International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-2 Issue-6, May 2013

RF Energy Harvesting for Hybrid Application: Review and Analysis

Rajiv Dahiya, A. K. Arora, V. R. Singh

Abstract—Wireless Sensor node is one of the important technologies for the recent world applications like military, agriculture, health etc. But the major problem associated with these nodes is their battery dependence. The Battery Dependence for such nodes responds to the life time of the complete node.Failure of network due to node failure occurs when the battery completely depleted. To beware from such conditions for critical conditions there is one more option of Energy harvesting. In this paper we have discussed about many kinds of energy harvesting procedures. RF energy harvesting and related work discussion are the major issues which we have discussed in this paper. The Power transmitted and received, DC power output, efficiency enhancement due to multipliers or charge pumps are the areas which have been discussed in this paper. Some protocols and routing techniques are also discussed in this paper.

Keywords— WSN, RF Energy harvesting, Energy harvesting techniques, Ambient energy harvesting.

I. INTRODUCTION

The greatest problem in case of WSN is the energy. If the energy is depleted the nodes no longer can provide the information and also the routing is effected seriously [2]. Therefore, it is generally accepted that the usefulness of a wireless sensor expires when its battery runs out. Much of the research on wireless sensor networks has assumed the use of a portable and limited energy source, namely batteries, to power sensors and focused on extending the lifetime of the network by minimizing energy usage [3],[5],[7],[8]. Portable energy sources like batteries will experience current leakages that drain the resource even when they are not used; furthermore, any flaws in the packaging due to long term wear and tear can result in environmental problems [2]. A wireless sensor network that is not dependent on a limited power source (like a battery) essentially has infinite lifetime. Failure due to other causes (like structural hardware damage) can be overcome by self-organization and network re-configuration [4]. This has motivated the search for an alternative source of energy to power WSNs especially for applications that require sensors to be installed for long durations (up to decades) or embedded in structures where battery replacement is impractical.In this paper, we have discussed about the ambient energysource and compared them, although our main area of interestis RF energy harvesting.

Manuscript published on 30 May 2013.
***Correspondence Author(s)**
Mr. Rajiv Dahiya, Electronics, Manav Rachna International University, Aravalli Campus Sector – 43, Delhi – Surajkund Road Faridabad, Haryana 121004, India.
Dr. A. K. Arora, **Executive Director (Administration)**, Manav Rachna International University, Aravalli Campus Sector – 43, Delhi – Surajkund Road Faridabad, Haryana 121004, India.
Prof. Dr. V.R.Singh, **PDM College of Engineering** Sector-3A, Sarai Aurangabad , Bahadurgarh Haryana,India.

Let's discuss the WSN node for more understanding the concept. Fig 1 shows the block diagram of node. Node is associated with three main units: RF Section, Microcontroller unit, and Sensor transducer. All these units needs power and power is provided by means of Energy Source. Energy Source is the battery no doubt. But we need a power management unit as well as en Energy harvesting technique [3], [5] to enhance the capability of the node or shortly we can say to enhance the life time of the node.

When the point of the life time came in picture then there is a major issue come on which the life time depends when we exclude the energy harvesting architecture. And this issue is its Application. The WSN node having variety of application for which the life time for one kind of battery is different. So let's discuss about key points of the applications. We will not discuss the application in details but it's important because of lifetime dependence.

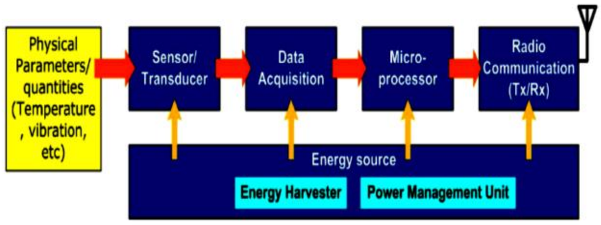


Figure 1: RF Energy Harvesting and power management [3]

Ambient energy sources are discussed and analyzed. On the base of the analysis we have developed the comparison between all types of harvesting techniques. Than RF energy harvesting is taken at priority [3].

For RF energy harvesting many things are important like antenna transmitted power and antenna received power. Conversion efficiency and conversion circuit analysis. Protocols defined for RF energy harvesting. Study and review of Routing technologies and MAC layer optimization for RF energy harvesting have been also done in this paper.

Let's discuss the organization of the paper. In Section II the applications are discussed. Section III is designed for the discussion of ambient energy sources for WSN. Design challenges and operations are discussed in Section III. The antenna transmitted power and received power is discussed in section IV, the discussion is important for different types of antenna associated with RF energy harvesting. Section V is discussed for multipliers charge pumps design for conversion of RF energy into DC energy. Section VI discussed about the enhancement of technology for the RF energy harvesting.

II. APPLICATIONS FOR WSN

A large number of potential applications of sensor networkshave been reported ranging from early research investigationsto commercial systems[5]. A review of a broadrange of applications is given in [8] as the basis for the proposalof a design space model.The applications of the WSN node are as follows:

A. Environmental monitoring

A widely considered area for the application of sensornetworks is in environmental monitoring. Measurement ofglacier dynamics using nodes capable of measuring location,temperature, pressure, and orientation at points insidethe glacier over a period of several years was describedin [4]. The research described in [5] used nodes on the seabed to monitor pressure, temperature, conductivity, current,and turbidity. These nodes were connected to buoyson the surface to allow radio communication through self-organizing ad-hoc wireless networks. The Argo project[6]uses a sensor network to observe the temperature, salinity,and current profile of the upper ocean. Nodes are attachedto free-drifting carriers which cyclically sink to adepth of 2 000m and then resurface to allow communicationwith a satellite. WSNs have been considered for precisionagricultural applications such as monitoring grape growingconditions [11]. Here, nodes with temperature, soil moisture,light, and humidity sensors are deployed on a 20m gridacross a vineyard to provide information to guide the adaptationof water/fertilizer/pesticide supply to the needs ofindividual plants and to optimize harvesting.

B. Animal tracking and control

Tracking and controlling the movements of domesticand wild animals presents interesting challenges inWSNs. Thebreeding behavior of birds was considered byMainwaring et al. [12] using sensor nodes installed inside burrows.Clusters of nodes, each capable of measuring humidity,pressure, temperature, and ambient light level, along with infrared sensors to detect the presence of the birds,form local networks and each cluster has a node fitted witha long-range directional antenna to pass cluster data to abase station. Nodes fitted to wild animals (e.g., wild horses,zebras, and lions) are capable of roaming over a very largearea was considered in [13]. Each node logs the animal'sbehavior and environment and passes data to any othernode which comes within range. At regular intervals, a mobilebase station (e.g., a car or a plane) moves through theobservation area and collects the recorded data from theanimals it passes. In the case of [14], the WSN is used bothto monitor behavior and to control it. In this case, thepositions of cattle are monitored and "virtual fences" createdby using an acoustic stimulus to discourage an animalfrom crossing a defined line. The network of nodes is connectedto a base station so that feeding behavior can bemonitored and virtual fences adjusted to improve usage ofthe feedstock.

