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Energy Efficient Routing Solution (EERS) for Wireless Body Sensor Network Considering Critical Situations

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Abstract: The need for communication becomes mandatory during critical conditions of the patient. The wireless body sensor node dies due to its power starving nature and becomes unavailable when it is in need. Considering this problem, the lifetime of the network has been increased by choosing relay node based on the energy status of the relay node. The patient state is classified into normal and abnormal state based on the data from the sensor. The data from the HB and ECG signal are cross correlated with the patient reference signal. The patient state is realized as a Finite State Machine (FSM) and analyzed with markov model. Under abnormal condition the network is realized as star topology and all sensors are awakened and close monitoring is done. The node reserves a part of energy for monitoring critical condition of patient. The proposed Energy Efficient Routing Solution (EERS) is compared with existing protocols. The algorithm outperforms the other algorithm in terms of lifetime by 1.26 times, throughput by 1.12, when compared with M-ATTEMPT and avoid energy hole problem. The algorithm serves to be the better solution for uninterrupted monitoring of patient in critical condition.

Key words: Wireless Body Sensor Network (WBSN), energy efficient, Markov Model and Finite State Machine (FSM), outperforms, EERS

INTRODUCTION

The Wireless Body Sensor Network (WBSN) has become the mandatory stuff for monitoring in countries with lack of medical facilities. The patient in a out of hospital should be monitored without having a feel of being monitored. The feel of being monitored is cleared by the use of WBSN. The WBSN nodes senses the physiological signal of the subject and transmits to the Central Monitoring Unit (CMU). The CMU transmits the signal to the sink, a primary monitoring system. The health assistant should always be inline with the primary monitoring unit to sense the abnormality of the patient (Akyildi *et al*., 2002; Kanagachidambaresan and Chitra, 2015; Javaid *et al*., 2013; Razzaque *et al*., 2011; Zhou *et al*., 2008). The WBSN serves the purpose of monitoring children's activities inside the smart home, elderly andpost surgical patients and sport's person monitoring (Javaid *et al*., 2013). The sensor nodes either implanted or worn over the body surface to monitor the physiological events. Table 1 shows the type of the sensor and its bandwidth requirement.

Table 1: Physiological parameters characteristics

Physiological parameter	Data type	Power consumption	Band-width
ECG	288 kbps	Low	100-1000 Hz
EMG	300 kbps	Low	0-10,000 Hz
EEG	43.2 kbps	Low	0-1 Hz
Blood pressure	16 bps	High	0-150 Hz
Temperature	120 bps	Low	0-1 Hz

These sensor nodes are powered using the rechargeable batteries. The rechargeable power sources makes the sensor node power starving in nature. Figure 1 shows the typical architecture of the WBSN (Zhou *et al*., 2008; Javaid *et al*., 2013; Braem *et al*., 2009; Qiao *et al*., 2007; Linz *et al*., 2010; Ali *et al*., 2008; Otal *et al*., 2008). All energy of the node is used at the initial condition itself. Hence, the node lacks with energy when the patient switches to abnormal condition and fails to communicate on critical condition (Fig. 1).

Increase in size of the battery compromises the size constraint, increase in size makes the node unsuitable to be worn or implanted creating a feel of being monitored to the patients. Providing an increased lifetime without compromising the size is the major challenge in the design

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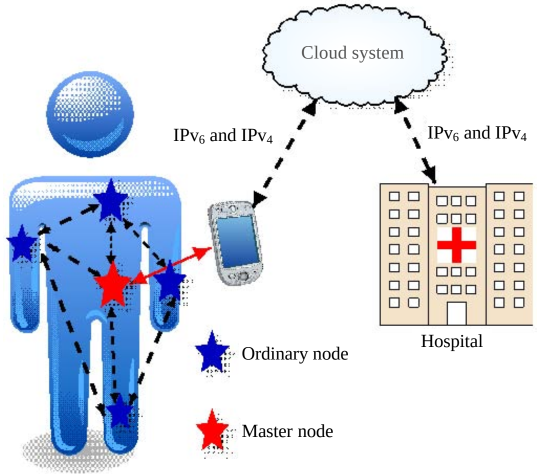

