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Adaptive PEH-QoS Aware Management Control Scheme Based on Peltier and Piezoelectric Hybrid Model for WBAN Applications

Hardeep Singh Dhillon, Paras Chawla

***Abstract**: Energy harvesting in the medical field is a reliable and effective method to charge the body sensor nodes in Wireless Body Area Networks (WBANs) for medical applications. WBANs provides health monitoring with real time updates for patient's record. In WBANs, the nodes are used to detect events, which give significant contribution to maintain the Quality of Service (QoS) demands in terms of delay in packet transmission and reception, throughput and packet loss during communication. However, harvesting energy from motion of human body with health is always a challenge for WBANs. This simply increases the need to apt a new hybrid approach of Peltier and Piezoelectric human energy harvesting model for WBANs application. In recent years, a lot of researches related to Piezoelectric and Peltier that are shown in this literature. This paper proposes a hybrid approach of Piezoelectric and Peltier sensors for a WBAN Application. Work involves energy harvesting from movements and temperature gradients (body to ambient). Moreover, to use both of energies at the same time needs effective algorithm which is possible with the optimized way proposed in this paper. Proposed work uses the approach to pass emergency data to neighboring nodes if neighboring node elected as forward node. Election of forward node is selected on the basis of threshold level (α). In WBAN systems criticalness of data depends upon the applications. There are some cases like heart attack, asthma attack, diabetic attack etc requires immediate attention. These cases are considered as critical in nature. As proposed work uses the concept of data forwarding even if the node has not the power to send data up to BNC. Using this concept node which needs to send critical/emergency packets with low battery condition is possible. Proposed approach enhances data delivery and reduces the packet drop.*

Keywords: WBAN, quality of service, energy harvesting, e-health, piezoelectric, peltier, body node.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) have created a wide range of fields where close interaction with objects in the physical globe is vital. The distributed sensing skills and ease of deployment that a wireless communication paradigm provides make WSNs a significant element of our daily life. WSNs are implemented in a multiple field of medical, military and home applications. Quality of Services (QoS) considered various important parameters such as delay; throughput and packet loss performed by the Body Nodes (BNs). Moreover, these networks having face space constraints to adapt continuously to the human body. The BN dimensions mostly depend upon the weight and size of the battery and battery capacity. The BN operation is comprised and finally stops due to battery level falls, as it is limited energy source. The battery must be replaced or recharged as quickly as possible to resume the operation. But it is not always feasible to replace the battery, since it might damage the BN or sometimes it can be risky for patient's health because we might not able to collect data on that interval of time. This issue is exacerbated where replacement of BN would require surgical procedures [1]. However, as long as battery power retains it increases the lifetime of the BN, this alternative is not feasible in WBANs [2]. As it would result in increasing size and make the BN bulky. Harvesting energy from the sources could give the permanent supply to the body node with some power, providing the efficient method to resolve the issue of power supply. BNs can convert non electrical energy into electrical energy such as heat and motion [4]. In principle, human-powered energy harvesters or micro generators will harvest energy from human body motions/ activities or body heat. The energy concentrations produced from these movements are distinct [5]. The applications of energy harvesters can be classified primarily according to their use whether it is medical purpose or non-medical purpose. Non-medical applications include movement and gesture detection, cognitive and emotional driving recognition for interactive gaming and fitness tracking apps. Medical applications primarily include healthcare alternatives for aging populations and diseases. Typical examples include early detection, disease prevention and tracking, home care for the elderly, post-operative rehabilitation, biofeedback applications that control mental states and assisted living apps that enhance the quality of life for disabled individuals [6]. In such cases we need harvesters that can continually collect tiny quantities of energy over a large time span through power management circuit and gives large output power in a small time. The energy collected by movements of human body, along with the required essential health signals in terms of QoS to give some major problems for Wireless Body Area Networks [7]. Moreover energy can also be harvested from other sources including kinetic, thermal and biochemical sources, in the framework of WBANs [8][9]. WBANs are primarily used in patient monitoring functions for healthcare applications.

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In these networks, the sensors are allotted in the human body with different physiological parameters, which are considered most valuable in this field [10]. Human body with wireless capabilities are of widely used application of WBAN. Sensors nodes around the body makes it possible to send or receive the wireless signals, as they provide a easy method to monitor a health status of patient over large time span to avoiding the use of bulky wires network around the patient. In general, there are distinct quantities of water in the human body tissue structure [11]. Several important performance-influencing criteria must be considered in the design stage of the WBAN energy: management policy, reliable design, energy efficient [12]. WBAN enables dynamic surveillance of physiological parameters, providing patients with higher flexibility. WBANs also provide specific time intervals of information from patient, physicians will have a clearer perspective on the status of patient's health [14].

