

Power Management of RF Energy Harvesting for Healthcare Communication System

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Abstract: In Telemedicine system, the automated vital signs collection and transmission can be implemented using set of medical sensors connected to wireless transmission system to be sent over internet. Vital signs include body temperature, blood pressure, and Heart rate sensing. This research work will use wireless sensors network to monitor body functions of a patient during daily activity. Possible implementation of personal healthcare can be seen where set of medical sensors are fitted into wearable fashion. The proposed system is wearable, easy to use, small medical devices, comfortable to wear, minimally obtrusive, Low cost, easy to clean, water-proof and combine Ultra Low Power (ULP) electronics with an efficient energy harvesting, generation and storage. The proposed system acts as a portable gateway connecting sensors network to the Internet. The autonomy of power-source of sensors-nodes is still a major challenge in wireless sensor network (WSN) nodes. This paper provides the Radio Frequency Energy Harvesting Technology RFEH that can increase the autonomy of wireless sensor network (WSN) nodes. It presents a wearable health-monitoring application and discusses the suitability of RF energy harvesting technology with respect to typical human activities. The hardware interface to the information network to establish telemedicine system with energy-efficient communication and optimization of power dissipation are also proposed. The constraints and assumptions of Radio Frequency Energy Harvesting are considered. We discussed that how these constraints are tackled. And we analyze the short comings of our approach and how it would affect the overall performance of the proposed system.

Keywords Telemedicine, Healthcare, Radio Frequency Energy Harvesting, Wearable Wireless Body Sensors Network WBSN, Medical Informatics MI, Wearable Technology.

1. INTRODUCTION

RECENT research has resulted in various ideas for extending nodes operating life-time in accordance to their power source usage so as to overcome the challenges and inconvenience related to battery replacement in deployed system. By using "Energy Harvester" there is no need to periodically recharge the battery by replacing it or connecting it to external charger. Then it will charge a rechargeable battery which is including the power supply to body gateway unit. Feasibility of telemedicine can be achieved by benefiting from technology advancements in microelectronics of medical sensing and wireless communication, and advancements in ICT that enable proper management of medical and personal information using internet. Energy harvesting is one of the best proposed ideas for recharging the power source of WSN nodes, which logically results in increased autonomy [1][2]. WSN nodes typically contain various components of power source, microprocessor, and external memory, several sensors, A/D converters and RF transceiver. In WSNs, such nodes are linked together by means of wireless communication system to serve various applications as;

monitoring human and structure health, etc. The signals collected by sensors are typically magnified into the shape of electrical signals. Sensor nodes can use rechargeable or non-rechargeable batteries. Thus, energy harvesting can be valuable asset in various applications such as wearable health-monitoring, which is really challenging due to some factors like convenience, trust, cost, portability, and reliability. Thus, harvesting energy is highly desirable and could possibly exploit human movements, body temperature, as well as ambient energy such as solar and RF waves[3][4].

1.1. Wireless Body Sensors Network (WBSN)

Wireless sensor networks (WSN) combine three basic features in single system: sensing, processing, and wireless communicating. All of these functions are kept in single device called Sensor node. The main components of sensor node are microcontroller, memory, sensors, actuators, power supply, transceiver and antenna. This research work will use wireless sensors to monitor body functions of patient during day activity. Currently, body sensors are directly connected with cables to PC that stores data or visualizes it on the display. In some cases mobile data loggers are used to gather data over certain time with aim to analyze later by physician. But still body sensors are connected with data logger by cables. This has the disadvantage that the patient is disrupted or obstructed in his natural movement. Furthermore, the cables limit the possible positions where the sensor could be attached to the

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body. Patients feel not comfortable carrying these sensors and because of this reason they do not accept to use body sensors for a long time [5]. This research aims to increase acceptance of usage by placing wireless sensors on body where they do not hinder person movements. Mobile wireless sensors can be flexibly placed to any part of the body. If patients would accept to carry sensors permanently, a lot of diseases could be recognized much earlier. This would help patients and physicians to react in a much proper way using more efficient treatments and counter measures. The attached body sensors establish an ad hoc local network in self-organized way. Self-organization is also required during network operation to adapt to changes, e.g. node losses due to energy deficits. The destination of sensor data is called sink or base station [5][6]. After establishing a network, sensor nodes send all relevant information to one or more sinks. Base stations are often more powerful devices and can store huge sizes of data. In our approach, the base station is wearable small device that acts as mobile gateway connecting the sensor network to Internet.

