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Power Challenges in Wireless Body Area Network for Mobile Health Powered by Human Energy Harvesting: A Survey

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Abstract

Objectives: This survey of energy harvesting techniques is carried out with an aim to select the best combination of energy harvesting techniques in Wireless Body Area Networks (WBAN). In this paper the scope and demands of WBAN in mobile health and the power requirements is discussed. **Methods**: The modern and future trends in healthcare have been reviewed to conclude that the Wireless body area network has become a leading solution in mobile health. The prominent use of wireless sensor networks and miniaturization of electronic and electrical devices on a regular basis has authorized the progress of wireless body area networks. **Findings:** These devices are used to provide a health monitoring on a continuous basis and real time feedback to the user and medical personnel. As these devices are wireless in nature and wide variety of sensors are available so it offers many innovative ways to improve systems involved in healthcare and quality of life. The biggest challenge in use of WBAN is the battery power requirement. Scavenging of energy in human environment has been focused on locating new tremendous ways to charge body nodes in human environment. In such networks the quality of service by considering various parameters like latency, throughput and packet loss is most important. **Application/ Improvements:** It has been concluded that various energy harvesting techniques are to be incorporated into the nodes at the time of node designing. The intelligent energy optimizing algorithms are to be used. The harvesting technique most suitable for healthcare monitoring applications is piezoelectric harvester as it provides significant power to miniaturizing electronic devices while being small and efficient.

Keywords: Ehealth, Human Energy Harvesting, Mhealth, Telehealth

1. Introduction

An ageing population and desk bound behavior is inciting the predominance of chronic diseases such as cardiovascular diseases, hypertension, and diabetes. As per the study carried out by the World Health Organization, 30 % of all deaths in the world is caused by cardiovascular diseases (about 17.5 million people in the year 2005). The study on Global Ageing and Adult Health (SAGE) of the World Health Organization (WHO) reveals that the population of aged people is increasing globally as the life expectancy is increased around the world. It is the priority for each economy to provide healthy years in their life by lowering the risk of numerous chronic diseases[1].

These types of diseases create a considerable trouble for health system and obligate the governments to invest a huge amount in cure, health infrastructure, services and workers. The burden on healthcare system is increased beyond limits in the care of aged population effected from chronic diseases[2]. Patients need regular diagnosis and help to perform basic activities for better quality of life. Increasing demands in healthcare is endeavoring pressure

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on healthcare system to provide services to check over the quality of life and mortality rate. Inadequate numbers of skilled workers and limited healthcare budgets have worsened the forthcoming healthcare crises around the world. Moreover, higher spending does not imply improved quality of service or prolonged lifetime. These economic and social drifts motivate the use of technological innovations to provide reasonable and economical healthcare solutions at the peoples' disposal to uplift and maintain their quality of life. Along with health crises the ample advancement in mobile and wireless technology in developing and developed nations is remarkable and provides a new vision in healthcare system. The Mobile health takes advantage of these advancements to carry out various functions associated with access, transmission and diagnosis of patient health. It is an excellent way to improve the existing healthcare system and improving the quality of life of the patient.

Mhealth is an advanced idea which is a component of electronic health that provides health services through mobile phones for better care of the patients[3]. Mhealth provides a new way to diagnose patients on regular basis without affecting their regular routine from a distant location. Mhealth is also an essential part of Ehealth that provides a better life with the advent of new technologies such as pacemakers, insulin pumps and provides a better treatment with little cost along with better quality of life[4]. These technologies can become more reliable by overcoming these challenges such as getting miniaturized, healthier and more protected for patients.

Wireless body area network is the evolution of telemedicine that defines the health services in new horizons i.e. telehealth a typical remote health monitoring system architecture. It consists of three tier systems that include set of sensors, the data hub and medical network. Moreover, the author describes the need of data security and integrity to provide a better health services to patients[5].