Fig. 1: Wireless body sensor network architecture

of WBSN. The uninterrupted communication is very make the node to loose its energy and the node becomes unavailable when it is really in need mandatory, when the patient is under critic condition. The loss of communication during critic conditions may lead fatal condition to the subject. Early usage of nodes (Kuryloski *et al*., 2009; Otal *et al*., 2009; Kanagachidambaresan *et al*., 2012; Dhulipala *et al*., 2012). This study concentrates in providing a novel algorithm which enhances the lifetime of the network and provides a uninterrupted communication when the patient is under abnormal condition. The patient condition is classified to states based on the basic signals. Any abnormality in the signal signifies that the state of the patient is abnormal. The sensors attached in the body surface are scheduled to find the status of the subject. Markov model helps in predicting the status of the subject for effective scheduling of nodes.

Literature review: Many algorithms had been proposed regarding energy efficient communication on WBSN. The basic WBSN concentrates in providing the connection to the sink irrespective the energy of the node, distance of communication and status of the subject. The algorithm proposed in (Akyildiz *et al*., 2002; Kanagachidambaresan and Chitra, 2015; Javaid *et al*., 2013) discusses providing data communication to the subject during the critical situations. However the algorithm does not provide solution to the subject under enhanced lifetime. Several physiological sensors works in coordination for monitoring the patient. The algorithm proposed in (Abdur) discusses the multihop communication. The data is hoped through the high energy node. The data-centric multiobjective QoS-aware routing protocol (Zhou *et al*., 2008) discusses the optimal scheduling of nodes, the packet is classified as NP and CP. The M-ATTEMPT algorithm proposed by Javaid *et al*. (2013) concentrates on providing reliable solution to WBSN. The residual energy, delay time are concentrated on choosing cluster head. However, the algorithm proposed does not concentrate in providing reserved energy for critical condition usage. The sensors like electro cardiograph, Pulse Rate (PR), Heart Beat (HB), SpO_2, internal temperature, external temperature. Scheduling of all sensors throughout is unnecessary, hence the primary sensors HB and PR are scheduled throughout. Any abnormality in these signals will immediately tell the status of the subject.

Finite State Machine (FSM): The state of the node is modeled as active, sleep and reserved states. In active state, the energy of the node is high and active. When the node energy is below a particular limit, the node goes to sleep state. The minimum limit of setting the energy limit is said as reserved energy. There is always a quantum of energy reserved for the use of monitoring subject under abnormal condition. When the patient state is normal, the primary nodes are made active and remaining nodes are made to communicate I am alive packet. When the node looses its energy to a particular limit it goes to the reserved state. The network follows mesh topology when it in normal state and the network follows star topology when the subject condition is in abnormal state. Figure 2 shows the FSM realization of the proposed algorithm.

Markov model: The proposed FSM in Fig. 2 is realized by a Markov model. The Markov model is a memory less model. The transition of one state to other state is based on the current input and not on the past interaction. The markov model does not require any memory. Since, the transition of the subject are purely based on the current input parameters and not based on the past interaction. The operation of the sensor node is realized as the Markov model. Probability of choosing x state to y state for n steps is given by:

$$P_{xy} = P_r\,(P_n = y|P_0 = x) \quad (1)$$

Equation 1 denotes the next state transition in Markov chain. The probability of single-step transition from x to k is given by:

$$P_{xk} = P_r\,(P_1 = y|P_0 = x) \quad (2)$$

Equation 2 represents the time homogenous transition from one state to other. The r step transition is chosen based on Eq. 3. For a time-homogeneous Markov chain.