A. Medical Applications of WBAN

Wireless Body Area Networks (WBANs) have potential to enhance the future capabilities of health monitoring through the diagnosis of many life threatening disease and real time patient monitoring [15]. Demographers have anticipated that from the population of 357 million in 1990, the world population of people over 65 years of age will increase to 761 million by 2025. This means that medical elderly care will become a significant problem by 2050. By 2009, U.S. health care spending was about 2.9 trillion, and by 2015, nearly 20 percent of gross domestic product is estimated to reach 4 trillion [16][17]. The use of WBANs in medical apps enables ongoing surveillance of critical patient's characteristics such as heart beat, temperature of body and blood pressure. In small instant of time where abnormal activity of the parameters is diagnosed, sensor information can be transfer to special gateway such as a mobile device [18]. The gateway then transmits the relevant information to a doctor room or emergency centre via internet services, where necessary action can be taken [19]. WBANs will be a better alternative for early diagnosis, monitoring and therapy of patients with deadly disease of various types, including diabetes, blood pressure and cardiovascular diseases [20].

B. Characteristics of WBAN

A node in a WBAN is described as a communication capable autonomous device. The functionality-based node classification in WBANs is as follows:

1. Personal Device (PD) –This device collects all the data obtained from sensors and actuators and manages communication with other users. The PD then tells the user on the machine or actuator via an internal gateway, display / LEDs. In many applications, the unit also known as body gateway, sink unit or Body Control Unit (BCU) [21].

2. Sensor–Sensors in WBANs evaluate parameters inside or outside the body. The present nodes are to gather and respond to data on physical stimuli, preprocess and process of data required and provide suitable information with wireless reaction. These sensors are physiological or bio-kinetic sensors [22].

Now a days, some sensors can be used as wrist watch or earphone and enable an individual to be wirelessly monitored anywhere, anytime and with anyone. The list of these sensors is EMG, EEG, ECG, Temperature, Humidity, Blood pressure, Blood glucose, Pulse Oximetry (SpO_2), CO_2 Gas Sensor, Thermistor, Spirometer, Plethysmogram, DNA Sensor, Magnetic Biosensor, Transmission Plasmon Biosensor, Motion (Gyroscope/ Accelerometer/ Tri-Axial Accelerometer) etc.[22]. When receiving information from the sensor nodes, the actuators reacts accordingly with customer. Its main function is to give feedback in the network by acting information present from the sensor, for instance by simply pumping the correct amount of dose of medicine into the body in modern healthcare applications [23].

IEEE 802.15.6 standard has preferred another node classification in a WBAN based on the suitable manner in which it is retained within the body as follows [24, 25]. The functionality, execution in the network decides the where nodes can be categorized into three different groups as follows:

1. Implant Node – The node is placed in the human body, either below the skin or within the tissue of the body.
2. Body Surface Node – This node is either positioned on or 2 centimeters away from the upper surface of the human body.
3. External Node – This node is not directly touch with the human body, but a few centimeters to 5 cm from the human body.

II. SYSTEM MODEL

A. Architecture of Body Node and Topology Section

Proposed work uses the system model for BN (body node) as shown in figure 1. Node consists of various parts like sensing unit, processor unit, storage unit, energy harvesting unit and transceiver unit. We focus on the power consumption required by BN for detection unit (E_{det}), data transmitting unit (E_{tx}), Processing unit (E_{pt}). It is assumed that BN is directly connected with Body Node Connector (BNC) in star topology. In various research BNC is the main unit which collect data from BN at specific interval of time, but in emergency conditions or even driven conditions we need BN to send data whenever required. Proposed work includes the algorithm to send emergency and even driven packets from BN to BNC. BN node is capable of charging super capacitor with the help of energy harvesting unit (Piezoelectric and Peltier).

