen $_{J\ Or\ K\ Or\ K}$ ⇇ D_{Emgy}
12. Ack_{ST} ⇉ D_{Emgy}
13. **END**
14. **Else**
15. **If** !receive (**$SETUP_{RP}$**) Sen $_{j\ or\ k\ or\ r}$ **THEN**
16. Sen_x_Ʀ (**T_{Slot}_S_{Main}**)
17. **If** (T_{Slot}_S_{Main}) ← Allocated **THEN**
18. Receive ($C_{conn\_Ack\_}$ Sen $_{J\ Or\ K\ Or\ R}$) D_{Emgy}
19. Sen $_{J\ Or\ K\ Or\ R}$ ⇇ D_{Emgy}
20. ACK_{ST} ⇉ D_{Emgy}
21. **END**
22. **Else**
23. **If** (Sen-i ← D_{Emgy_H} && G_{Rate}_Re && Sen-j ← D_{Emgy_L} && G_{Rate}_Ea) **THEN**
24. **If** (Sen $_{J\ Or\ K\ Or\ R}$ Energy ≥ TH_{value} (p)) **THEN**
25. **If** (Sen $_{J\ Or\ K\ Or\ R}$ SAR<TH_{Heat}) **THEN**
26. **CALL Steps 6 to 20**
27. **END**

END

Output: The emergency data after priority analysis is sent to main-sensor

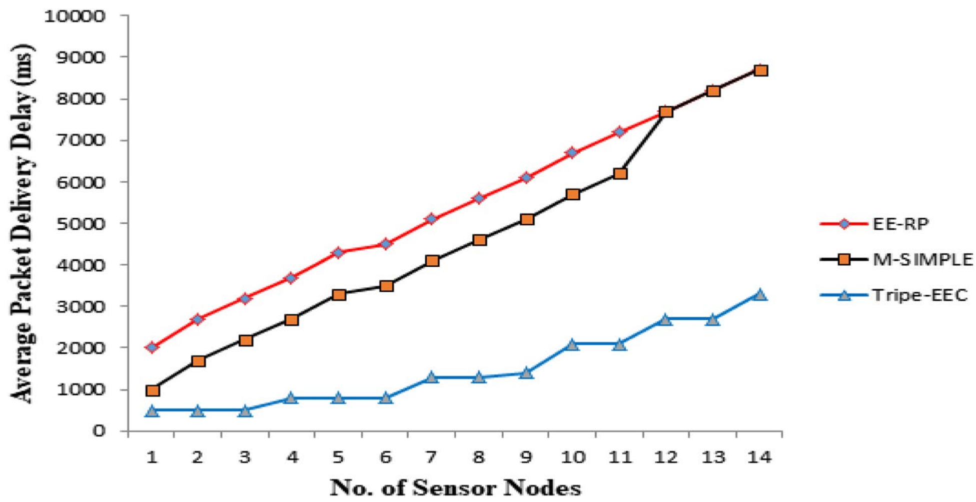


Fig. 6 Average packet delivery delay vs No. of sensor nodes with data rate 40 kbps

4 Performance evaluation

The extensive simulation have been performed to evaluate the performance of the proposed Tripe-EEC routing protocol in WBAN in the realistic medical environment. Table 3 presents simulation parameters which have used in NS-2 underpackage *nsallinone-2.34*. There are fourteen nodes installed in simulation coverage area of 2.5×3 m^2 and all nodes report their data to the body coordinator which are connected in the mesh topology. Furthermore, the data communication channel rate is 250 kbps while type of traffic for transmission is CBR. The scheduling algorithms are CSMA/CA and TDMA used for non-emergency and emergency based nodes, respectively. IEEE 802.15.4 technology is used in this simulation. The simulation has run for 300 s. The proposed Tripe-EEC protocol is based on the proposed algorithms as aforementioned and the performance of these algorithms are compared with M-SIMPLE Khanna et al. (2018) and EE-RP Roy et al. (2017) in terms of packet delivery delay, packet delivery delay for delivery-driven packets, throughput; and energy consumption of nodes and the body coordinator.

4.1 Simulation metrics

The following simulation performance metrics are used for evaluation of performance of the proposed Tripe-EEC with state-of-the-art routing protocols.