WBAN comprise of smart tiny medical devices which may be implanted in body or are the wearable ones. Various low power devices which are operational in a short range make use of IEEE 802.15.6 standard and provide services to WBAN. IEEE 802.15.6 is the latest international standard for wireless body wideband, human body communication and medium access control layers for WBAN. Three different security levels are described by this standard; level 0 is defined as unsecured communication, level 1 is defined as authentication only, level 2 is described as both authentication and communication. Moreover, increase in the payload size improves the bandwidth efficiency[5].

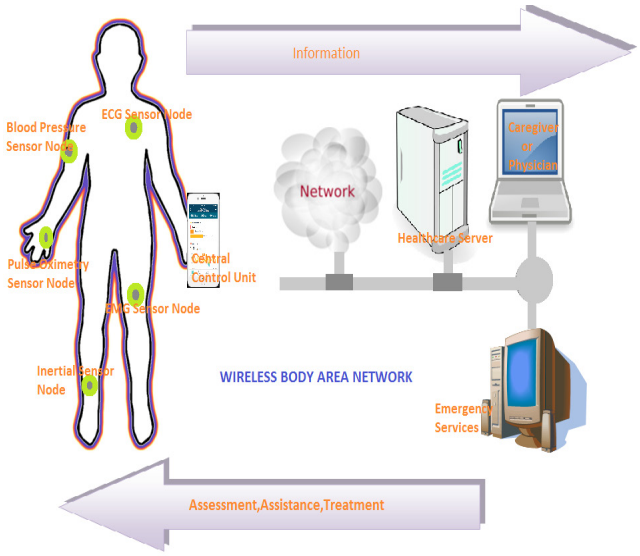

Figure 1. WBAN network.

The major responsibility of WBAN is to proficiently supervise the data transmission among all medical apparatus or equipments associated with the network. Figure 1 shows a WBAN in an Mhealth system. As shown, the gathered data is transmitted through smart phone to the remote server. WBAN will be principal operator in the development of Mhealth system. This allows remote monitoring, diagnosis and treatment of patients on regular basis without interrupting their routine life[6]. This will enhance the medical facilities and moreover increase the research potential in telemedicine, biotelemetry and use of artificial intelligence in healthcare. WBAN provides quality life along with reducing the risk of chronic diseases while decreasing the cost of health system.

The development of miniaturized Micro-Electro-Mechanical System (MEMS) based sensors and actuators for observance, diagnostic and healing purposes and advances in wireless technology exhibit modern trends in the race to conquer healthcare challenges. Our goal should be to provide health services to older people or the affected ones by monitoring their medical status and keeping them safe without forcing them to live at or near a hospital. To attain social acceptance, WBAN nodes must be protective and concise relative to conventional wireless sensor network. Moreover, as WBAN is associated with human health so the responsibility to provide

service through node is enhanced further to fidelity, security, throughput, latency and quality of service and powering body node are the major challenges for WBAN to overcome in practical world which are discussed in next sections.

2. Challenges in WBAN

To implement WBAN system in the telemedicine world, we have to remove several flaws by exploiting the recent technological advances. Medical equipments that are used to create a network are called Body Nodes (BNs). These BNs are different from one another and perform distinct functions, where each function requires dissimilar power to perform a specific task related to examination, treatment and monitoring of patient health. Therefore there arises a need for varied quality of service from each BN.

Furthermore the number of nodes and their size has to be limited as the human body nodes face space constraints. Therfore, because of limited space availibilty the function performed by each node should be exclusive and effective. To perform the functions effectively and to provide the desired power to the body nodes we need a battery capable of producing suitable power.