1.2. RF Energy Harvesting System level

Energy harvesting is the process by which ambient energy is captured and converted directly into electricity for small and mid-sized devices, such as autonomous wireless sensor nodes, consumer electronics and vehicles. Energy harvesting can make some devices self-sufficient and improve energy efficiency of device. Energy harvesting includes photovoltaics (energy from light), thermovoltaics (energy from heat), piezoelectrics (energy from pressure) and electrostatics. It is enabling battery-free, maintenance-free devices. In addition, new forms of energy storage are being developed which overcome previous technology limitations by being able to be recharged tens of thousands of times, accept lower input voltages and deliver charge more quickly.

1.2.1. Radio Frequency Energy Harvesting

The conversion of radio frequency signal into electricity is known as radio frequency energy harvesting (RFEH). Normally, converted energy could be utilized for enhancing on-time period of WSNs nodes power source (batteries). Usually, the architecture of RFEH has three major components, i.e. information gateways, RF energy sources and network nodes/device. The information gateways are called as base stations, wireless routers and relays. Power Source could be either Ambient RF sources (e.g., TV towers) or dedicated RF energy transmitters. Usually, WSNs nodes can communicate with information gateways where information gateways and RF energy sources are supplied by fixed electric source. WSNs nodes can harvest energy from RF sources to conduct some monitoring operations in various fields such as health monitoring system and surveillance [7][8][9].

1.2.2. Power Sources Management

When WBAN is controlled by main processor of personal server, the entire system cannot operate for long periods of time because this type of processor is not designed for continuous operation. This problem can be mitigated by making WBAN self-organizing so that the individual sensor nodes can operate without constant interventions from personal server. In that case, the personal server would assume a more secondary role as simple repository for information collected locally as opposed to that of the coordinator of the network. The main obstacle for wider adoption of wearable health monitoring is current battery technology. Long-life batteries for WBAN sensors are highly desirable, especially when the replacement of the battery needs to be done surgically [10][11]. To resolve this problem there are new developments in the market for WBAN's batteries. One of these is the case of printed batteries, which are especially suited for thin and flexible products like medical sensors in which they can be easily integrated. The transceiver has ultra-low-power consumption, there are already WBAN applications that use sophisticated energy harvesting mechanisms. Some common energy sources are human body, from which vibrational or thermal energy is collected, or the surrounding environment, where ambient electromagnetic fields may provide the necessary energy. These technologies enable wireless sensor users to collect more data over time and offer more opportunities to operate autonomously in diverse environments. In WBAN, most energy-saving operations use duty-cycling approaches that periodically turn off the nodes so that they can operate in ultra-low-power modes for prolonged periods of time and be in active mode only when necessary, thereby achieving great energy savings. Evidently, such techniques strongly depend on time synchronization mechanisms. For this reason it is also important to evaluate in every communication protocol which mechanisms it uses to achieve the synchronization between sensors and how effectively [12][13].

1.2.3. Constraints and Assumptions of Radio Frequency Energy Harvesting

The power allocation of EH node is subject to two constraints: energy causality and battery capacity. The energy causality constraint (also known as the energy constraint) stipulates that the energy cannot be used until it is harvested, and the battery capacity constraint confines the amount of energy stored in the battery. In this work, we study the throughput maximization problem in an off-line half-duplex EH communication system. In the off-line setting, all energy harvesting profiles of the EH nodes, as well as all the channel state information are assumed to be known at the beginning of the transmission. Specifically, the energy harvesting profiles contain the arrival time and the amount of every harvested energy packet. In contrast, in an on-line setting case, only the past and current information of energy profiles and the channel state information are available.

A two-way communication system, which allows two users to communicate in both directions, can be categorized as full-duplex and half-duplex. In a full-duplex system, a user can simultaneously receive and transmit signals. As mentioned earlier, the need for green wireless communication devices is growing and this requires a wide range of wireless communication models using the EH technique. How to utilize the harvested energy in a most efficient way to satisfy user requirement has become a challenge for researchers. Moreover, the EH system models, which rely on various relaying strategies or different system settings, vary from case to case. Many specific models await examination from the aspect of both mathematical research and structural property observation. Current investigations in this field mainly focus on point-to-point and one-way relay systems. However, due to the bidirectional nature of communication, a two-way relaying scheme has its own merit in wireless communication. The objective is to maximize the system throughput subject to individual energy harvesting constraints and transmit power constraints. So, we discussed that how these constraints are tackled by the impact of our proposed system.

