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REEC: Reliable Energy Efficient Critical data routing in wireless body area networks

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***Abstract*—Energy efficient routing is important for increasing the lifetime of Wireless Body Area Networks (WBANs). Uniform load distribution is necessary for reliable and long term monitoring of patients in WBANs. In this paper, we propose Reliable Energy Efficient Critical data routing in WBANs (REEC). We deploy eight nodes and a sink on the human body. Two forwarder nodes are used which reduce the communication distance between nodes and the sink. The nodes send only critical data to the forwarder nodes. In order to distribute the load uniformly, forwarder nodes are selected/rotated in each round. Simulation results show that the proposed protocol achieves increased network lifetime and throughput. Therefore, REEC is useful for reliable health monitoring in WBANs.**

Keywords: Wireless; Body; Area; Networks; WBANs, Forwarder; Energy; Efficiency; Critical

I. Introduction

A Wireless Body Area Network (WBAN) presents a solution to the problems related to health care. It consists of miniaturized, low power and intelligent sensor nodes deployed on, in or around the human body to monitor different body functions and the surrounding environment. In this paper, we use the term sensor, node and sensor node interchangeably. Each node has enough capability to process and forward information to base station for diagnosis and prescription. A WBAN offers two main advantages for patients'monitoring. The first benefit is location independent monitoring and the second is mobility of patients without any interruption.

There are a number of applications of WBANs ranging from biomedical to soldiers'and players'monitoring in the field. The nodes placed on the human body sense vital parameters like pulse rate, body temperature, glucose level, electromyography (EMG), electrocardiography (ECG), electroencephalography (EEG), etc. Later on, this information is sent to the medical centre for diagnosis and treatment.

In this paper, we propose REEC for efficient monitoring of patients in WBANs. The proposed protocol utilizes two forwarders Ψ_α and Ψ_β which collect the data of other nodes, aggregate it and route it to the sink. REEC routes only critical data of the patients. We define critical data as the abnormal data that demands immediate medical aid and treatment of the patient.

II. Related Work

G. R. Tsouri *et al.* [1] propose augmented efficiency for global routing in WBANs. Augmented efficiency is a new link cost, designed for balanced energy consumption in WBANs. It causes substantial improvement in the network lifetime. Authors in [2] suggest a new cross layer communication protocol for WBANs called Cascading Information Retrieval by Controlling Access with Distributed slot Assignment (CICADA). It consumes less energy and is designed for mobile WBANs. Moreover, this protocol forms a network tree in a distributive manner. This tree is used to route data to the sink with guaranteed collision free access to the medium. M. Quwaider *et al.* [3] present an opportunistic store and forward packet routing protocol for WBANs with frequent postural partitioning. They develop a location based routing protocol. Their protocol achieves better routing delay performance.

Energy-Balanced Rate assignment and Routing Protocol (EBRAR) is presented in [4]. It is an energy efficient routing protocol in which routing is based on the residual energy of nodes. As a result, instead of one fixed path, data is intelligently sent through different routes by equally distributing the load among the nodes. E. Reusens *et al.* [5] focus on increasing the network lifetime by relaying and cooperation techniques. First, the relay nodes perform relaying of traffic only so that, more energy is available for communication purposes. Furthermore, the relays cooperate in forwarding the data from nodes to the sink. Authors in [6] suggest a scheme in which nodes are grouped into a number of clusters. There is a cluster head (CH) in each cluster which is responsible for collecting the data from nodes. CH aggregates the collected data and sends it to the sink. Virtual groups are formed in [7] between devices of doctors, nurses and patients for efficient patients'monitoring. These groups are formed and modified according to the requirements of patients and doctors. Authors propose a new metric named as Quality of Health Monitoring. Data is efficiently collected using their proposed model.

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III. Motivation

Different routing schemes are used in WBANs like single-hop, multi-hop and minimum-hop etc. However, these techniques are not as energy efficient as needed. In single-hop routing scheme, distant nodes die faster as compared to nodes nearer to the sink. On the other hand, in multi-hop and minimum-hop routing schemes, the nearer nodes die earlier as they have more data to route. Authors in [8] present Mobility-supporting Adaptive Threshold-based Thermal-aware Energy-efficient Multi-hop Protocol (M-ATTEMPT). It uses multi-hop scheme for routing data from sensor nodes to sink. It is a thermal aware routing protocol which selects a new route after a hotspot detection. However, the hotspot detection causes more energy consumption. Q. Nadeem *et al.* propose Stable Increased-throughput Multi-hop Protocol for Link efficiency in Wireless Body Area Networks (SIMPLE) [9] to overcome the deficiencies in M-ATTEMPT. It selects a new forwarder in each round that receives and aggregates the data of other nodes and routes it to the sink. However, this protocol burdens the single forwarder node by routing all the data through it. In SIMPLE, nodes send data continuously which is unnecessary in most of the scenarios in WBANs. Therefore, we present REEC which uses two forwarders in each round. In the proposed protocol, nodes send only critical data and avoid the transmission of redundant data. It saves energy of nodes resulting in longer network lifetime. So vital signs of the human body are monitored for longer time.