Since, size and weight of body nodes are directly proportional to the power capacity of battery, any effot to increase the power capacity of the battery will also increases the size and weight of body node which makes it uncomfortable for the human body to wear. There arises a challenge to make BN as small as possible so that the human body can carry it comfortabaly. Moreover, limited capacity of battery also puts a constraint at body node life span. A battery powered node can efffectively perform its function as long as battery is charged to acceptable level. But as the battery charge declines from its ample level, the task performing rate of body node also goes down. At last, the battery is drained out and the node becomes permanently inactive. To restart the proper functioning of body node, there is a need to replace battery as soon as possible, which may not be practical all the times as it may jeopardize the patient. This problem becomes more acute when the node is implanted inside the body, as this will require the patient to undergo a surgical procedure. It is illustrated that body sensor nodes work on batteries, and this is necessary to recharge battery at finite intervals to resume or to continue the body sensor operation. Replacement of battery by stopping the sensor operation in case of patients is not advised and should be avoided because it may lead to severe complications which may lead to death[7]. The increase in battery capacity may extend the life time of sensor but the battery capacity can only be increased to a limit as it strictly depends upon the size and weight of the battery and also the sensors being used.

3. Need for Energy Harvesting

The most promising solution to energy problem is energy harvesting and preferably harvesting from the host environment. Energy harvestors use specialised devices to convert the energy which is present in the sorrounding environment in the form of light, heat and vibrations etc. into electric energy[8]. It eliminates the problem of replacing or charging the battery at frequenct intervals unlike traditional battery sources and provides power to body nodes without the need of replacement at frequenct intervals. Moreover this energy is a clean energy, free from pollution and easily available in human environment.

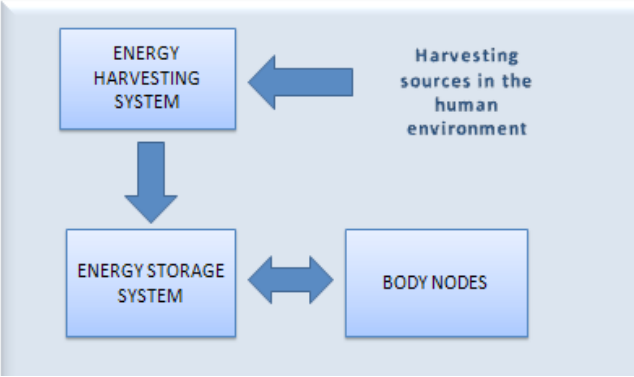

Figure 2. Energy harvesting in human environment.

Energy harvestors introduce new factors in network, that are availabilty of energy, its collection and utilization in intelligent way. When energy is extracted from human environment, the energy harvestors provide limited power as compared to the batteries. To ensure the availibilty of harvested power at required time it motivates us to store energy with capacitors or/and batteries, so that the harvested energy/power can be utilized efficiently and efectively. When the battery charging is below a specific level to perform its operation, the body nodes become inactive and it completely interrupts all tasks inside the network. To resume the operation of body nodes in network the battery needs to achieve acceptale power level and meanwhile the node is suspended from operation. From above, we can conclude that for the smooth

operation of body nodes, the intelligent exploitation of collected energy is an important factor. This has lead to the indtroduction of energy neutral operation[9], which is a state in which energy consumed is always less than the harvested energy in the network.

The wireless interface consumes a considerable amount of energy during the transmission of data to a remote location. The medium access protocol is proved to be the most genuine layer in order to address the energy efficiency related issues. Medium Access Control (MAC) layer is the sub layer in Open System Interconnection (OSI) communication model. It is the common interface to share common medium between two similar or different networks. MAC layer defines a set of procedures and protocols to resolve conflicts between different media to access the common medium. A high throughput and low delay is always desired in WBAN. In order to meet these desired requirements in an energy efficient manner a Medium Access protocol needs to be designed in an efficient manner, because it is the function of MAC to coordinate access to the nodes for wireless medium which is shared by different other nodes. Therefore, the selected MAC mechanism defines the energy utilization and its dissipation by a network[10]. The major task of MAC layer is to enhance the system quality such as throughput along with quality of service.