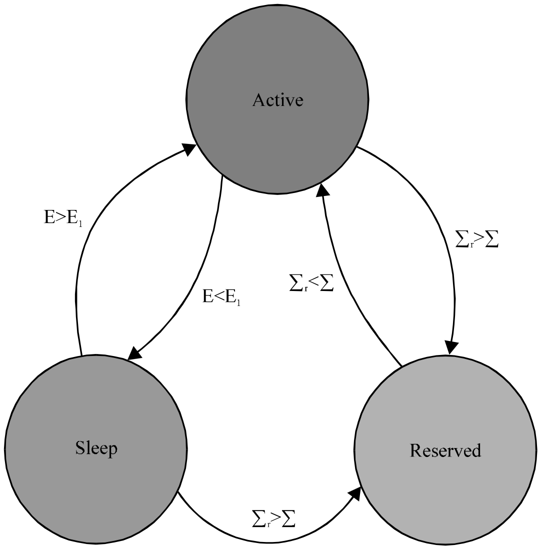

Fig. 2: Finite State Machine (FSM) realization of sensor node

$$P_r (P_n = y) = \sum_{r \in s} P_{ry} P_r (P_{n-1} = r) \quad (3)$$

Generalized probability of choosing r steps is Eq. 4:

$$P_r(P_n = y) = \sum_{r \in s} P_{ry} P_r (P_0 = r) \quad (4)$$

The probability P of transition from one state to other is represented by the matrix given in Eq. 5. The Pr11 indicates probability of transition from states in FSM after r steps:

$$P = \begin{matrix} & S1 & S2 & S3 \\ S1 \\ S2 \\ S3 \end{matrix} \begin{pmatrix} P_r 11 & P_r 12 & P_r 13 \\ P_r 21 & P_r 22 & P_r 23 \\ P_r 31 & P_r 32 & P_r 33 \end{pmatrix} \quad (5)$$

Figure 3 shows the typical architecture of sensor node. The sensor node is equipped with two transceivers; main transceiver and wake up transceiver. The main transceiver is a high energy consuming subsystem, it consumes more energy for transmitting data. The wake up energy transceiver is mainly used for sharing I am alive packet, it is a low energy consuming subsystem. The distance of communication of a wakeup transceiver is very much less when compared to the main transceiver.

The pseudo code of the proposed EERS algorithm is shows in Fig. 4. The Electro Cardio Graph (ECG), Heart Beat (HB), Pulse Rate (PR), SpO2, T_i, T_e, Glucometer (G) are used for monitoring the subject. The HB and ECG signals are considered as the primary sensors, the value of the sensors are cross correlated with the subject initial state.