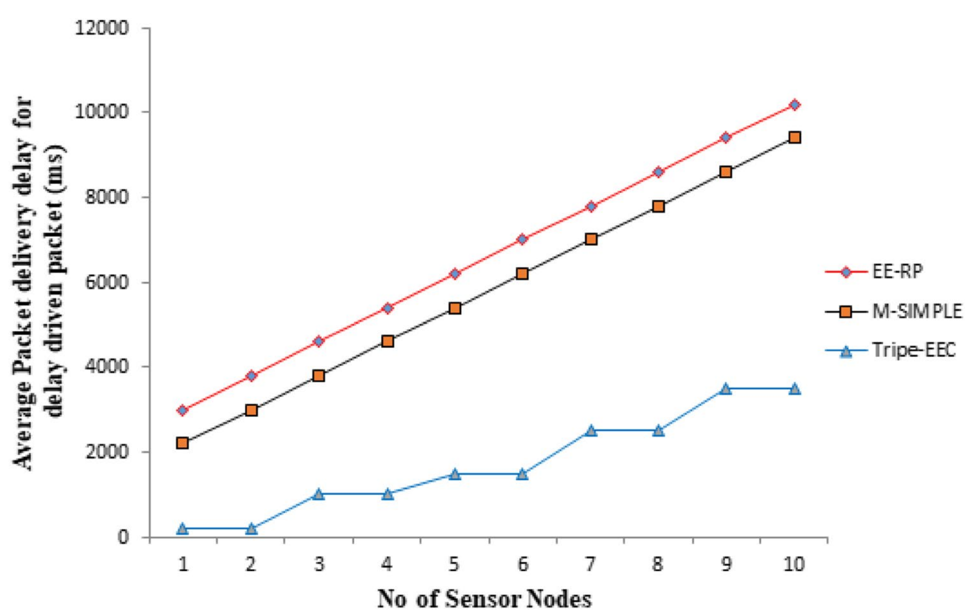


Fig. 7 Average packet delivery delay for emergency data vs No. of sensor nodes with data rate 20 kbps

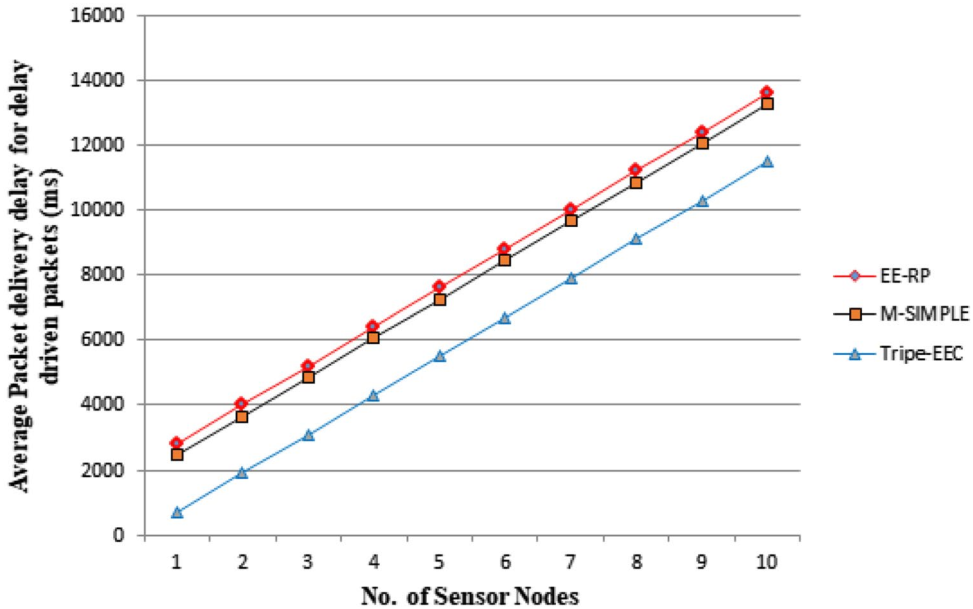


Fig. 8 Average packet delivery delay for emergency data vs No. of sensor nodes with data rate 40 kbps

4.1.1 Packet delivery delay and delay-driven for packets

The sensory data of patient's body comprises of non-emergency data and emergency data. The non-emergency data is associated with normal packet delivery while emergency data is associated with delay-driven data packets. Therefore, the packet delivery delay and delay-driven packets can be defined as time is measured between the source node and the recipient node for packet transmission.

4.1.2 Throughput

The emergency and non-emergency based nodes transmit data packets in unit of bits per second successfully to the destination node. The same performance parameter is used for ND, DOD and ED.