C. Safety, security, and military applications

WSNs have been developed to assist rescue teams in savingpeople buried in avalanches [15]. By monitoring heartrate, respiration activity, orientation, and blood oxygenlevel, it is possible to automate the prioritization of victimsand to guide rescuers to their location. Tracking ofmilitary vehicles using networks of nodes deployed by unmannedaerial vehicle (UAV) was considered in [16]. Datacollected from the nodes by a UAV was used to identifythe path and velocity of ground vehicles. Anti-tank landminescapable of self-monitoring for signs of tampering havebeen formed into networks so that, if an individual mine isdisabled, a neighboring device is able to take its place usingrocketthrusters to effect the necessary movement[17].Combining data from a network of acoustic sensors in orderto determine the location of a sniper and the directionof the bullet based on the time of flight of muzzle blastwas considered by Simon et al.[17] . Monitoring of buildingsand emergency response personal has been considered byYang and Frederick[18] with the aim of improving safety indealing with fires and other life threatening situations inthe built environment.

D. Built environment

Monitoring of the internal environmental conditions andadaptation of heating, lighting, etc. in response to humanoccupancy and activity is a major potential application forsensor networks, whether based on wireless communicationsor on wired connections. In [19], a WSN was developedto monitor power consumption in large and dispersed officebuildings with the aim of detecting locations or devices thatare consuming a lot of electrical power.

E. Health

Health applications for WSNs include patient monitoring,drug administration, tracking of patients at home[17, 18]and doctors in hospitals. Body sensor networks[20] are usedin the medical sector; implanted medical devices with integratedwireless technology are used for therapeutic and diagnosticapplications. Physicians can use this technology tomonitor device performance and patient response withoutthe need for invasive surgery. Drug manufactures are alsointerested in this technology to reduce their costs when introducinga new drug. The patients can be monitored wirelesslyand data about the patient's internal chemistry can beanalyzed for abnormal reaction and side effects over a securelink. Yang[20] undertook a thorough analysis of the wirelesstechnologies available and concluded that the IEEE802.15.4wireless standard with provisions for body sensor networks(BSN) in the ZigBee application layer was the most appropriatefor the body sensor networks. An analysis of theperformance of medical sensor body area networking [21] alsoendorsed the advantage of using IEEE802.15.4 and ZigBeefor medical sensor technologies.

F. Hybrid Networks

In general, complete application scenarios contain aspects of all three categories.For example, in a network designed to track vehicles that pass through it, the networkmay switch between being an alarm monitoring network and a data collection network.During the long periods of inactivity when no vehicles are present, the network willsimply perform an alarm monitoring function. Each node will monitor its sensorswaiting to detect a vehicle. Once an alarm event is detected, all or part of the network,will switch into a data collection network and periodically report sensor readings up to abase station that track the vehicles progress. Because of this multi-modal networkbehavior, it is important to develop a single architecture that and handle all three of theseapplication scenarios.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

III.AMBIENT ENERGY SOURCES

In order for a sensor network to operate, it requires electricalpower and given that it is frequently desirable to installnodes in inaccessible locations, it can be difficult toprovide a sufficiently large store of energy for long termoperation or to replace the power source at appropriate intervals.Although the performance of non-renewable energysources, such as batteries and fuel cells, has improved overthe years[23], this improvement is fairly gradual comparedwith other areas of electronics[24] and cannot satisfy all ofthe simultaneous demands for long life, low volume, lowweight and limited environmental impact.There are a great many sources of energy and conversiondevices which have been considered for energyharvesting[25, 26] and in order to compare different approaches,it is useful to consider the criteria for comparison.

Clearly, a key consideration is whether the energyharvesting device can provide the level of power requiredby the sensor node but it is also important that the electricalpower is at a suitable voltage and current level sinceconversion between voltage levels implies some dissipationof energy and, in general, the greater the ratio between inputand output voltage, the greater the power losses.

In order to achieve a desired power level, some conversiondevices can be appropriately scaled. Thus, for instance, ifa photovoltaic (PV) cell is considered then an increase inpower demand can be accommodated by an increase in cellarea. However, other sources/converters cannot be so readilyscaled. For instance, energy derived from human activitycannot generally be scaled up without either increasing the effect on the person concerned or increasing the number ofpeople involved. While it may be possible to scale up a conversiondevice, many applications of sensor networks requirenodes which are small and light weight. Thus, an importantconsideration is the power density (in either W/m3 orW/kg) which can be achieved. In assessing power density,the volume and weight of associated energy storage mayalso be important.

A number of authors have proposed classification systemsto categorize energy sources suitable for harvestingwhich, while broadly similar, do exhibit some differences. In[22], sources are grouped as human and environmental withkinetic and thermal considered as sub classes. Buren[27]uses a similar classification of thermal energy, radiant energy,and mechanical energy sources when considering wearablemicro-generators. This classification will be adoptedhere although mechanical source will be subdivided betweenthose which are continuously present over long periods, suchas air flow, those which involve vibration and those whichinvolve short periods of energy availability such as footfallduring walking.

A. Electromagnetic radiation

Although radio frequency signals can be used to powerpassive electronic devices such as radio frequency identification(RFID) tags, these must be carefully tuned to thefrequency of the radio source and are typically only capableof transmitting power over a distance of a few meters[31].Without the use of such a dedicated source of radio frequency(RF) energy, the ambient levels are very low andare spread over a wide spectrum. Harvesting useful levelsof electrical energy in these ambient conditions wouldrequire large broadband antennas.

B. Thermal Energy

Extraction of energy from a thermal source requires athermal gradient. The efficiency of conversion from a thermalsource is limited by the Carnot efficiency to

$$Efficiency \leq \frac{T_h - T_c}{T_h}$$

where$T_h$is the absolute temperature on the "hot" sideof the device, and $T_c$is the absolute temperature on the"cold" side. Thus, the greater the temperature differencethe greater the efficiency of the energy conversion. A potentialheat source in many environments would be a roomheater. A domestic hot water radiator typically delivers approximately1.4 $kW{\cdot}m^{-2}$ when heated to 50◦C above ambientand so a relatively small section of such a radiatorcould provide a useable power source.

C. Mechanical Energy Sources

Sources of mechanical energy may usefully be groupedas those dependent on motion which is essentially constantover extended periods of time, such as air flow used in aturbine, those dependent on intermittent motion, such ashuman footfall and those where the motion is cyclic, as invibration sources. These different types of sources will beconsidered separately.

1. Steady state mechanical sources

Sources of ambient energy which are essentially steadystate are based around fluid flow, as in wind and air currentsand water flow either in natural channels or throughpipes, or around continuous motion of an object such asa rotating shaft. Fluid flow based sources of energy arewidespread and used on the macro scale for electrical powergeneration as in wind turbines and hydroelectric plants buthave also been considered for smaller scale harvesting applications.Starner[32] considered the potential for energyharvesting from blood flow and breathing in human subjectsand determined that significant power was availablebut that these might not be acceptable to subjects.