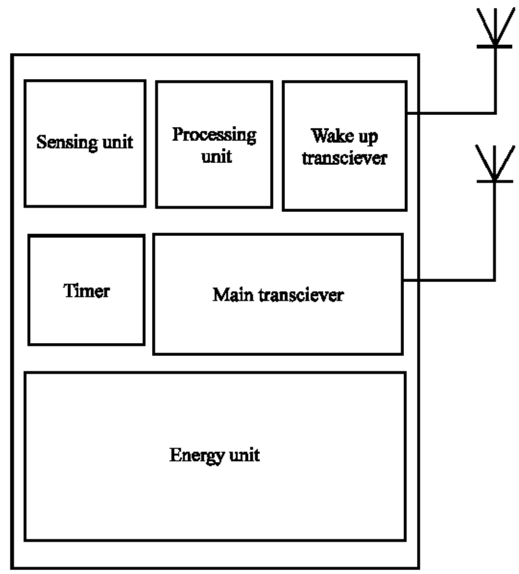

Fig. 3: Sensor node architecture

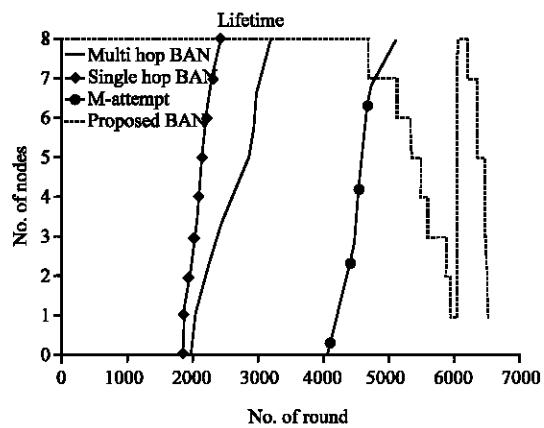

Fig. 4: Network lifetime

Energy efficient routing solution algorithm: The subject HB and ECG sensors are taken as the primary sensor for monitoring the state of the subject. The values from these two sensors are cross correlated with the subject normal signal and the state is determined. The other sensors embedded with the subject is kept in sleep state and the sensors transmit the I am alive packet to the CMU to check the availability of the sensor. The network follows mesh topology during this condition. The node with high energy is hops the data towards sink. The SN acts as the transceiver (i.e.) full functioned device till it reaches the reserved energy. The sensor node on reaching the reserved energy point, it moves to sleep state. The remaining energy of the node is saved for monitoring the patient during abnormal condition. Once the cross correlation coefficient exceeds a prescribed limit, the system goes to the abnormal state. All sensor are awakened and follows the star topology. The system under abnormal condition follows star topology till the total energy goes to zero. The residual energy of the node is determined by the location of the patient, total number of bits transmitted by the corresponding node and the distance between the location of the subject to the nearest medic centre. The patient will be rescued within the decay of the residual energy to zero. The state transition of the subject is determined by markov model using the equation.

Algorithm

Pseudo code energy efficient routing solution

Definition:

```
    HB→Heart Beat; ECG→Electro Cardiograph; S→SpO2; Ti→Internal
    Temperature
    Te→External Temperature; G_ Glucometer
    S1→Normal State
    S2→Abnormal State
    εr→Ross correlation coefficient
    ε→Cross correlation coefficient upper limit
    Er→Reserve energy
    E1→Upper energy limit
    d→Distance between sender to CMU
    d0→Distance upper limit
Input:    HB, ECG
Output:   State (S1&S2)
Begin process:
    cross correlate (HB,ECG)
if1(εr<ε)
          state→S1;
          if2(E>Er)
                if3(d>d0)
                      choose relay having E>E1; //following mesh
                      topology
                else
                      transmit data to the sink;
          end if3
else
        sleep;
        transmit I am alive packet;
     end if2
 else
      state→S2;
      awake all nodes;
      transmit data to the sink; //following star topology
  end if1
END PROCESS
```

Mathematical proof: Total number of energy dissipated is given in Eq. 6:

$$E_{total} = E_{tx}+E_{rx} \quad (6)$$

Considering 1st order radio model:

$$E_{tx}(k, d) = E_{elec}k+E_{fs}kd^2;\ d<d_0 \quad (7)$$

Table 2: Simulation parameters

Parameters	Values
Simulation results and network parameters	
Network size	160×80 cm^2
Number of nodes	8
E_{elec}	50 nJ/bit
Efs	10 pJ/bit-m^2
Initial energy	2 J
Probability of becoming a cluster head	0.1
Normal data message size	2000 bytes
Critical data message size	4000 bytes
Header bytes	50 bytes

$$E_{tx}(k, d) = E_{elec}k+E_{mp}kd^4;\ d>d_0 \quad (8)$$

Equation 7 and 8 represents energy dissipated by the transceiver on transmitting a bit of data:

$$E_{rx}(k) = E_{elec}k \quad (9)$$

Equation 9 represents the energy dissipated by the transceiver on receiving a bit of data. Equation 7-9 represent that the amount of energy dissipated is directly proportional with number of bits and distance. On reducing the distance between the nodes the amount of energy is minimized. On scheduling the nodes based on the subject status, the amount of bit transmitted is reduced thereby the energy is minimized saving it for critical situations.

Calculation of residual energy: The residual energy is calculated based on the distance between the medic centre and the present location of the subject as per (Eq. 10):

$$\text{Residual energy} \propto \text{No. of packets to be communicated} \times \frac{\text{Distance between subject and medic center}}{\text{Speed of ambulamce}} \quad (10)$$

Network model: The proposed algorithm is simulated in Matlab. The SN are deployed in 160×80 cm^2. The energy dissipated by the node is given in Eq. 7-9. The deployment of nodes is given in Table 2.

The data communicated to the CMU is low, since only the primary nodes are made active, remaining nodes only share the I am alive packet to the CMU. Hence, the energy dissipated by the nodes during normal condition is low. The nodes under abnormal condition dissipated high energy since, all nodes are active and transmits its full data to the CMU forming a star topology (Fig. 4).