4.1.3 Energy consumption

The energy consumption of the deployed nodes and the body coordinator is the lowest as compared to other schemes. So the energy consumption can be defined as the total amount energy consumed of nodes and the body coordinator in different activities like monitoring of vital signs, selection of optimal path and data transmission.

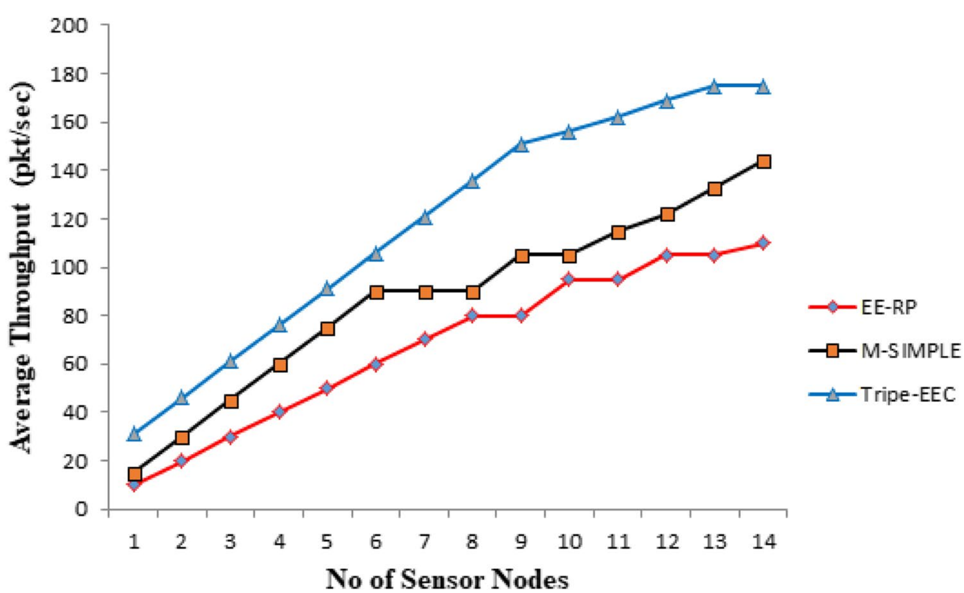


Fig. 9 Throughput vs No. of sensor nodes

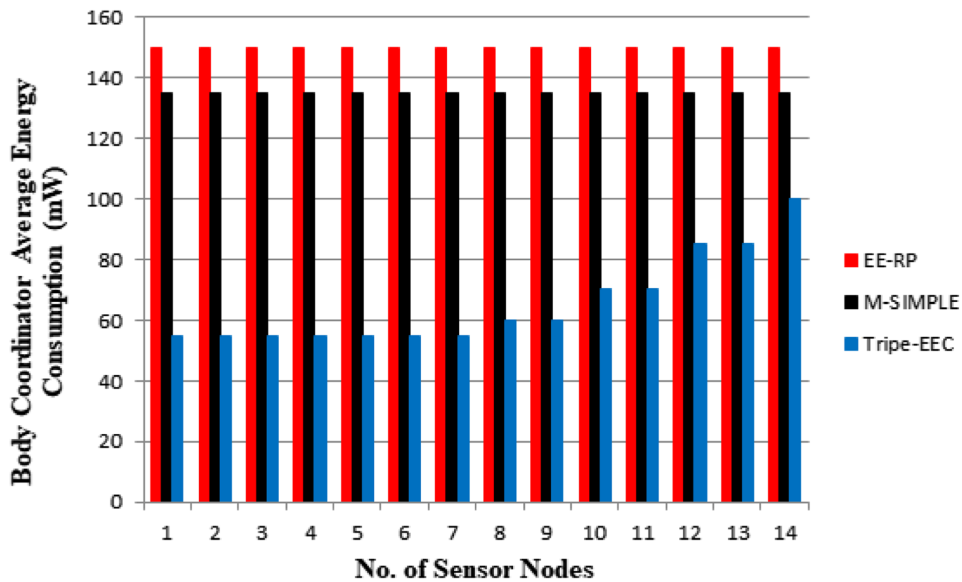


Fig. 10 Body coordinator energy consumption vs No. of sensor nodes

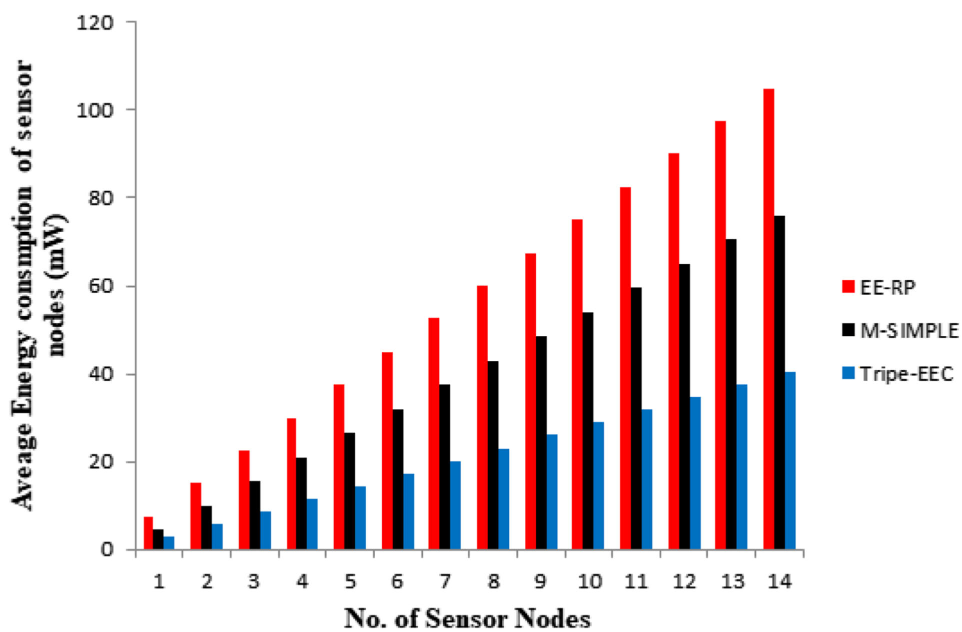


Fig. 11 Sensor nodes energy consumption vs No. of sensor nodes

5 Results analysis and discussion

This section briefly explains results of the proposed Tripe-EEC routing protocol and compare with state-of-the-art routing protocols.

5.1 Average packet delivery delay

The non-emergency based sensor nodes packet delivery delay of the EE-RP (Roy et al. 2017) is high due to checking of various conditions before transmission of data, as shown in Fig. 5. In addition, this scheme does not classify the patient's data into different levels as specified in the proposed Tripe-EEC protocol due to which it has no specify policy to transmit on alternate routes as compared to the Tripe-EEC routing protocol. Similarly, the delay in delivering of packet of M-SIMPLE (Khanna et al. 2018) is comparatively low as compared to Roy et al. (2017) but it is high as compared to Tripe-EEC protocol due to no path allocation for transmission of high priority data. Tripe-EEC protocol performs better and allocates dedicated paths to each type of patient's data and transmission of emergency data on the priority basis without conflicting situations. The generation rate of data is 20 kbps.