2. Intermittent mechanical sources

Energy is available from motion which may be cyclic innature but in which the energy is only available for a shortpart of the cycle. Examples of this type include energyavailable from vehicles passing over an energy harvestingdevice[33] and intermittent human activity such as walkingor typing where, for instance, footfall occurs over a periodof milliseconds during a gait cycle of around one second.Harvesting of energy from these intermittent sources wasalso considered by Starner[32] who concluded that availableenergy ranged from around 7mW from finger motion duringtyping to 67W for lower limb movement. This paperalso considered the effect that extracting this energy wouldhave on the subject and concluded that inconvenience to thesubject could only be avoided if significantly lower powerlevels were extracted. A particularly attractive source ofenergy in this context is footfall or heel strike since normalwalking involves dissipation of significant energy in theshoe and walking surface, so the user might be unawareif some of this energy were converted to electrical energy.It may readily be calculated that a subject weighing 60 kgmust apply a force of at least 588N through the foot duringwalking (the peak force is typically 25% above body weightduring walking and up to 2.75 – 3 times body weight duringrunning [34]).

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

If this is accompanied by a 10mm deflectionof the floor or shoe, then the available energy is 5.88 Jand assuming two steps per second, an available power of5.88W per foot. Similar calculations may be carried outfor the case of vehicles passing over a deflection device and, given the far greater weight, a significantly greater energylevel is found (for example, a single 40 t vehicle causing a10mm deflection could provide 4 kJ), although clearly thefrequency of vehicle passage will affect the average powerlevel achievable.

3. Vibration

Vibration energy is available in most built environments.The energy that can be extracted from a vibration sourcedepends on the amplitude of the vibration and its frequency.It also depends on the extent to which the presenceof an energy harvesting device affects the vibration.This, in turn, depends on the mass of the harvesting devicerelative to that of the vibrating mass. Vibration sourcesvary considerably in amplitude and dominant frequency.Roundy et al. [42] presents measurement for a number of vibrationsources that indicate that the amplitude and frequencyvaries from $12m \cdot s^{-2}$ at 200Hz for a car engine compartmentto $0.2m \cdot s^{-2}$ at 100Hz for the floor in an officebuilding with the majority of sources measured having afundamental frequency in the range 60–200 Hz. Vibrationpresent in most environments is not made up of a singlefrequency but is typically made up of a number of fundamentalfrequencies and their harmonics. For instance, thevibration data shown in Fig. 2, which is taken from a domesticfreeze, indicates a fundamental frequency of 50Hzwith an acceleration amplitude of $0.1m \cdot s^{-2}$ with the $2^{nd}$and higher harmonics present at lower amplitudes. The energy that can be extractedfrom a vibration source depends on the frequency and amplitudeand, since the majority of vibration based conversiondevices have a relatively narrow range of operatingfrequencies, it is important that the nature of the sourcebe understood. It is difficult to establish a strong relationshipbetween the amplitude and fundamental frequency ofambient sources because of the limited frequency range typicallyfound. However, if a harvesting device is tuned to afrequency above about 200 Hz, it may be necessary to useharmonics rather than the fundamental frequency of thesource. The amplitude of these harmonics tends to be ofsignificantly lower amplitude than the fundamental.

Table 1: Comparison of various ambient energy harvesting

Technology	Power Density {29} (w/cm^2)	Energy Harvesting Rate (Mw)	Duty Cycle (%)
Vibration-electromagnetic	4.0	0.04	0.05
Vibration-piezoelectric	500	5	6
Vibration-electrostatic	3.8	0.038	0.05
Thermoelectric	60	0.6	0.72
Solar-direct sunlight	3700	37	45
Solar-Indoor	3.2	0.032	0.04

III.DESIGN CHALLENGES AND RF ENERGY LAYOUT

So the overall thing is that we want to generate some energy.Obviously we have different kind of sources but because our main point of interest is energy harvesting by means of RF power sources. So first we will discuss about the design challenges of the WSN node and then we will discuss about the design metrics of WSN-Node which is powered with RF energy harvesting. Instead of focusing on energy-efficient networking protocolsto maximize the lifetime of sensor networks, the main objectiveis to maximize the information or data collected from thesensor network given the rate of energy that can be harvestedfrom the environment. In the following subsections, we brieflydiscuss the networking-related research issues.

A. Topology Control

Topology control schemes can exploit transmission powercontrol to increase the probability of successfully deliveringthe data to the next hop [36]. Larger transmission power meansthat more energy is required to be harvested before the nodecan receive or transmit data packets, thereby decreasing theduty cycles of the node. This may be necessary if a node'sneighbours have not harvested sufficient energy to operate.This also influences thelogical topology and deployment strategies [37].

B. MAC

Typically, MAC protocols designed for WSNs aim to reduceenergy usage and prolong network lifetime at the expenseof longer delays. It makes moresense to find a means of efficiently using the harvested energyto maximize throughput and minimize delays. Furthermore,unnecessary waiting (to synchronize with time slots) or retransmissionscan be counter-productive; it has been shownin [38] that a slotted CSMA MAC performs worse than anun-slotted scheme because energy is consumed during the slotsynchronization process, resulting in longer harvesting periodsthereby reducing throughput.

C. Routing

Since the wakeup time of any sensor cannot be estimatedaccurately because the exact rate of energy harvested fluctuateswith time and other environmental factors, it is very difficultto ensure that the next-hop node is awake to receive a packet.The uncertainty in how long it takes a node to harvest enoughenergy before it can function again makes existing sleep-wakescheduling schemes for WSNs unusable since a node maynot have harvested sufficient energy at the scheduled wakeuptime. Furthermore, if it has depleted all its energy in itsprevious cycle, it may lose its timing reference when it wakesup again. However, broadcasting mayresult in many duplicates if many nodes are awake; therefore,some form of duplication-suppression is needed so that theharvested energy is not wasted on delivering duplicates. Theideal situation would be anycast where exactly one node(among those awake and heard the packet transmission) willforward data packets towards the sink. This ensures that thesink receives exactly one copy of each packet from the source.

If there are insufficient awake forwarding nodes, either becausethe density of the nodes deployed is too low or the averageenergy harvesting period is too long, then it becomes anintermittently connected mobile network, where the use ofdelay-tolerant network (DTN) techniques may be appropriate.

D. Reliable Data Delivery

Reliable data delivery may be required for some applications.