3.1 Scales of Energy Harvesting

For providing power to electronics circuits various energy sources are available in environment in raw form such as sunlight, temperature, vibrations, radio waves and many-more. These sources are being developed rapidly to make the electronic devices free form battery dependence. According to the need of the system energy, harvesting can be described as macro harvesting and micro harvesting. In macro level the system like solar panel and wind mill harvests high levels of power in the range of few hundreds of watt and these projects require regular maintenance, component design and heavy space. On the other side, in micro level system generates very low levels of power in the range of microwatts to few watts. These include mini projects at small level and are used to power small electronic devices that may be portable[10].

4. Vibration Energy Harvester

Vibration energy harvesting is the technique to collect otherwise waste kinetic energy resulted from any vibration or moving body and convert that into electrical energy through different methods. Based on vibration energy harvesting techniques, we come across three types of harvesters to collect energy from vibration in following patterns: electrostatic, electromagnetic and piezoelectric.

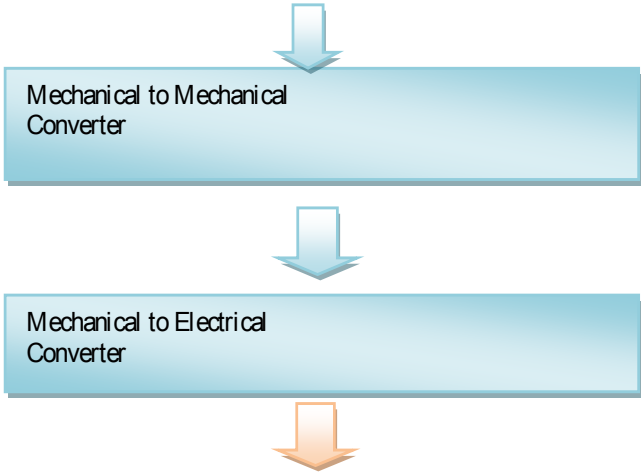

Figure 3. Two step process of vibration energy harvesting.

4.1 Electrostatic Energy Harvester

The working of this harvester depends upon the varying capacitance of vibration based capacitors. In this we are able to produce electrical energy from mechanical energy as the vibrations result in the separation of plates which are charged at varying capacitance. A polarization source is always intended by the electrostatic source to make it operational in the range of few hundreds of volts and to produce electricity by transferring mechanical energy from vibrations.

Let us assume two parallel plates having surface area 'a' and separated by distance 'd', permittivity and capacitance 'c' and charge on capacitor is given by

q = C.V; where, capacitance is function of separation between plates and surface area of plates.

$C = €_o €_d (A/d)$; Where €o is the dielectric constant of the air;

'$€_d$' is dielectric constant for the dielectric material separating the parallel plates

Initially the capacitor is charged to very low value using external polarization source. When an external mechanical force is applied against the electrostatic force between the oppositely charged plates of capacitor,

it results in the separation of plates with the decrease in capacitance as distance between the plates of capacitor is inversely proportional to its capacitance. We have 'q = C.V' relation which results in two cases, first is voltage increases when charge is constant to some value and in converse when voltage is fixed charge is increases to some value. Where charge constraint cycles are used practically. So by this means mechanical force is converted into electric current to feed a sensor[11].

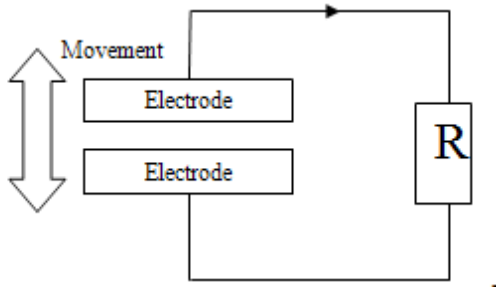

Figure 4. Electrostatic converter.

Figure 4 illustrates the mechanism in which electrical energy is harvested by variable capacitors. Grasped kinetic energy moves one of the two plates horizontally to vary the exposed surface area and hence capacitance. As kinetic energy keeps varying the position of plates and as a result charge 'q' is collected. The same process can also be induced when collected charge q is harvested as kinetic energy.