The packet delivery delay is also measured with 40kbps transmission rate. Both scheme M-SIMPLE (Khanna et al. 2018) and EE-RP (Roy et al. 2017) has increased delay as number of traffic increases for traffic generation, as shown in Fig. 6. In addition, the proposed Tripe-EEC protocol faces delay in transmission of packet but comparatively it is very low to M-SIMPLE (Khanna et al. 2018) and EE-RP (Roy et al. 2017) due to different paths allocation based on the types of patient's data and transmission is performed with priority basis. The 20 kbps is the amount of speed for generation of data while 40 kbps is also showing generation rate with high speed as compared to 20 kbps. The aim of these generation rates is to measure how much load can accept by the proposed protocols and state-of-the-art routing protocols with low and high data rates.

5.2 Average packet delivery delay for delay-driven packets

The delay-driven packets means low and high threshold readings of vital signs, known as emergency data. All schemes have experienced with emegency data and the delay for emegency data is very minimum of the proposed Tripe-EEC protocol compartively to the M-SIMPLE (Khanna et al. 2018) and EE-RP (Roy et al. 2017) because of the proposed protocol assigns dedicated paths to transmit data and allocation of paths on the priority-basis which removes the conflict of allocation of paths, as shown in Fig. 7. SIMPLE (Khanna et al. 2018) and EE-RP (Roy et al. 2017) uses same paths for all types of patient's data for transmission. Due to this reason the proposed protocol performs better in terms of reducing relay.