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-2 Issue-6, May 2013

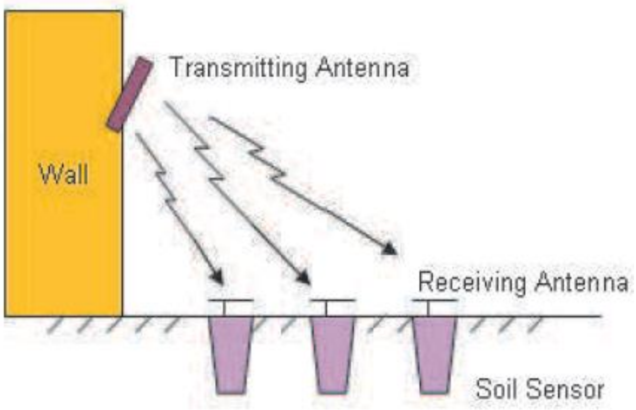
Since the source node is not awake all the time,it is a challenge to design reliable transport protocols asmany reliable transport protocols need to make use of positivefeedback for retransmissions. Another requirement to ensureeach flow gets its fair share of bandwidth given the amountof energy that can be harvested from the environment. Sinceenergy is free because it is renewable, nodes further away fromthe sink may starve the nodes nearer the sink if forwardingpackets have higher priority than the node's own packets.Therefore, there is a need for a transport protocol to regulatethe data flow such that any source will get its fair share ofbandwidth no matter where it is located in the network.

Here we can conclude from the discussion in this section that not only the hardware issues but also some software algorithm like routing schemes, definition of MAC layer and topology control can also define some key concept for the case of max RF energy harvesting. The RF energy harvesting also declares the individual node hardware specification. In the rest of the paper we will see the individual node only because the RF energy harvesting is our main point of discussion.

The Concept of RF energy Harvesting has many aspects like Transmitting antenna, receiving antenna or received power, efficiency, Multiplier, Algorithm specialized for Energy harvesting. In the next section let us define the professionally available hardware like transmitting antenna, receiving antenna, high frequency diode for energy conversion.

IV. ANTENNA ANALYSIS: TRANSMITTING ANTENNA AND RECEIVING ANTENNA

Before discussion the facts let us discuss about an important picture 2.



A. Transmission Antenna:

Selection of a proper operating frequency band for the proposed RFenergy harvesting system is crucial since it will affect the overall sizeof the receiving antenna and operating range of the system. Twounlicensed UHF bands 867MHz and 2.45 GHz were evaluated.867MHz was chosen due to its lower free space attenuation (as thefree space path loss at 2.45 GHz is about 9 dB higher than at 867 MHz).Table 1 shows the frequency allocation for the selected UHF band invarious countries with its permitted radiated power level. For thissystem to be used worldwide, the receiving antenna has to be designedto resonate over a frequency range of 860MHz to 960 MHz, with animpedance bandwidth ($S11 \leq$ -10 dB) covering the chosen band.

Table2: Permitted radio power and frequency

Country	Frequency band	Power
USA	902-928MHz	4W EIRP
UK	865.6-867.6MHz	2W ERP/ 3.28 EIRP
Japan	952-954MHz	4W EIRP
ASIA/EUROPE	2.4-2.5GHz	4W EIRP

When we want to include some patch antenna in our experiments then we can consider some commerciallyavailable antennas and also some of the transmitting antenna which is mainly designed for energy harvesting. Let us include some important pictures for that case.

Let us see Table 2, which shows many important aspects regarding a transmitting antenna.

Table 3: Important parameter of Patch Antenna (902-928MHz)

902-928MHz flat panel antenna series specifications		
Model	**ZDAFP928-8**	**ZDAFP928-11**
Frequency Range	902-928MHz	902-928MHz
Gain	8dBi	10.5dBi
Polarization	Vertical or Horizontal	Vertical or Horizontal
Horizontal Beam Width	90 °	60 °
Vertical Beam Width	70 °	55°
F/B Ratio	>15	>15
VSWR	<1.5	<1.5
Input Impedance	50 ohm	50 ohm
Input Maximum Power	200 W	50 W
Lightning Protection	DC Ground	DC Ground
Connector	N female or customized	N female or customized
Size	8.6x8.6x1 in (216×216×25mm)	12x12x1 in (306×306×25mm)
RadomeMaterial	ABS	ABS
Operating Temperature	-40°C to 85°C (-40°F to 185°F)	-40°C to 85°C (-40°F to 185°F)
Diameter of Installation Pole	1.2-2 in. (30-50 mm)	1.2-2 in. (30-50 mm)
Weight	3.08 Lbs (1.4Kg)	3.96 Lbs (1.8 Kg)
Wind Loading: **100MPH** **125MPH**	8 lb. 16 lb.	11lb. 21lb.

Another frequency rating which we have considered is 2.4-2.5 GHz. The antenna whatever we have taken in table 2 or table 3is designed by commercial industry. The tablesincluded from the "ZDA Communication Company".

The main challenge faced in harvesting RF energy is the freespacepath loss of the transmitted signal with distance. The Friistransmission equation relates the received (P_r) and transmitted(P_T) powers with the distance R as

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R^2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where,$G_t$and $G_r$are antenna gains, and $\lambda$is the wavelengthof the transmitted signal.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

The received signal strength, diminisheswith the square of the distance, requires special sensitivityconsiderations in the circuit design. Moreover, FCC regulationslimit the maximum transmission power in specific frequencybands. For example, in the 900-MHz band, this maximumthreshold is 4W EIRP [39]. Even at this highest setting, the receivedpower at a moderate distance of 20 m is attenuated downto only 10.We describe a new circuit design in this sectionthat is capable of scavenging energy with high efficiency, beginningwith the selection of the circuit components.

Table4 : Important parameter of Patch Antenna (902-928MHz)

2400-2500MHzflat panel antenna series specifications				
Model	ZDAFP2400-16-30	ZDAFP2400-17-25	ZDAFP2400-18-20	ZDAFP2400-21-15
Frequency Range	2400-2500MHz	2400-2500MHz	2400-2500MHz	2400-2500MHz
Gain	16dBi	17dBi	18dBi	21dBi
Polarization	Vertical or Horizontal	Vertical or Horizontal	Vertical or Horizontal	Diamond
Horizontal Beam Width	30 °	25 °	20 °	15°
Vertical Beam Width	30 °	25°	20 °	15°
F/B Ratio	>25	>25	>28	>28
VSWR	<1.5	<1.5	<1.5	<1.5
Input Impedance	50 ohm	50 ohm	50 ohm	50 ohm
Input Maximum Power	100 W	100 W	100 W	100 W
Lightning Protection	DC Ground	DC Ground	DC Ground	DC Ground
Connector	N female or customized	N female or customized	N female or customized	N female or customized
Size	8.6x8.6x1 in (216x216x25 mm)	11x11x1 in (268×268 ×22mm)	12x12x1 in (306x306 x25mm)	17.72x17.72x1in (450x450 x25mm)
RadomeMaterial	ABS	ABS	ABS	ABS
Operating Temperature	-40 to 85°C (-40to 185°F)	-40 to 85°C (-40 to 185°F)	-40 to 85°C (-40 to 185°F)	-40 to 85°C (-40 to 185°F)
Diameter of Installation Pole	1.2-2 in. (30-50 mm)	1.2-2 in. (30-50 mm)	1.2-2 in. (30-50 mm)	1.2-2 in. (30-50 mm)
Weight	3.04 Lbs (1.2Kg)	3.08 Lbs (1.4 Kg)	3.96 Lbs (1.8 Kg)	6.2 Lbs (2.8 Kg)
Wind Loading: 100MPH 125MPH	8 lb. 16 lb.	10lb. 18lb.	11lb. 21lb.	23lb. 46lb.