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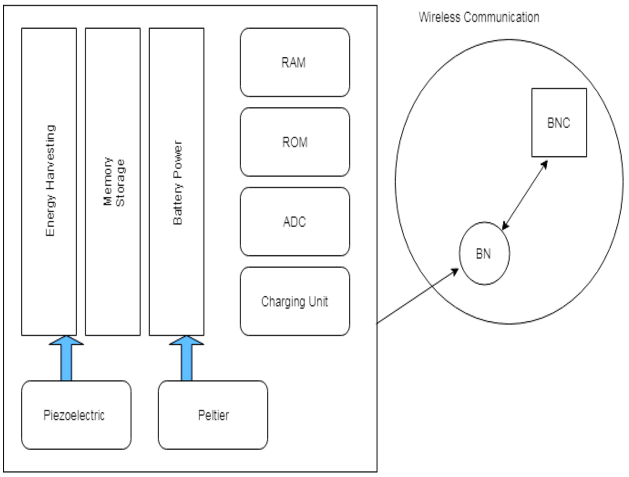

Figure 1: System Model

B. Energy Harvesting Model

This model is basically using two electronic devices (piezoelectric and peltier) for energy harvesting. Piezoelectric crystal is well known of producing power when dimensions changes, like if we make a wrist band of it and places over a wrist, it will start producing power when body is in movements. Produced power is directly proportional to the activity and movements. The best results are observed while running and the least power is produced while sleeping. On the other hand, peltier based unit will harvest power when there will be temperature gradient between body temperature and ambient temperature. Power produced by piezoelectric and peltier will be denoted as P_{pz}, P_{pt} respectively. $P_{(total)}$represents the total harvested power in our model.

$$P_{(total)} = P_{pz} + P_{pt} \quad (1)$$

P_{pz}	*Power produced by piezoelectric*
P_{pt}	*Power produced by peltier*
$P_{(total)}$	*Total Power Produced by harvester*

III. ADAPTIVE POWER-QoS AWARE MANAGEMENT CONTROL SCHEME (APEH-QoS)

The proposed Scheme is a combination of three algorithms:

1. **Adaptive Power EH aware management**, which calculate various power levels of all the units and make decisions of ON OFF states. Power management algorithm also take care of broadcast messages for adjustment nodes to self elect as forwarding node, if the power is sufficient to forward extra data. Proposed adaptive algorithm is different from PEH-QoS in terms of broadcasting self elective forward node concept. As we know some of the nodes are at the position where energy harvesting is better than rest of the nodes. With respect to this say if a node X1 has power more than it needs to execute its own operations, at this time X1 will broadcasts a message of self electing forward node to its adjacent nodes. Say X2 is a node adjacent to X1 which has low power harvesting posture. At this time X2 needs multi hop transmission to send its packet up to destination. X2 will send its packet to X1, which further send to destination after data aggregation process. X3 is the node having limited power for its own use, so this will not broadcast to self-elected node. As shown in figure below, multi hop routing.

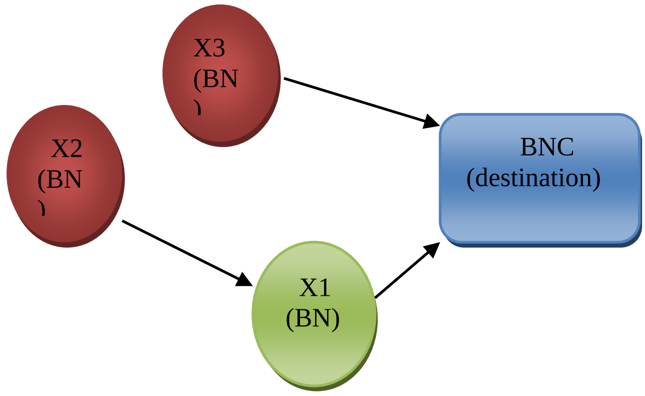

Figure 2: Multi hop Routing

Algorithm 1 Adaptive Power Management Algorithm

if *($E_{st} \geq E_{det} + E_{tx} + E_{brd}$)***then**

detection unit **ON** state
broadcast unit **ON** state

if *($N_Q \geq N_{tx}$)***then**

transceiver module to **ON** state
transmission of N_{tx}packets

else

Set transceiver module to **SLEEP** state

end

else if($E_{st} \geq E_{det} + E_{tx}$&$E_{st} < E_{det} + E_{tx} + E_{brd}$) ***then***

detection unit ***ON*** *state*
broadcast unit **OFF** state

else if($E_{st} \geq E_{det}$&$E_{st} < E_{det} + E_{tx}$) ***then***

messages queuing algorithm **ON**
detection unit **OFF**state
broad cast unit **OFF** state

else

messages queuing **OFF**
detection unit **OFF** state
broadcast unit **OFF** state

end

2. **Data Queue Aware Control** (DQAC), this part calculates the delay caused in packet to reach its destination. With clinical validity if the packet is out of time to reach at destination it automatically deletes such packets from queue. Algorithm contributes in system memory management to free the memory with deletion non useful packets.