2. PRE-IMPLEMENTED TELEMEDICINE SYSTEM FOR THE PROPOSED SOLUTION

The Architecture of our pre-implemented embedded system is composed of 3 levels (Fig 1):

Level-1: application Platform for Data Processing supported by Android operating system is used for monitoring and measuring the readings from physical world into electrical signals in order to use these signals to map the readings to our core board. The processing phase consists of three algorithms for measuring Heart beats and Body temperature independently from patient's body, process those readings, and submit them into database related with the patient profile. The specialized physician can remotely examine and diagnose the patient's condition remotely and efficiently. The processing unit samples analog values from sensors through Analog to Digital Converter module (ADC) and send through Bluetooth connection based on serial communication between processing unit and Bluetooth module.

Level-2: Data Communication and Sensor nodes: a. Central Control Unit (CCU) interface, b. Communication with sensors: ADC module and sensors are connected via wired connection, it is communicating with smartphone using USB or via Bluetooth connection.

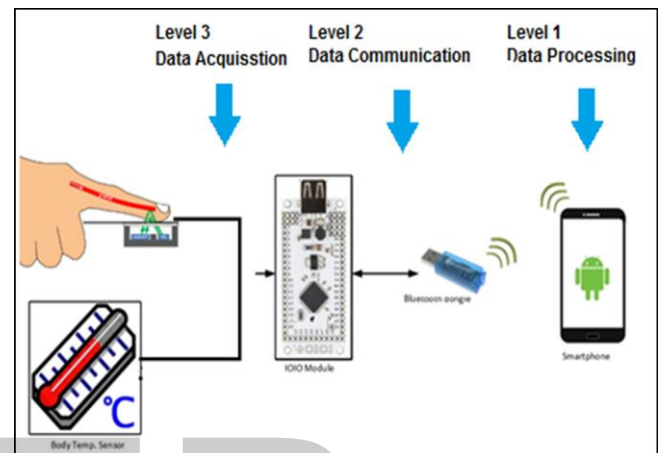
Level-3: (Data acquisition) Biological Sensors, they produce voltage or digital signal that is indicative of physical variable they measure. Those signals are often imported into computer programs, stored in files, plotted and analyzed on computers and mobile applications.

To have a suitable wearable sensors for human body we must handle 3 problems:

1. **The communication:** Which is the data transfer from sensor or memory on wearable module to

central unit for processing. Since it is wearable module so, the communication must be wireless through suitable communication protocol.

2. **The physical dimension and mounting:** To have a suitable wearable system the physical dimension, weight and volume must be considered
3. **The power source:** the power source for the wearable unit (which named as Body gateway in our solution) as battery operation time must be expanded.

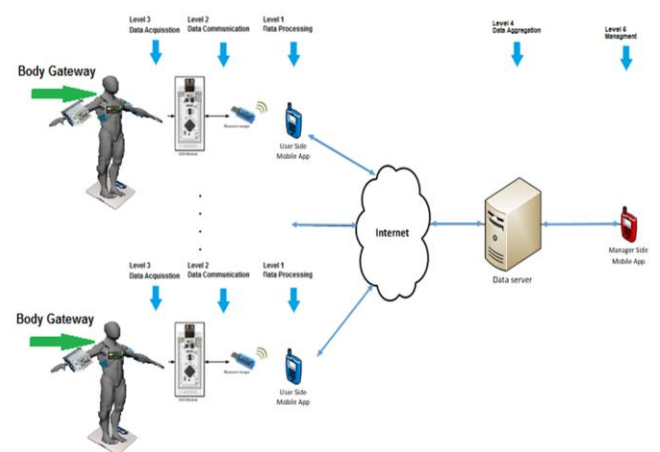


1. Fig. 1. Pre-implemented System architecture and levels

3. PROPOSED EMBEDDED SYSTEM DESIGN OF WEARABLE WIRELESS SENSORS NETWORK

The new proposed system focuses on developing level 3 of data acquisition, (of the pre-implemented system in the above section) which collects vital signs from human body, to have two major added contributions which are : wearable fashion and has standalone Energy source (Energy harvester) as shown

"Body Gateway" in the Fig. 2.