B. Receiving Antenna

Wireless technology is one of the main areas of research in the world of communication systems today. Wireless provides no connectors, safe/flexible connectivity, improves resources sharing, ease of installation, mobility etc.

Antennas are dual, metallic devices which are designedfor radiating and receiving electromagnetic energy. An antenna actsas a transitional structure between the guiding device (e.g. waveguide, transmissionline) and free space.

In radio communication, an **Omni-directional antenna** is an antenna which radiates radio wave power uniformly in all directions in one plane, with the radiated power decreasing with elevation angle above or below the plane, dropping to zero on the antenna's axis. This radiation pattern is often described as "doughnut shaped". Omni-directional antennas oriented vertically are widely used for non-directional antennas on the surface of the Earth because they radiate equally in all horizontal directions, while the power radiated drops off with elevation angle so little radio energy is aimed into the sky or down toward the earth and wasted. Omni-directional antennas are widely used for radio broadcasting antennas, and in mobile devices that use radio such as cell phones, FM radios, walkie-talkies, wireless computer networks, cordless phones, GPS as well as for base stations that communicate with mobile radios, such as police and taxi dispatchers and aircraft communications.

A dipole antenna is a very basic type of radio antenna. It comes in various geometries with different feeding mechanisms and radiating elements. This antenna is the simplest practical antenna from a theoretical point of view Hertzian dipole is a small length of conductor $\delta\ell$ (small compared to the wavelength λ) carrying an alternating current:

$$I = I_0 e^{j\omega t} \quad \text{.........A}$$

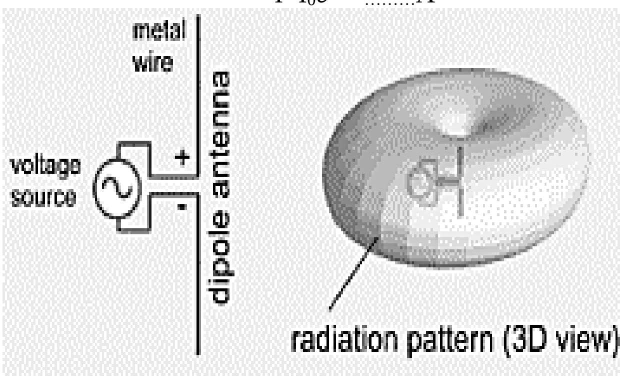


Fig 3. Radiation pattern of Antenna

Here $\omega = 2\pi f$ is the angular frequency (and f the frequency), and $i = \sqrt{-1}$ is the imaginary unit, so that I is a phasor.

It is used in analytical calculation on more complex antenna geometries.This small length of conductor will be just one of the multiple segments into which we must divide a real antenna, in order to calculate its properties.

The closed-form expressions for electric field, **E**, and magnetic field, **H** (In spherical coordinates) are:-

$$E_r = \frac{Z I_0 \delta\ell}{2\pi}\left(\frac{1}{r^2} - \frac{i}{kr^3}\right)e^{i(\omega t - kr)} \cos\theta \text{ ......2}$$

$$E_\theta = i\frac{Z\, I_0 \delta\ell}{4\pi}\left(\frac{k}{r} - \frac{i}{r^2} - \frac{1}{kr^3}\right)e^{i(\omega t - kr)}\sin(\theta) \text{ ....3}$$

$$H_\phi = i\frac{I_0 \delta\ell}{4\pi}\left(\frac{k}{r} - \frac{i}{r^2}\right)e^{i(\omega t - kr)}\sin(\theta) \text{ ....4}$$

$$E_\emptyset = H_r = H_\theta = 0 \text{ ......5}$$

Where$r$ is the distance from the doublet to the point where the fields are evaluated, $k = 2\pi/\lambda$ is the wavenumber, and $Z = \sqrt{\mu/\varepsilon} = 1/\varepsilon c = \mu c$ is the wave impedance of the surrounding medium (usually air or vacuum).

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Some of the researchers also developed a four side patch antenna for better directivity and gain. We have borrowed one figure[4].

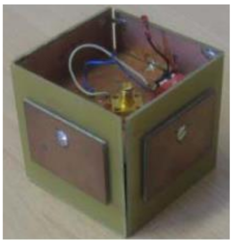


Figure 4: 4 side patch Antenna [40]

The antenna produces a truly omnidirectionalpattern in both E-plane and H-plane, which allows fornon-intermittent communication that is orientation independent. The frequency of operation lies in the UHF RFID band, 902MHz–928 MHz (centered at 915 MHz). The ultra-compact cubicantenna has dimensions of 3cm x 3cm x3cm (27 cm^3), which features a length dimension of '$\lambda/11$. The cubic shape of theantenna allows for "smart" packaging, as sensor equipment maybe easily integrated inside the cube's hollow (or Styrofoam-filled)interior. The prototype fabrication was performed on six (planar)sides on liquid crystal polymer (LCP) substrate, and then foldedinto the cubic structure. The geometry of the design is inspired bythe RFID inductively coupled meander line structures, which arefolded around the sides of the cube. Due to the large number offreedom degrees, this antenna concept may be easily reconfiguredfor many values of impedances and design parameters. Experimentaldata verify the simulation results.

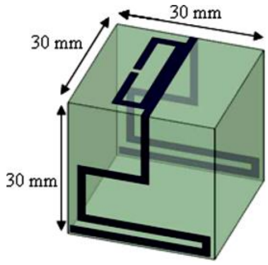


Figure.5 : Node Antenna

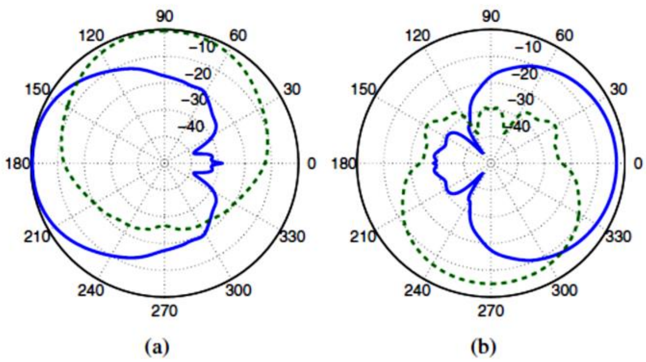


Fig. 6. Radiation pattern of the four antenna faces. a) Patch 1 (solid) & Patch 2 (dashed); b) Patch 3 (solid) & Patch 4 (dashed).