TABLE I
Energy Parameters of Transceivers

Parameter	nRF 2401A	CC2420	Units
DC current (TX)	10.5	17.4	mA
DC current (RX)	18	19.7	mA
Supply voltage (min.)	1.9	2.1	V
$\Delta_{TXelect}$	16.7	96.9	nJ/bit
$\Delta_{RXelect}$	36.1	172.8	nJ/bit
ε_{amp}	1.97	271	nJ/bit/m^n

IV. Radio Model

There are different radio models in the literature. We use first order radio model given in [10]. The equations for first order radio model are given below:

$$\Delta_{TX}(\kappa,\ell) = \Delta_{TXelect}(\kappa) + \varepsilon_{amp}(\kappa,\ell) \tag{1}$$

$$\Delta_{TX}(\kappa,\ell) = \Delta_{TXelect}.\kappa + \varepsilon_{amp}.\kappa.\ell^2 \tag{2}$$

$$\Delta_{RX}(\kappa,\ell) = \Delta_{RXelect}(\kappa) = \Delta_{RXelect}.\kappa \tag{3}$$

Where Δ_{TX} is the energy consumed in transmission process. Δ_{RX} is the energy consumed by the receiver. $\Delta_{TXelect}$ and $\Delta_{RXelect}$ are the energies required to run the electronic circuit of transmitter and receiver, respectively. ε_{amp} is the energy required by the amplifier circuit whereas κ is the packet size. The distance between transmitter and receiver is represented by ℓ.

In WBANs, the communication medium is human body which introduces attenuation to the radio signals. Therefore a path loss coefficient parameter n is included in the radio model. Equation for the transmitter energy consumption is:

$$\Delta_{TX}(\kappa,\ell) = \Delta_{TXelect}.\kappa + \varepsilon_{amp}.\kappa.\ell^n \tag{4}$$

Energy parameters depend upon the hardware of the system. We consider two transceivers, Nordic nRF 2401A and Chipcon CC2420 that are used frequently in WBANs. The energy parameters for these transceivers are enlisted in table I.

V. REEC: Proposed Protocol

In this section, we describe the proposed routing protocol. One of the major challenges in WBANs is to increase the network lifetime for continuous monitoring of patients. REEC consumes energy efficiently that leads to increased network lifetime. The detail is given in the following subsections.

A. Deployment of Nodes

In the proposed protocol, eight nodes are deployed on the human body. All nodes are homogeneous $i.e.$ having equal initial energy. The sink is placed on the abdomen of the human body as shown in fig. 1. The information from sink is sent to the physician via internet for inspection and diagnosis. It is also sent to the ambulance service office for immediate help in case of emergency. Medical server stores the patients'data for future purposes. The whole scenario of WBAN is shown in fig. 1.

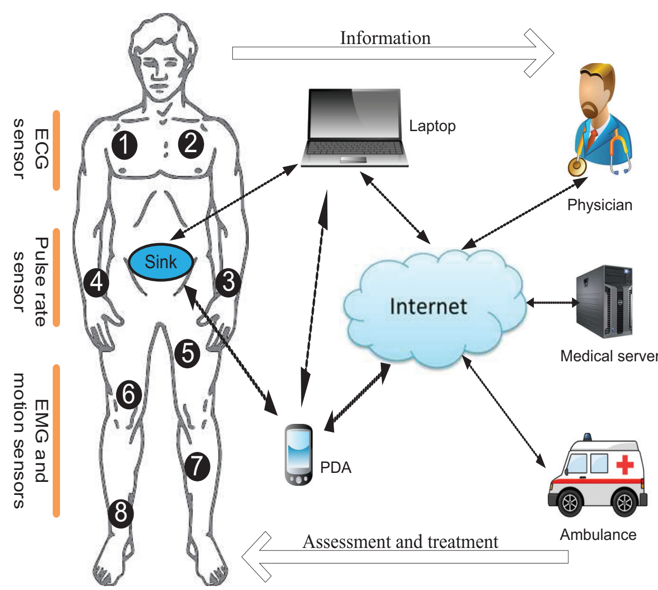

Fig. 1. Deployment of nodes on human body in WBAN

B. Start-up Phase

In this phase, sink broadcasts a short information packet which contains the location of sink on the human body. Each node receives this packet and stores the location of the sink. Afterwards, each node broadcasts a packet which contains the ID of node, its location and residual energy status. In this way, all nodes are updated with the location of neighbouring nodes and the sink.