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Algorithm 2 Data Queue Control

if *(N_Q>0)* **then**
  if *(E_{st}≥E_{tx-neg})*
    Transmit packet to neg node
else
for *(i=* 0 *:NQ)* **do**
if *(DQ(i) ≥DQmax)* **then**
Delete data packet *i*
end if
end for
end if

if Event is detected **then**
if *(NQ<SCmax)***then**
Store data packet in the queue
else if *(NQ== SCmax)***then**
Delete oldest data packet
Store new data packet in the queue
end if
end if

Abbreviations

E_{st}	*Energy stored in node super capacitor*
E_{det}	*Energy needed in even detection*
E_{tx}	*Energy needed in transmission*
E_{brd}	*Energy to broadcast self electing forward node*
N_Q	*Packets in a queue to send*
N_{tx}	*No. of packets network is able to send at a time*

3. **Packet Aggregator, algorithm** uses the amount of power stored in the unit to schedule the queue packets transmission. this ensures that valid packets of sent over the network and maximum number of packets can send at a time with particular compression technique.

IV. PERFORMANCE EVALUATION

Proposed work gets evaluated in MATLAB environment, We have created an even driven system based on BN (Body Nodes) and BNC (Body Node Connector). Taking in account two energy harvesting units i.e. piezoelectric and peltier. Evaluation is carried out in QoS constraints of medical requirements. We have taken into account four body postures to produce energy and harvest the power source. Whose data is given below in the Table-I.

TABLE I BN CHARACTERSTICS

Data and Traffic	Packet arrival time		2ms
	Data queue size		200 packets
Features	Packet size		12 bits
Power Consumption Distribution	Sensor READ-OUT and ADC		30μW
	MCU		19.25μW
	Transceiver	Reception	3.85mW
		Transmission	*4.86mW*
		Idle	*0.712mW*
		Sleep	*4μW*
QoS Requirements	Delay Constraint		*<250ms*
	Packet Loss Constraint		*<10%*

TABLE II SYSTEM PARAMETERS

Parameters	**Value**
Noise Power P_N	-94dBm
Rate Set R_{dev}	[121,243,486,971]Kbps
Transmission Power Range P	-30dBm to 0dBm
One slot length t_{slot}	0.5ms
One superframe length T	100ms
Transmission circuitry power P_{ct}	0.5μW
Number of Sensors N	5
Factor α	1.4

Four BN nodes placed on hands and legs to mark the output of energy harvesting unit in every posture. This harvested energy is further used to calculate the performance parameters of the network with communication using algorithms discussed above. Below are the tables used to simulate network with BN characteristics and network parameters.

V. SIMULATION RESULTS

Figure 1 presents the simulation results of Efficiency detection of with PEH-QoS, without PEH-QoS with compare to adaptive PEH-QoS. This shows significant improvement in efficiency detection of postures. figure 3 explains the results of data queue for adaptive PEH-QoS, data queuing is better than 21% from PEH-QoS as because of self-electing forward node strategy. Figure 4 shows 15% of improvement from PEH-QoS algorithm.

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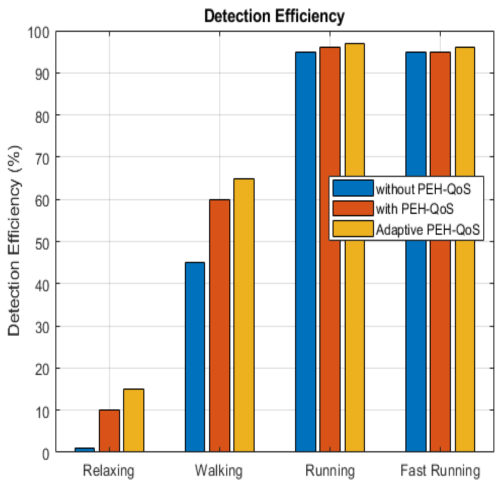

Figure 3: Detection Efficiency

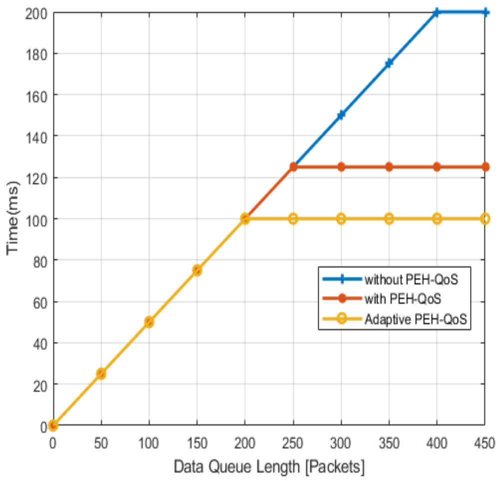

Figure 4: Data queue for adaptive PEH-QoS

Simulation results show overall improvement in all parameters for the proposed work APEH-QoS algorithm. the Table II and Table III shows that average energy harvested by piezoelectric and peltier values and four BN nodes placed at different positions of human body is analyzed. The Table V and Table VI shows the packet loss and detection efficiency respectively.