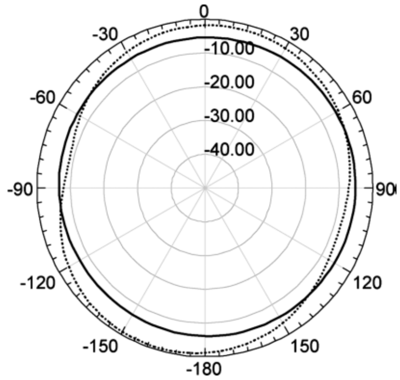


Fig. 7. Radiation pattern of the four antenna faces. a) Patch 1 (solid) & Patch 2 (dashed); b) Patch 3 (solid) & Patch 4 (dashed).

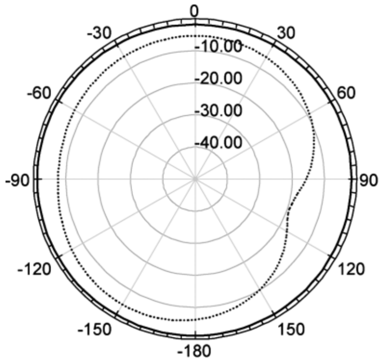


Fig. 8. E-phi (solid) and E-theta (dashed) in dB, Φ=90degfor cubic antenna fabricated with Styrofoam.

A*Four-Beam Patch Antenna* (FBPA)designed to meet the size, cost and complexity constraints ofsensor nodes [40]. We use in-field experiments with COTS motesto demonstrate substantial benefits to WSN applications. Usedoutdoors, the FBPA extends the communication range from 140mto more than 350m, while indoors it suppresses the interferencedue to multipath fading by reducing the signal variability ofmore than 70%. We also show interference suppression fromIEEE 802.11g systems and discuss the use of the antenna as aform of angular diversity useful to cope with the variability ofthe radio signal. Experimental data are analyzed to derive modelparameters intended for use in future network simulations

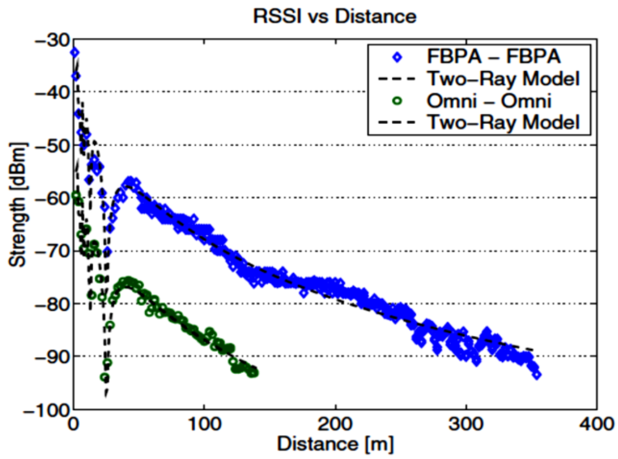


Fig 9: Received signal strength as function of the distance. Transmission power is 0 dBm; values are averaged over 200 radio packets.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

V. OTHER PARTS FOR RF ENERGY HARVESTING AND SOME SIMULATION COMPARISON

A. Choice of Diodes

One of the crucial requirements for the energy harvestingcircuit is to be able to operate with weak input RF power. For atypical 50dB antenna, the 20 dBm received RF signal powermeans amplitude of 32 mW. As the peak voltage of theac signal obtained at the antenna is generally much smallerthan the diode threshold [12], diodes with lowest possibleturn on voltage are preferable. Moreover, since the energyharvesting circuit is operating in high frequencies, diodes witha very fast switching time need to be used. Schottky diodesuse a metal–semiconductor junction instead of a semiconductor–semiconductor junction. This allows the junction tooperate much faster, and gives a forward voltage drop of aslow as 0.15 V. In this paper, we employ two different diodesfrom Avago Technologies, HSMS-2822 and HSMS-2852. Theformer has the turn on voltage of 340 mV while the latter is at
150 mV, measured at 1 and 0.1 mV, respectively. Consequently,HSMS-2852 is suitable for LPD used in the weak RF environment,while HSMS-2822 is preferred for HPD in the strong RFenvironment. Saturation current is another critical parameterthat impacts the efficiency of diodes. It is desirable to havediodes with high saturation current, low junction capacitance,and low equivalent series resistance (ESR). Moreover, diodeswith higher saturation current also yield higher forward current,which is beneficial for load driving. However, higher saturationcurrent is usually found in larger diodes, which have higherjunction and substrate capacitance. The latter two parameterscan introduce increased power loss, where the benefit of highersaturation current is lost.

B. Number of Stages

The number of rectifier stages has a major influence on theoutput voltage of the energy harvesting circuit. Each stage here is a modified voltage multiplier, arranged in series. The outputvoltage is directly proportional to the number of stages usedin the energy harvesting circuit. However, practical constraintsforce a limit on the number of permissible stages, and in turn, theoutput voltage. Here, the voltage gain decreases as number ofstages increases due to parasitic effect of the constituent capacitorsof each stage, and finally it becomes negligible. Figs. 3 and 4show the impact of number of stages on efficiency and outputvoltage of energy harvesting circuit, respectively.We have usedAgilent ADS with parameters sweep of 20 to 20 dBm for theinput RF power and varies numbers of circuit stages from 1 to 9stages. The circuit stage in simulation is a modified voltagemultiplier of HSMS-2852, arranged in series. We observe thatthe circuit yields higher efficiency as the number of stages increases.However, as more stages are introduced, the peak of theefficiency curve also shifts towards the higher power region. Thevoltage plot shows that higher voltage can be achieved by increasingnumber of circuit stages, but a corresponding increasein power loss is also introduced into the low power region.

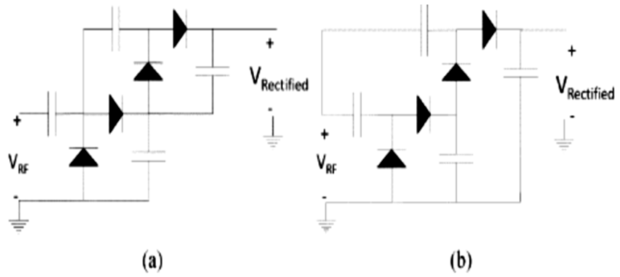


Fig. 10.(a) Villard multiplier and (b) Dickson multiplier.

C. Effect of Load Impedance

It is important that the load impedance be carefully selectedfor a specific energy harvesting circuit, whose impact on the circuitperformance can be seen in Fig. 5.We simulate the effect ofload impedance on the efficiency of the energy harvesting circuitusing Agilent ADS with parameters sweep of 20 to 20 dBmand 1–181 for input RF power and load value, respectively.
We observe that the circuit yields the optimal efficiency at aparticular load value, that is, the circuit's efficiency decreasesdramatically if the load value is too low or too high. The energyharvesting in simulation is five-stage circuit, each stage isa modified voltage multiplier of HSMS-2852, arranged in series.For the particular case of WSNs, the sensor mote draws adifferent amount of current when it in the active (all radios operational),low-power (radios shut down for short interval but internalmicrocontroller active), and deep-sleep (requires externalinterrupt signal to become active again) states. To correctly identifythe impedance in the deep sleep state, where we presumethe node harvests energy, we measure the voltage and currentof Mica2 sensor mote in deep sleep state to consume 30 at3.0 V, which translates to a 100- resistive load. A 100-resistive load is further used in our optimization.