C. Forwarders' Selection Phase

In this section, we present the selection criteria of the forwarder nodes. The complete set of nodes, denoted by A, is given as:

$$A = \{1, 2, 3, 4, 5, 6, 7, 8\} \tag{5}$$

In order to consume the energy efficiently, REEC uses cost function ξ to select new forwarders in each round. The ξ is calculated as:

$$\xi(i) = (\frac{\ell(i)}{\Re(i)}) \forall i \in A \tag{6}$$

Here, ℓ is the distance between the node and sink and $\Re$ is the residual energy of node. The node having minimum value of ξ is selected as forwarder. We consider two sets of nodes as:

$$\alpha = \{1, 2, 3, 4\} \tag{7}$$

$$\beta = \{5, 6, 7, 8\} \tag{8}$$

$\therefore$

$$\alpha \subsetneq A \tag{9}$$

$$\beta \subsetneq A \tag{10}$$

$$\alpha \cap \beta = \emptyset \tag{11}$$

$$A = \alpha \cup \beta \tag{12}$$

In REEC, two forwarders are selected in each round, one from α and second from β. The Ψ_α is selected from α and Ψ_β is selected from β. The total number of nodes is $\aleph$.

$$\Psi_\alpha = \aleph_{min(\xi(i))} \forall i \in \alpha \tag{13}$$

$$\Psi_\beta = \aleph_{min(\xi(i))} \forall i \in \beta \tag{14}$$

The node having minimum value of ξ is selected as a forwarder node. Sink broadcasts the IDs of Ψ_α and Ψ_β after calculating ξ. The nodes from α send their data to Ψ_α whereas nodes from β send their data to Ψ_β. The forwarder nodes aggregate the data of all the nodes and route it to the sink. In the next round, again two new forwarder nodes are selected based upon ξ. In this way, forwarder nodes rotate and all the nodes get a chance to become a forwarder. Therefore, energy is consumed more efficiently than in SIMPLE and M-ATTEMPT resulting in increased lifetime and throughput.

D. Scheduling Phase

In this phase, forwarder nodes assign Time Division Multiple Access (TDMA) based time slots to their corresponding nodes. The nodes send their data to the forwarders Ψ_α or Ψ_β in their allocated time slots. Proper scheduling of nodes minimizes their energy consumption. It also avoids collision to achieve better network throughput.

E. Data Transmission Phase

The initial energy Δ_o of all nodes is 0.5 J. The nodes send only critical data. The forwarder nodes aggregate the received data and route it to the sink. If a node possesses energy less than a threshold τ, it communicates directly to the sink. In addition, it does not further take part in the selection of forwarder. This is done to avoid energy consumption in data aggregation. If a node has shorter distance to the sink than forwarder, it routes its data directly to the sink. The nodes from α send their data to Ψ_α and nodes from β send their data to Ψ_β. The flowchart of the proposed protocol is shown in fig. 2.