Table III. Average Energy Harvested by Piezo harvester (mW)

BN	Relaxing	Walking	Running	Fast Running
1	19.989	124.986	252.139	302.807
2	20.028	125.111	252.014	301.863
3	19.963	124.815	252.246	302.123
4	20.016	125.099	252.458	302.260

Table IV. Average Energy Harvested by Peltier harvester (mW)

BN	Relaxing	Walking	Running	Fast Running
1	2.992	7.480	10.979	20.045
2	3.011	7.521	11.032	20.024
3	3.007	7.510	11.012	19.963
4	2.982	7.481	11.045	19.969

Table V. Packet Loss

Techniques	**Packet Loss (%)**			
	12	**20**	**28**	**36**
Without PEH-QoS	50.08	55.12	60.56	60.76
With PEH-QoS	42.76	45.12	49.89	51.21
Adaptive PEH-QoS	35.21	37.35	41.22	45.06
Improvement	7.55	7.77	8.67	6.15

Table VI. Detection Efficiency

Techniques	**Detection Efficiency (%)**			
	Relaxing	**Walking**	**Running**	**Fast Runing**
Without PEH-QoS	2.1	45.2	95.3	94.1
With PEH-QoS	10.0	60.1	97.2	95.9
Adaptive PEH-QoS	15.3	65.7	98.7	96.7
Improvement	***5.3***	***5.6***	***1.5***	***0.8***

VI. CONCLUSION

Proposed work shows significant improvement with introducing the concept of forwarding node using threshold value (α). This approach contributes in emergency packets to get delivered even with low battery conditions. In direct communication node treated as dead node if the battery is below threshold value. one hop communication requires power greater than threshold value else dropped the packet.
Using Adaptive PEH-QoS enhances packet loss around 8.5% from PEH-QoS for 0.1 ON state probability. Moreover, packet loss is almost same in case of 0.2 ON state probability. Adaptive PEH-QoS enhances mean Detection Efficiency by 3.3% as compared to PEH-QoS. With all these benefits proposed Adaptive method Reduces mean packet loss with different packet size by 7.53% with respect to PEH-QoS. All these comparisons concludes that Adaptive PEH-QoS has the capability of sending emergency packets even with low battery conditions, which is very much useful in many critical situation in medical field.

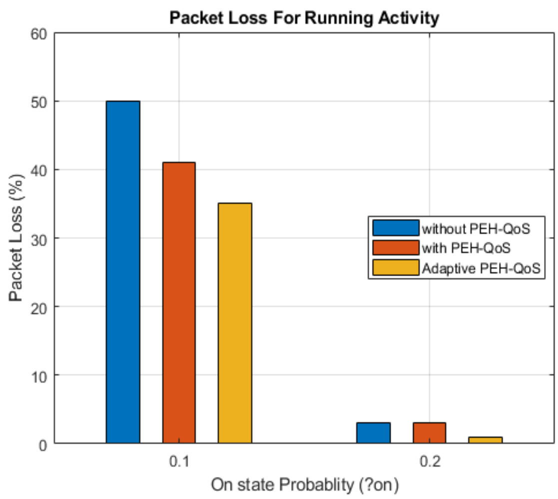

Figure 5: Packet Loss

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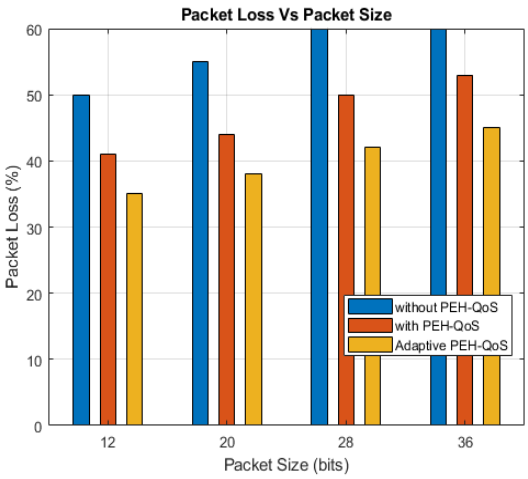

Figure 6: Packet Loss Vs Packet Size

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