4.2 Piezoelectric Energy Harvester

Piezoelectric energy harvesting technology is becoming familiar in WBAN as this technology is very efficient to provide power to various microelectronic devices. Certain materials when come under mechanical stress or vibration they are able to generate an AC (alternating current) or when subjected to AC (alternating current) starts producing vibrations. This effect of producing AC and vibrations is termed as piezoelectric effect. These piezoelectric materials are available in many forms such as thin films, thick films and single crystals or in powder form. This technique produces voltage in the range of 2 to 10 volts.

Dikshit et al. presents the basics of piezoelectric property as it is the property of material in which mechanical pressure is converted into voltage. Since single piezoelectric crystal provides voltage in milli volts range. To obtain higher voltages piezoelectric crystals are arranged in series. In this paper two important techniques are stressed out, energy harvesting through piezoelectric wind mill and increasing bandwidth of crystal[11,12].

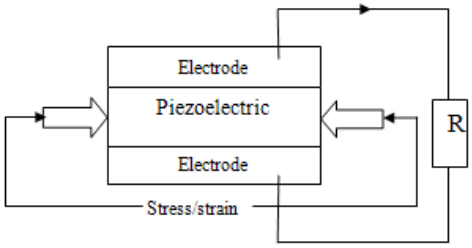

Figure 5. Piezoelectric converter.

4.3 Electromagnetic Energy Harvester

According to Faraday's law of electromagnetic induction when a conductor moves across a magnetic field, it will develop a potential difference between its terminals as it cuts the magnetic field lines. This transduction mechanism is based on using kinetic energy to create relative motion between a conducting wire and a magnetic field i.e. in electromagnetic induction in which an electromotive force is produced due to relative motion between coil and magnet, and so corresponding current is produced in the coil. The relative motion between coil and magnet will affect the current induced in the coil. The induced current also depends on the number of coil turns. This produces a very low voltage current in the range of 0.1V [12].

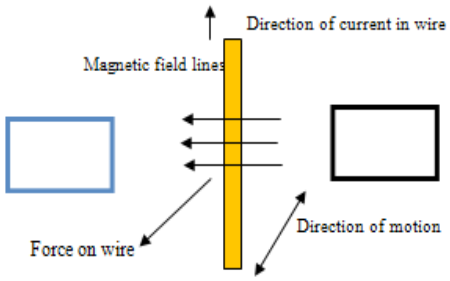

Figure 6. Electromagnetic converter.

Figure 6 illustrates the basic principle of electromagnetic induction, here voltage V = - (d⍰/dt); Where voltage generated for a coil having N number of turns and is given by, V = - N (d⍰/dt). Where '⍰' is magnetic flux per coil turn.

For electromagnetic harvesting, relative position of coil with respect to the magnetic field source is changed

Table 1. Comparison of different vibration based energy harvesting techniques[11]

Features	Piezoelectric	Electrostatic	Electromagnetic
Separate Voltage source	Not required	Required	Not required
Energy Density	Highest energy density	Energy density increases with a decrease in the separation of capacitor plates	Energy density is low
Output Voltage achieved	approximately (2-10)V	approximately (2-10) V	Outputs only up to 0.1 V
MEMS Implementation	Difficult MEMS implementation	Easy to be implement in MEMS	Difficult tointegrate with MEMS
Frequency Dependence	Highly frequency dependent	No dependence	No dependence
Issues	Possible bio compatibility issue	Requires initial polarizing charge	May interfere with other electromagnetic principle base medical equipments such as MRI
Other features	Materials can be expensive	Initial charge is to be provided	Bulky in size

by using kinetic energy and magnetic field source which varies magnetic flux as a function of displacement.

Hence, output voltage can be expressed as V_{out} = - N [(d⍰/dt) (dx/dt)]; Where, (dx/dt) is the rate of change of relative displacement.