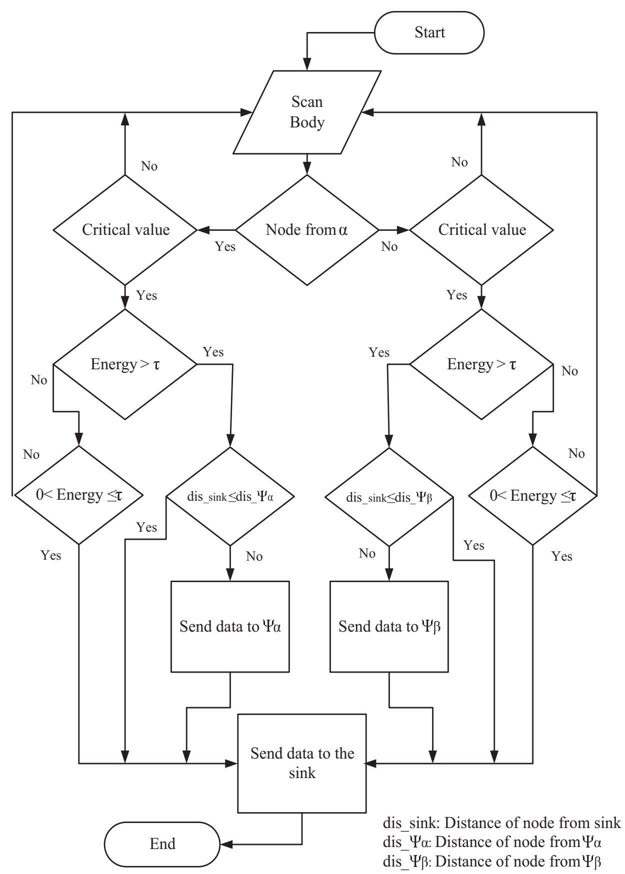

Fig. 2. Flowchart of REEC

VI. Energy Consumption Analysis

In this section, we develop equations for single-hop and multi-hop communications. Energy consumed for single-hop communication is:

$$\Delta_{SH} = \Delta_{TX} \quad (15)$$

Here, Δ_{TX} is the transmission energy as given by:

$$\Delta_{TX} = \kappa \times (\Delta_{elect} + \varepsilon_{amp}) \times \ell^2 \quad (16)$$

The energy consumed during multi-hop communication is given by:

$$\Delta_{MH} = \kappa[\aleph \times (\Delta_{TX}) + (\aleph - 1) \times (\Delta_{RX} + \Delta_{da})] \quad (17)$$

Where, Δ_{da} is the data aggregation energy and $\aleph$ is the number of nodes in the network.

VII. Experiments and Discussions

In order to verify the performance of REEC, simulations are performed five times and average results are plotted. Table II presents the simulation parameters. We ignore the sensing energy consumed by the nodes in simulation. We assume that the probability of critical data is 70%. In the simulation of REEC, we set the value of τ as 20% of Δ_o.
We study the performance of the proposed protocol in comparison with SIMPLE and M-ATTEMPT. Different performance metrics of REEC are evaluated which are discussed in the following subsections.

TABLE II
Simulation Parameters

Parameter	Value	Units
$\Delta_{TXelect}$	36.1	nJ/bit
$\Delta_{TXelect}$	16.7	nJ/bit
ε_{amp}	1.97	nJ/bit/m^2
Δ_{da}	5	nJ/bit
ℓ_o	0.1	m
κ	4000	bits
ν	2.4	GHz
Δ_o	0.5	J

A. Stability Period and Network Lifetime

The network lifetime of the proposed protocol is shown in fig. 3. Our protocol selects two forwarders in each round which aggregate the data of other nodes and route it to the sink. The proposed protocol has 25% and 159% improved stability period than SIMPLE and M-ATTEMPT, respectively. It shows that energy of all the nodes is consumed uniformly. Due to efficient energy usage, the proposed protocol also achieves the high network lifetime of about 10767 rounds.

B. Network Throughput

Throughput is the number of packets successfully received at sink. In WBANs, routing protocols are needed which give high network throughput for reliable monitoring of the patients, elderly peopole, etc. REEC consumes energy efficiently resulting in longer network lifetime. The nodes are alive for longer time and send more packets that leads to increased throughput. We use Random Uniform Model [11] for packet drop calculation. The status of communication link can be good or bad depending upon the probability. We suppose the probability of link status to be good is 0.7. The proposed protocol gives better throughput than SIMPLE and M-ATTEMPT as shown in fig. 4.