Figure 8 shows performances of all three schemes with 40 kbps data transmission rate. Due to frequently generation and transmission of data with high rate increases delay for emergency data as shown in Fig. 8. However, the proposed protocol performs better as compared to SIMPLE (Khanna et al. 2018) and EE-RP (Roy et al. 2017), as shown in Fig. 8.

5.3 Throughput

The packet delivery to the *main_sensor* is the important aim by designing alternate paths to avoid hotspot nodes and path loss, as aforementioned in Fig. 3. The proposed Tripe-EEC transmits all types of patient's data without delay, path loss and without dropping of the packets, as depicted in Fig. 9. At the beginning of traffic transmission of the proposed routing protocol, the performance is very high but its performances are downing gradually as more nodes transmit data to the *main_sensor*, as shown in Fig. 9. Comparatively, the performance of the proposed routing protocol is better than M-SIMPLE (Khanna et al. 2018) and EE-RP (Roy et al. 2017) by assigning alternate paths if there is hotspots nodes in the designated paths. In addition, the emergency data is transmitted on the priority-basis without blocking data transmission of other nodes. However, M-SIMPLE (Khanna et al. 2018) and EE-RP (Roy et al. 2017) schemes assign paths to non-emergency data without caring of emergency data if it needs to transmit on the priority basis in life critical situation of patient. Due to this, their performances in delivering of data packets have reduced as compared to the proposed scheme, as shown in Fig. 9.

5.4 Energy consumption

The state-of-the-art routing schemes are M-SIMPLE (Khanna et al. 2018) and EE-RP (Roy et al. 2017) consume a high energy of the body coordinator, as shown in Fig. 10. The reason is the increased number of traffic generation by EE-RP (Roy et al. 2017) which affects the performance in terms of high path loss causing packet delay in delivery and requires a high energy consumption to re-establish the paths and re-transmit the delayed/dropped packets. Similarly, M-SIMPLE (Khanna et al. 2018) has same limitations and the body coordinators are not able to go in sleep mode due to increased number of packets retransmission. Moreover, the frequently changing of paths and path losses introduce delay in packet delivery by consuming a high energy of nodes and in the same situation the body coordinator takes decision for changing of path due to which the nodes become hotspots. These different activities as aforementioned consume a high energy of nodes of both schemes, as shown in Fig. 10. The energy consumption of the proposed Tripe-EEC performs better for the body coordinator due to classified patient's data into different types, assigns alternate paths if there is any hotspot node and transmission of emergency data is transmitted on the priority-basis without delay, drop and re-transmission. Thus, the energy consumption of the proposed routing protocol is very optimal as compared to the existing schemes, as depicted in Fig. 10.

The continuous monitoring of vital signs consumes a high energy of sensor nodes. However, the deployed sensors transmit the sensory data periodically depends on the health criticality of a patient. Thus, the energy consumption of state-of-the-arts protocols such as and EE-RP (Roy et al. 2017) M-SIMPLE (Khanna et al. 2018) are very high due to continuous monitoring and delay in re-transmission of the collided data packets which happens of network congestion of sensory data transmission of other nodes, as depicted in Fig. 11. Similarly, the energy consumption is also high due to waiting of sensory's data for selection of the appropriate paths which is usually verified based on types of patient's data. These reasons reduce performance of the existing schemes in terms of high energy consumption due to other factors as discussed. Furthermore, the energy consumption of the proposed Tripe-EEC is also high but comparatively, it is very low to both schemes, as shown in Fig. 11. The justifications are the efficient designs of the proposed algorithms for delay-aware path selection, handling of temperature rise issues and priority based path selection for transmission of critical data.

6 Conclusion

This paper has presented a traffic priority based delay-aware and energy efficient routing protocol for WBAN, along with different proposed algorithms for transmission of non-emergency data, on-demand data and low and high threshold readings of vital signs as emergency data. The path's calculation equation is based on the efficient energy technique which reduces energy consumption of the selected path. Similarly, if the threshold of energy of the designated path is sufficient, then at the same time also verifies temperature of the whole path in advance for reduction of energy consumption of the network as described in Eq. 1. Furthermore, the allocation of paths to readings of low and high threshold of vital signs is based on the priority with the support of Eq. 2 which removes conflict if readings of two vital signs are generated at the same time. The proposed Tripe-EEC performs better in terms of reduction in delay of the packet delivery for normal packets and emergency packets. In addition, the energy consumption is very optimal of the proposed schemes as compared to the state-of-the-art schemes due to continuous monitoring of health and transmission of sensory data.

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