RESULTS AND DISCUSSION

The proposed algorithm is evaluated in Matlab 7.0. The proposed EERS algorithm is compared with basic star

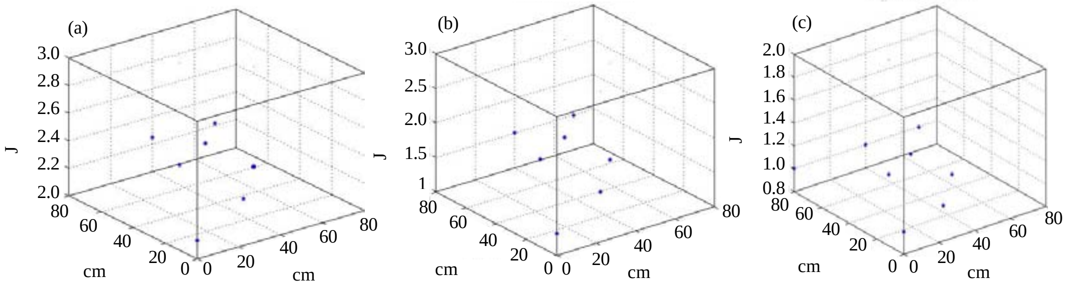

Fig. 5: a) Energy status after 2000 rounds; b) Energy status after 4000 rounds and c) Energy status after 8000 rounds

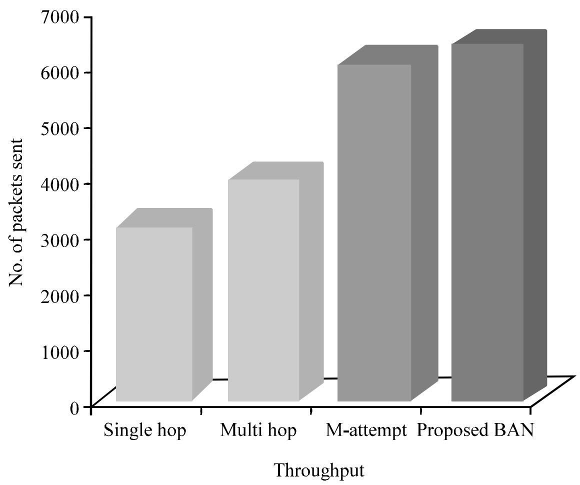

Fig. 6: Throughput of the network

based WBSN, Multihop WBSN, M-ATTEMPT routing protocols. The proposed algorithm outperforms the other algorithms in terms of lifetime. Figure 4 shows that the proposed algorithm outperforms the other algorithm in means of lifetime. The first dead node in case of the proposed algorithm is far away from the other algorithms. The algorithm works till the reserved energy and goes to the sleep state. The status of the subject is transited from normal state to the abnormal state by markov model at round 6000. All the nodes are awakened and the node transmits the data following star topology till the reserved energy is lost. The residual energy is calculated based on the type of the node and the amount of event occurring based on Eq. 10. The node is allowed to transmit, receive and transceive energy till it reaches the reserved energy state. The reserved energy is utilized during the critical condition of the patient.

Figure 5a-c shows the total amount of energy consumed by the nodes after every 2000 rounds. The nodes having low size of data bit is used as transceiving node as per the proposed EERS algorithm. Figure 5c shows the amount of energy dissipated after 6000 rounds. The network works satisfying close monitoring during critical condition. Figure 6 shows the amount of data shared to the CMU in case of all algorithms. The EERS outperform the M-ATTEMPT by 1.26 times in means of lifetime and 1.12 times by throughput.

CONCLUSION

The proposed EERS algorithm serves to be the key for energy efficient and monitoring of subject in critical condition. EERS algorithm outperforms the other algorithm in terms of lifetime by 1.26 times and with increased throughput with 1.12 times when compared with M-ATTEMPT protocol. The EERS algorithm also serves the close monitoring of patient during critical conditions. The real time testing of the proposed algorithm is in progress.

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