D. Effect of RF Input Power

Since the energy harvesting circuit consists of diodes, whichare nonlinear devices, the circuit itself exhibits nonlinearity.This implies that the impedance of the energy harvesting circuitvaries with the amount of power received from the antenna.Since the maximum power transfer occurs when the circuit ismatched with the antenna, the impedance matching is usuallyperformed at the a particular input power. Fig. 6 depicts the effectof RF input power, ranging from 20 to 20 dBm, on theimpedance of the energy harvesting circuit. The nonlinearityin operation is shown by a sharp bend at 5 dBm. This furthermotivates our approach of a clear separation of two optimizedsister-circuits of the LDP and HDP, where each has its own (reasonably)constant impedance.

E. Energy Harvesting Circuit

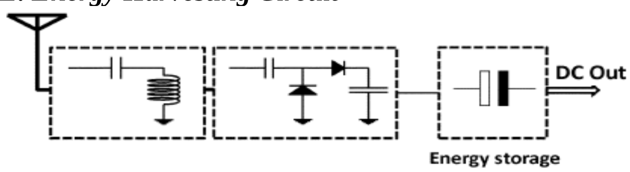


Fig. 11: Energy Harvesting Circuit

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

The simulation results obtained previously are under an assumptionthat all components, except Schottky diodes, exhibitan ideal behavior. With non-ideal components and parasiticeffects, this is rarely achievable in practice. Consequently, itis imperative that all related parasitic parameters and precisemodels of components have to be incorporated into the simulation.
This not only yields a closer result to that of the prototypebut also provides an upper bound on achievable efficiencywith respect to a particular prototype design. For this purpose,Agilent ADS simulation with co-planar waveguide with groundplane (CPWG) is used to observe the effect of the PCB. Moreover,components are modeled with ADS and vendor suppliedcomponent libraries. The effect of nonidealcomponents and PCB becomes clear as the received RF inputpower goes beyond 16 dBm. This implies that the fabricationmethod plays an important role on the performance ofthe energy harvesting circuit. “Systemon Chip” (SoC) is a highly recommended fabrication method,which however lies beyond the scope of this paper.With the effect of nonideal components and PCB, it is unlikelythat one can achieve the optimal result obtained in theoptimization section. We propose the use of multiple antennasin addition to the existing circuit..Antenna collects its ownsignal, connects to its own matching network and voltage multiplier.However, they all share the energy storage. Note thatthis concept does not increase conversion efficiency of the circuitsince the efficiency of the circuit remains the same. It is obvious thatboth voltage and efficiency of the circuit can be increased byintroducing additional antennas. However, the gain increase isnot linear and reduces drastically with additional antennas introduced.
This limits the amount of multiple antennas used forthe purpose of energy harvesting enhancement.The final fabricated PCB of our proposed energy harvestingmodule connected to a Mica2 mote. ThePCB is fabricated with FR-4 epoxy glass substrate and has twolayers, one of which serves as a ground plane. The prototypeconsists of the design obtained from the proposed optimization.
We select components with values and ratings of their performanceparameter as close as possible to ones obtained from thesimulation. This data is summarized in **Table 5**The energy harvesting circuit prototype is tuned to match simulationparameters using Agilent E5061B vector network analyzer.In order to measure dc power output from the prototype,Agilent N5181 MXG RF signal generator is used to provide aknown RF power to the prototype from 20 to 20 dBm. The dcoutput power from the prototype is obtained from measuring thevoltage and current associated with the resistive load of 100KOhm.

Table 5: Components value

Component	Value
Inductor	3.0, 7.12nH
Capacitor	1.5, 2.9pF
Stage Capacitor	36pF
Diode	HSMS-2852,HSMS-2822

We have more things to optimize the RF Energy harvesting. We can develop some of the energy harvesting specialized protocol for gaining energy from the Power radiator. We have to provide the current information of Energy stored in the nodes.

VI. CONCLUSIONS

From our most of the discussion and analysis of WSN RF Energy harvesting we have defined the hardware design issues. The discussion in the optimized research we included many of the aspects like the RF Antennas: Transmitting and Receiving. Not only this, we have discussed about the high frequency commercially available diodes. The Diodes are used to define the charge pump or multipliers to enhance the efficiency. The efficiency of the circuit can be increased by accurate usage of the diodes and capacitors. We can more optimize the charge pump circuit by parasitic extraction. Another important concept is storage of the converted energy. This can be achieved by super capacitor or by energy storage cells.

REFERENCES

1. N. Tesla, “The transmission of electric energy without wires,” in *13th Anniversary Number of the Electrical World and Engineer*, 1904.
2. J. Curty, M. Declercq, C. Dehollain, and N. Joehl, *Design and Optimization of Passive UHF RFID Systems*. New York: Springer, 2007.
3. J. A. Paradiso, “Systems for human-powered mobile computing,” in*Proc. 43rd Design Automation Conf. (DAC)*, Jul. 24–28, 2006, pp.645–650.
4. K.-W. Fan, Z. Zheng, and P. Sinha. Steady and fair rate allocationfor rechargeable sensors in perpetual sensor networks.In *SenSys ’08*, pages 239–252, 2008.
5. S. M. Jose, J. O. Mur-mir, R. Amirtharajah, A. P. Ch, andJ. H. Lang. Vibration-to-electric energy conversion. *IEEETransactions on Very Large Scale Integration (VLSI) Systems*,9(1):64–76, Feb 2001.
6. K. Klues, G. Hackmann, O. Chipara, and C. Lu. A componentbased architecture for power-efficient media accesscontrol in wireless sensor networks. In *SenSys ’07*, November2007.
7. Q. Li, J. Aslam, and D. Rus. Online power-aware routing inwireless ad-hoc networks. In *MobiCom ’01*, pages 97–107,2001.
8. [8] James M. Gilbert, FarooqBalouchi, “Comparison of Energy Harvesting systems for Wireless Sensor Networks”, International Journal of Automation and Computing, October 2008, pp:. 334-347
9. K. Martinez, R. Ong, J. K. Hart, J. Stefanov. GLACSWEB: A Sensor Web for Glaciers. In *Proceedings of European Workshop on Wireless SensorNetworks*, Berlin, Germany,pp. 46–49, 2004.
10. I. W. Marshall, C. Roadknight, I. Wokoma, L. Sacks.Self-organizing Sensor Networks. In *Proceedings ofUbiNet*, London, UK, [Online], Available:http://wwwdse.doc.ic.ac.uk/Projects/UbiNet/ws2003/papers/marshall.pdf, 2003.
11. R. Beckwith, D. Teibel, P. Bowen. Unwired Wine: SensorNetworks in Vineyards. In *Proceedings of IEEE Sensors*,IEEE Press, vol. 2, pp. 561–564, 2004.
12. A. Mainwaring, D. Culler, J. Polastre, R. Szewczyk, J. Anderson.Wireless Sensor Networks for Habitat Monitoring.In *Proceedings of the 1st ACM International Workshop onWireless Sensor Networks and Applications*, ACM, Atlanta,Georgia, USA, pp. 88–97, 2002.
13. P. Juang, H. Oki, Y. Wang, M. Martonosi, L. S. Peh, D.Rubenstein. Energy-efficient Computing for Wildlife Tracking:Design Tradeoffs and Early Experiences with ZebraNet.In *Proceedings of the 10th Architectural Supportfor Programming Languages and Operating Systems*, ACM,San Jose, USA, vol. 36, no. 5, pp. 96–107, 2002.
14. Z. Butler, P. Corke, R. Peterson, D. Rus. Virtual Fencesfor Controlling Cows. In *Proceedings of IEEE InternationalConference on Robotics and Automation*, IEEE Press, NewOrleans, LA, USA, vol. 5, pp. 4429–4436, 2004.
15. F. Michahelles, P. Matter, A. Schmidt, B. Schiele. ApplyingWearable Sensors to Avalanche Rescue.*Computers andGraphics*, vol. 27, no. 6, pp. 839–847, 2003.
16. UC Berkeley, MLB Company. The 29 PalmsFixed/Mobile Experiment: Tracking Vehicles with aUAV-delivered Sensor Network, [Online], Available:http://robotics.eecs.berkeley.edu/˜pister/29Palms0103/,April 27, 2008.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