2. Fig. 2. Proposed System based on Gateway implementation

3.1. PROPOSED APPLYING OF ENERGY HARVESTING IN BODY GATEWAY

Fig.3. shows the block diagram of RFEH device consists of few components such as application, low-power microcontroller (processing data from application), low-power RF transceiver (information transmission or reception), energy harvester, composed of RF antenna, capacitor and voltage multiplier (to collect RF signals and convert them into electricity), power management module and energy storage device. The RF energy harvester method is usually based on efficiency of an antenna along with impedance accuracy matching of an antenna with voltage multiplier. It converts the received RF signals to DC voltage. RFEH is very flexible and controls the transfer energy as requirement of WSNs nodes.

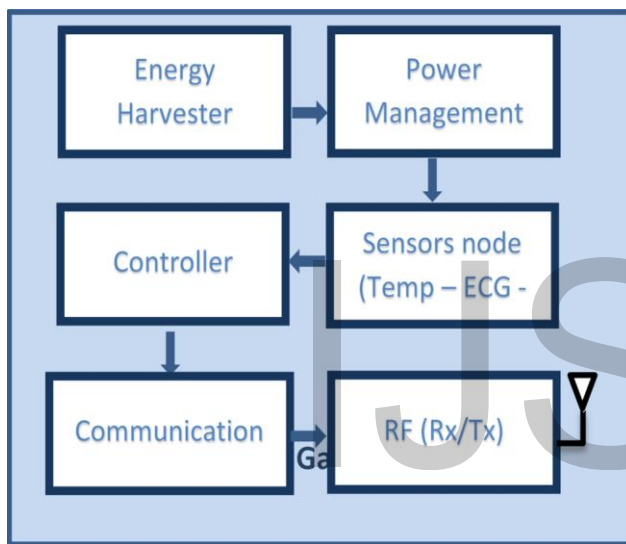


Fig. 3. Architecture of RF energy harvesting device, Body Gateway components.

The harvested RF power is small due to RF-to-DC low energy conversion efficiency[13]. we suggest an architecture to resolve power source through Energy harvesting system as described in section 1.2.3. The proposed architecture, Body gateway as shown in Fig 3 is composed from 6 modules:

1. Energy Harvesting
2. Power management
3. Sensors node (4mA heartbeat)
4. Controller (500mA @ 5V for IOIO and 150 mA

- maximum load for Arduino)
5. Communication (with controller for IOIO) and)1 mA with Arduino
6. Antenna (Rx/Tx)

Module 1: Energy Harvesting

This module is the power generator module which will act as battery recharger. By using "Energy Harvester", there is no need to periodically recharge the battery by replacing it or connecting it to external charger. The Energy Harvesting depends on harvesting the RF signal or human body heat or human body motion. Then it will charge a rechargeable battery which is including the power supply to the body gateway unit

Module 2: Power management

This module is many responsible about supplying power to all Body Gateway modules as controller and communication. It also include the rechargeable battery which will be recharged through Energy harvester module.

Module 3: Sensor node

This module includes all sensors required to be weird as temperature sensor, heart beat sensor...

Module 4: Controller

The controller module is the brain of the body gateway unit. It control all running process on the board sensors reading, data storage, data transmission and receiving etc... It is SOC (system on chip) microcontroller based system.

Module 5: Communication

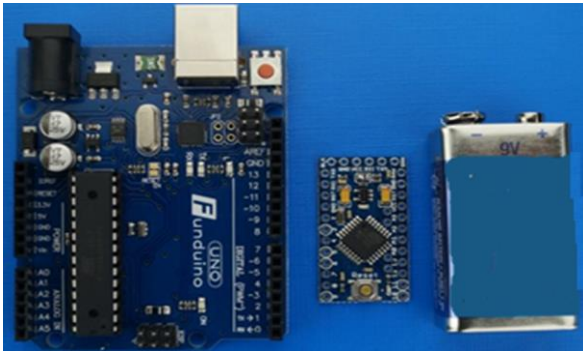
This module will be responsible about data communication as sensors reading or command control to/from the controller. It will use one from the common communication protocol as Zigbee or Blue tooth to be connected to main controller unit or mobile device respectively.