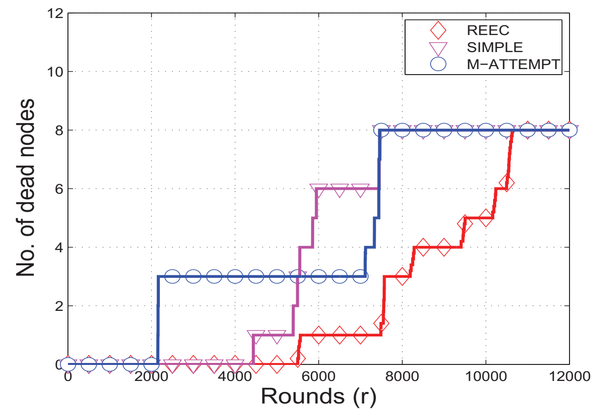

Fig. 3. Network lifetime

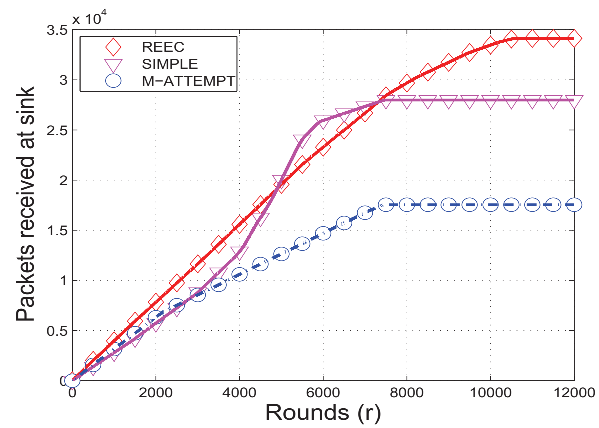

Fig. 4. Network throughput

C. Residual Energy

The residual energy of the network is shown in fig. 5. The forwarder nodes Ψ_α and Ψ_β receive the data of their corresponding nodes and route it to the sink. As nodes send critical data to the nearest forwarder node, so less energy is consumed and they stay alive for longer time. In REEC, the energy of nodes depletes slowly as shown in fig. 5.

D. Path Loss

Path loss is the difference between the transmitted and received power represented in decibels (dBs). The posture of the human body affects the electromagnetic signals. As a result, path loss shows different behaviour along different body parts. There are different models used to estimate the path loss. Path loss is a function of distance and frequency as

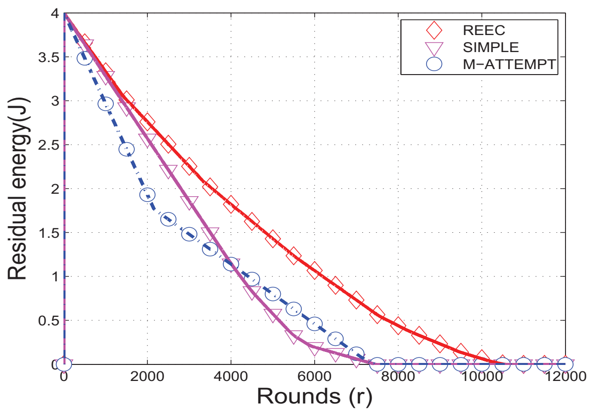

Fig. 5. Residual energy

shown below:

$$\Gamma(\nu, \ell) = \Gamma_o + 10.n.log_{10}(\frac{\ell}{\ell_o}) + X\sigma \quad (18)$$

Where Γ_o is path loss at reference distance ℓ_o and n is path loss exponent. The distance between transmitter and receiver is ℓ and ν is the frequency. X is a gaussian random variable and σ is the standard deviation [12].
Path loss at reference distance ℓ_o can be expressed as:

$$\Gamma_o = 10.log_{10}(\frac{4.\pi.\ell_o}{\lambda})^2 \quad (19)$$

Here, λ is wavelength of electromagnetic waves.
Fig. 6 shows the path loss in each round for the proposed protocol. In simulation, we use a fixed ν of 2.4 GHz from ISM band. We use the values of n and σ as 3.38 and 4.1, respectively.
The improvement in percentage provided by the proposed protocol to M-ATTEMPT and SIMPLE is shown in table III.

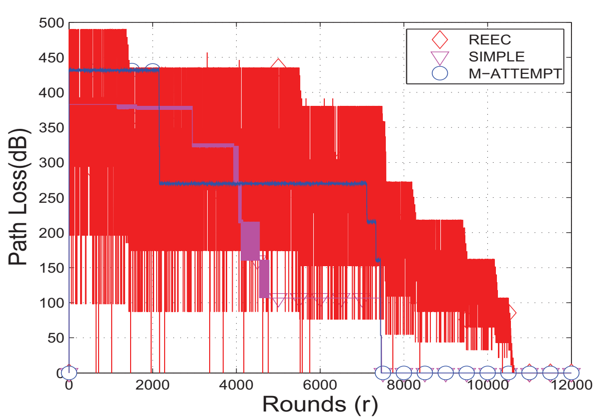

Fig. 6. Path loss

TABLE III
IMPROVEMENT IN PERCENTAGE

Parameter	Improvement (%) in M-ATTEMPT	Improvement (%) in SIMPLE
Stability period	159	25
Network lifetime	45	44
Throughput	94.4	22
Average residual energy	25.3	30.4
Average path loss	41	44

VIII. CONCLUSION

We propose REEC, a new routing protocol for WBANs which utilizes energy efficiently. Nodes send their data to forwarders which route it to the sink. The forwarders are selected on the basis of a cost function in each round. The node having minimum value of cost function is selected as a forwarder. The nodes send only critical data and save energy. They do not deplete their energy soon and stay alive for longer time. Simulations show that the proposed protocol achieves improved network lifetime, stability period and network throughput. We are aiming to implement the proposed technique on real experimental test bed in future.

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