17. G. Simon, M. Mar´oti, ´A. L´edezczi, G. Balogh, B. Kusy, A.N´adas, G. Pap, J. Sallai, K. Frampton. Sensor NetworkBased Countersniper System. In *Proceedings of the 2nd International Conference on Embedded Networked SensorSystems*, ACM, Baltimore, Maryland, USA, pp. 1–12, 2004.
18. S. H. Yang, P. Frederick. SafetyNET – A Wireless SensorNetwork for Fire Protection and Emergency Responses.*Measurement and Control*, vol. 39, no. 7, pp. 218–219, 2006.
19. C. Kappler, G. Riegel. A Real-world, Simple Wireless SensorNetwork for Monitoring Electrical Energy Consumption.In *Proceedings of European Workshop on WirelessSensor Network, Lecture Notes in Computer Science*, Springer-Verlag, vol. 2920, pp. 339–352 2004.
20. G. Z. Yang. *Body Sensor Networks*, Springer-Verlag, Germany,2006.
21. N. F. Timmons, W. G. Scanlon.Analysis of the Performanceof IEEE 802.15.4 for Medical Sensor Body Area Networking.In *Proceedings of the 1st Annual IEEE CommunicationsSociety Conference on Sensor and Ad Hoc Communicationsand Networks*, IEEE Press, pp. 16–24, 2004.
22. I. Stojmenovic. *Handbook of Sensor Networks: Algorithmsand Architectures*, John Wiley & Sons Inc, Hoboken, NewJersey, USA, 2005.
23. J. L. Gonzalez, A. Rubio, F. Moll. Human Powered PiezoelectricBatteries to Supply Power to Wearable ElectronicDevices.*International Journal of Society of Materials Engineeringfor Resources*, vol. 10, no. 1, pp. 34–40, 2001.
24. T. E. Starner. Powerful Change Part 1: Batteries and PossibleAlternatives for the Mobile Market. *IEEE PervasiveComputing*, vol. 2, no. 4, pp. 86–88, 2003.
25. S. Roundy, D. Steingart, L. Frechette, P.Wright, J. Rabaey.Power Sources for Wireless Sensor Networks.*Lecture Notesin Computer Science*, Springer-Verlag, vol. 2920, pp. 1–17,2004.
26. L. Mateu, F. Moll. Review of Energy Harvesting Techniquesand Applications for Microelectronics. In Proceedings of SPIE – The International Society for Optical Engineering, VLSI Circuits and Systems II, SPIE Press, vol. 5837, pp.359–373, 2005.
27. T. von B¨uren. Body-worn Inertial Electromagnetic Microgenerators, Ph.D. dissertation ETH 16466, Swiss FederalInstitute of Technology, Zurich, Germany, 2006.
28. A. H. Sellers, P. J. Robinson. Contemporary Climatology,Longman Scientific & Technical, Essex, UK, 1986.
29. J. L.Monteith, M. H. Unsworth. Principles of Environmental Physics, Edward Arnold, London, UK, 1990.
30. S. J. Roundy. Energy Scavenging for Wireless Sensor Nodeswith a Focus on Vibration to Electricity Conversion, Ph.D.dissertation, University of California, Berkeley, USA, 2003.
31. K. Finkenzeller. RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification,John Wiley & Sons, 2003.
32. T. Starner. Human-powered Wearable Computing. IBM Systems Journal, vol. 35, no. 3, pp. 618–629, 1996.
33. Highway Energy Systems Ltd., [Online], Available:http://www.hughesresearch.co.uk/, March 6, 2008.
34. M. Trew, T. Everett. Human Movement: An IntroductoryText, Churchill Livingstone, 2001.
35. S. J. Roundy, P. K. Wright, J. Rabaey. A Study of LowLevel Vibrations as a Power Source for Wireless SensorNodes.Computer Communications, vol. 26, no. 11, pp.1131–1144, 2003.
36. H. P. Tan, Z. A. Eu, and W. K. Seah, "Impact of Power Control in Wireless Sensor Networks Powered by Ambient Energy Harvesting for Railroad Health Monitoring," in Proc. of the 2nd Intl Workshop on Applications of Ad hoc and Sensor Networks (AASNET), Bradford, UK, May 26-29 2009.
37. Z. A. Eu, H. P. Tan, and W. K. G. Seah, "Routing and relay node placement in wireless sensor networks powered by ambient energy harvesting,"in Proc. of the IEEE Wireless Communications & NetworkingConference (WCNC), Budapest, Hungary, Apr 5-8 2009.
38. Z. A. Eu, W. K. G. Seah, and H. P. Tan, "A Study of MAC Schemes forWireless Sensor Networks Powered by Ambient Energy Harvesting," inProc. of the Fourth Intl Wireless Internet Conference (WICON 2008), Maui, Hawaii, USA, Nov 17-19 2008.
39. FCC Codes of Regulation, Part 15 [Online]. Available: http://www. access.gpo.gov/nara/cfr/waisidx03/
40. Gianni Giorgetti, Alessandro Cidronali, Sandeep K.S. Gupta, Gianfranco Manes," Exploiting Low-Cost Directional Antennas in 2.4 GHzIEEE 802.15.4 Wireless Sensor Networks", IEEE2011, pp:2098-2101

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)