Module 6: Antenna (Rx/Tx):

This module is communication protocol interface antenna

3.2. POWER CONSUMPTION CALCULATION OF MICROCONTROLLER

An Arduino Uno runs less than one day on 9 V battery because it uses about 45 mA current. Using an Arduino Pro Mini, with a simple modification, the power consumption goes down to 54 μ A (0.054 mA) with 3.3 V version or 23 μ A (0.023 mA) with 5V version, in power-down sleep. That is 4 years on a 9 V battery with 1,200 mA/h capacity or 2,000 times more efficient than the Arduino Uno. After removing the voltage regulator, the power consumption is only 4.5 μ A for the 3.3 V version and 5.8 μ A for the 5 V version, in power-down sleep.



3. Fig. 4 Arduino board compared to 9V battery

3.3. POWER CONSUMPTION CALCULATION OF COMMUNICATION MODULE IN PROPOSED SYSTEM

The best on Arduino power consumption: gammon.com.au/power We can get the ATmega current draw down to 100 nA in "power down sleep mode"; the rest depends on the other parts of the circuit and what percentage of the time you can stay asleep. You may want to rethink your LED: If you light a 20 mA LED for five seconds out of every 10 seconds, 50% "on" time, the LED alone will drain 500 mAh in 50 hours. The guy in the link found that flashing a LED for 5-10ms once a second was enough to make it visible. One year = 8765 hours. So average drain for 1 year life from 500 mAh = 500 mAh/8765h = 57 uA average. An efficient modern LED is usefully bright at 1 mA and probably at 0.1 mA.

4. RESULTS AND DISCUSSION

Power Consumption in sleeping mode = Controller + Sensor node + Communications
 $= 0.054 + 0.01 + 0.1 = 0.164 \text{ mA/hour}$

Power consumption analysis and calculations:

- To save power, we will assume that we will take one read twice per hour and the rest of the hour
- The controller will be in the sleeping mode controller consume 0.054 mA/hour
- Controller in running mode consume 150 mA/hour
- Assume that the controller will consume 10 second for the 2 reading to run all activities sensor reading, processing, saving, etc..)
- The average power consumption in the running mode will be 150 mA/hour X 10second/3600 second = 0.42 mA/hour.
- Adding this average to the power consumption rate for the whole gateway board in the sleeping mode : 0.164 + .0416 = 0.58 mA/hour

So, the total estimated power consumption for the board / hour is 0.58 mA

we analyze the short comings of our approach and how it would affect the overall performance of the proposed system. In this work, we studied the problem of maximizing the total energy in a two-way relay EH system. The problem is subject to the energy and battery constraints and solved by optimizing the transmitting power of EH node(s).

5. CONCLUSION

Energy harvesting provides a viable alternative to create long lasting wireless sensor networks, using harvested energy to supplement or replace stored battery reserves. Harvesting is not only useful but essential in some usage scenarios such as space exploration and extra-terrestrial sensor network deployments where the operating lifetime required is very long and battery replacements are next to impossible. WBAN technology is starting to make its way into areas such as sports and fitness monitoring, mobile device integration, rehabilitation, monitoring patients. Two very important characteristics to consider in choosing the WBAN sensors are power consumption and small size. It is important to achieve balance between these two features because they are generally conflicting, meaning that the more power a system demands, the largest the volume of its battery pack must be. Using WBANs, patients may be comfortably monitored at home while going about their daily activities, and doctors can monitor more patients simultaneously. This benefits both the patients and the medical services provided by the telemedicine system at the rural site are eagerly needed by the elderly. The system allows the elderly to avoid traveling long distance to get better healthcare. Evaluation results show that the telemedicine system is relatively feasible in the case of teleradiology. Telemedicine has shown the capability not only to improve the quality of healthcare, but also to increase the opportunity of continuing education for physicians at a rural sites. According to the results of the survey, the web environment's features of multimedia and hyperlinking made the web-based browser suitable for displaying medical teaching materials. We proposed body gateway system used to provide medical services to a rural healthcare center. Six modules of the body gateway are explored through the system designed. In order to fulfill the requirements of low power consumption for wearable system, RF energy harvesting technologies have been presented and their suitability for a wearable health-monitoring application has been discussed; hybrid solutions appear to be the most promising. The next step of our research effort consists of modeling these technologies, including the hybrid ones, for incorporation in a WSN simulation environment.

6. FUTURE WORK

There are many other aspects that can be explored in the future. One is to add a data mining technique to the system. This could allow the formulation of diagnostic behaviors and build a knowledge base to assist diagnosis and medical teaching. The other is to incorporate image compression technique to speed image transmission. These advances may help researchers to not only explore the knowledge of medical behavior, but also expand the feasibility of the telemedicine system.

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