Piezoelectric and electrostatic devices are proved to be a boon in case of small scale energy harvesters (<1-10 cm^3). On the contrary in case of larger devices electromagnetic converters are considered to be a better option[13,14].

5. Solar Energy Harvester

Solar power based on photovoltaic effect provides a significant amount of power with proper orientation of panel plates. Availability of light is significant problem in solar energy harvester. On the other hand, the body nodes sensor and devices which can be implantable or wearable under clothes may hinder the performance of harvester[14]. Moreover, the solar panel needs a large area for installation which may not be compatible with small size body nodes. Also it is not easy to carry the bulky solar pannel system along with the human subject under observation.

6. Thermoelectric and Pyroelectric Energy Harvester

In thermoelectric effect there exists a conversion from temperature change into electric current or voltage. In this one end of material is kept at one temperature and other end is kept at another temperature. This difference in temperature results in potential difference across the device. In case of pyroelectric effect, whole body attains a particular temperature and variation in temperature results in temporary voltage i.e. when the body is cooled or heated. The position of atoms in the crystal body will change with the change in temperature of body as the polarization of material changes which results in temporary voltage. So the basic principle behind this power source is thermal gradient between body temperatures and ambient across a thermopile i.e. the power generator converts temperature difference into electricity[14]. Since our body maintains the body temperature at specific value, so the devices have very little chances to extract energy from temperature variations in body.

7. Kinetic Energy Harvester

In this energy is extracted from movements of body, where harvester may be placed in knee cap or in wrist watch. A power around 10 micro watt can be extracted from a watch worn for full day. Since this is enough power to feed a bio sensor. But power may not be enough when the user is immobile for longer period. So in this harvester we cannot predict the energy availability in advance which makes it inefficient for WBAN networks as it is used to monitor critical biological signals.

8. Discussions and Conclusions

We have various ambient energy sources available in our surroundings where each source has its own merits and demerits. Sun is the most powerful source of energy and energy harvesting from solar equipments provides a huge amount of energy. It also depends upon the conversion efficiency of photovoltaic cells. But it provides negligible power in case of indoor devices near or inside the machines. And it is quite bulky and seems impossible to use in case of human implantable body sensors.

It is also not possible to extract power from thermal energy harvesters where thermal gradient is not available as our body maintains body temperature to a specific value and in rare cases our body faces temperature varying conditions.

Table 2. Energy harvesting comparison chart techniques

EH Technology	Voltage [V]	Typical output power [μW]	Challenges
Indoor Solar	0.5 – 6.0	160 at 200lx	Low light, Orientation
Thermal	0 – 5.0	100 for 5_K	charge pump
Piezoelectric	0 – 20	80 for $\pm 1 m/s2$	AC rectification, frequency tuning
Electromagnetic	0 – 10	700 for $\pm 1 m/s2$	AC rectification, frequency tuning, Bulky setup
Electrostatic	0 – 2.0	< 50 AC	AC rectification, low charge

We also have vibration based energy harvesters which includes electrostatic, electromagnetic and piezoelectric principle based power sources to generate power.

Since electromagnetic based harvester provides very low output power, have bulky setup and less energy density as compared to other two harvesters techniques. So we are left with piezoelectric and electrostatic energy harvester. Piezoelectric harvester provides high output voltages as compared to electrostatic harvester. Moreover, in piezoelectric harvester there is no need to control the gap between plates. Out of these two, electrostatic harvester provides low efficiency in case of low frequency and it is technologically difficult, expensive to come up with small size devices. It is also comparably difficult to integrate on MEMS devices. Hence we chose piezoelectric harvester as best suitable method to feed body sensors.

The harvesting energy from vibrations is gaining admirable research interest. Based on literature reviewed of different harvesting techniques it has been seen that a lot of work has been done in this field over the time. It can be concluded from the survey, the harvesting technique that seems so comfortable and suitable is piezoelectric harvester as it provides significant power to miniaturizing electronic devices while being small and efficient.

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