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# ŹRÓDŁA I TECHNIKI ENERGII DLA WSN

**Streszczenie:** W bezprzewodowych sieciach czujników (WSN) w celu poprawy wielu wskaźników wydajności (na przykład niezawodności, czasu życia sieci, przepustowości i opóźnienia) jednym z najważniejszych problemów jest optymalizacja wielkości pakietów. W systemie WSN ze względu na złe warunki kanału przesyłowego dłuższe pakiety są bardziej narażone na przekłamania. Z drugiej strony, małe pakiety mogą mieć przewagę. Dlatego należy wybrać maksymalny rozmiar pakietu, aby zwiększyć wydajność różnych metryk wydajności WSN. W tym celu przeanalizowano wiele metod w celu określenia maksymalnego rozmiaru pakietu w WSN. W literaturze, badania korekcyjne wielkości pakietu dotyczą docelowych środowisk wdrażania lub konkretnych aplikacji. Nie ma jednak najnowszych i obszernych dokumentów z badań, które zaklasyfikowałyby te różne metody. Aby sprostać temu zapotrzebowaniu należy zachęcić szerszy krąg naukowców i badaczy technologii do poprawy kształtowania rozmiaru pakietu danych w sieci czujników. Głównym celem tego artykułu jest wykorzystanie wybranych metod w różnych typach sieci i aplikacji czujnikowych w celu lepszego zrozumienia różnych metod optymalizacji pakietów. A także stawianie nowych otwartych problemów badawczych i wyzwań w tym obszarze.

**Słowa kluczowe:** optymalizacja wielkości pakietów, projektowanie między-warstwowe, niezawodność sieci, wydajność energetyczna, sieci czujników bezprzewodowych.

# SOURCES AND TECHNIQUES OF ENERGY FOR WSNs

**Summary:** In wireless sensor networks (WSNs) for bettering many performance metrics (e.g. reliability, network lifetime, throughput, and delay) one of the crucial concerns is a packet size optimization. In WSN, due to poor channel conditions, longer packages are more harmful. On the other hand, small packets may be full of head over. Therefore, maximum packet size should be selected to increase the performance of various WSN performance metrics. By this end, many methods have been analyzed to determine the maximum size of packet in WSN. In the literature, package size correction studies target deployment environments or specific applications. However, there are no recent and comprehensive survey documents to classify these different methods. To meet this demand, to encourage further research and technology research community to improve the underground sensor network's data packet size to further improve this research field. The main purpose of this paper is used in various types of sensor networks and applications, and to better understand the different packet optimization methods of opening open research issues and challenges in this area.

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**Keywords:** packet size optimization, cross-layer design, network reliability, energy efficiency, WSNs.

## 1. Introduction

Energy efficiency: Research on the wireless sensor network is encouraged by common concern (and some limits). WSN nodes are generally powerful by batteries. Once their energy will end, the node will crash. "Battery can be changed or charged only in very specific applications. However, the alternative / recharge operation is slow and expensive, and if possible, the network performance has deteriorated. Therefore, various techniques have been presented to reduce consumption of battery control, including power control and duty cycle-based operations. Later technology is the leading technology in low power mode of wireless transceivers, whose components can be turned off to save energy. When a node is at low power (or "sleep"), it consumes less power than the on transceiver [1], [2], [3]. However, while the node is in sleeping state packets cannot be receive or transmit. The ratio in the time on node is and the sum of the times when the node is asleep and on is represented by the duty cycle.

A protocol that runs a low duty cycle is a leading solution to implement sustainable WSN [4]. However, there are two main deficiencies to this approach. 1) A moderate trade is closed between energy efficiency (i.e. low duty cycle) and the dimension of the data, and 2) Battery-powered wireless sensor networks cannot meet the needs of many emerging applications that require a couple of decades of network life. Battery leak can batter the battery in a few years, even if they are at least used [5], [6]. For those reasons, the recent perspective of continuous wireless sensor network studies has taken a different approach; it suggests that the energy consumption combined with reverse chargeable batteries and supercapacitors (for energy storage) is permanent "WSN Operation "is the main driver.

Based on the energy-efficient wireless sensor, the wireless sensor network (EHWNN) has the ability to extract energy from the surrounding environment of WSN Nodes. Energy harvesting can utilize different energy sources such as solar energy, wind energy, mechanical vibration, temperature changes, magnetic fields, etc. Energy harvesting subscribers continually provides and store energy for future use, and allows WSN nodes to be permanently saved.

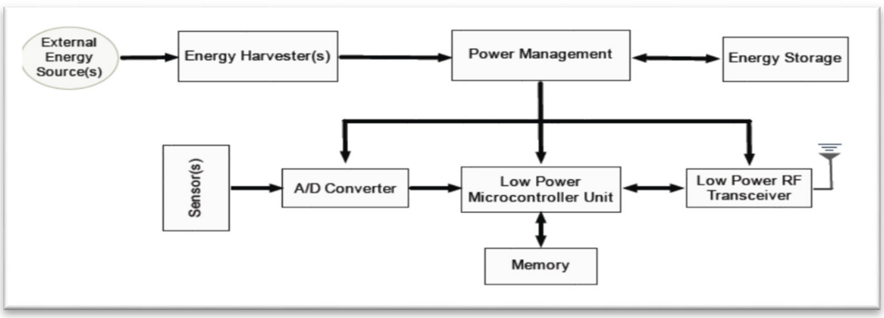


*Figure 1. System architecture of a wireless node with energy harvesters.*

The following components include the built-in wireless sensor node system (Figure 1) The energy harvester(s), that transform energy produced by an external environment or energy generated by human to electricity; 2) a power management module,which collects or store electrical energy from excavation or gives it in other system components for instantaneous use.; 3) energy storage, Used to preserve harvested energy for future use; 4) a microcontroller; 5) a radio transceiver, Used to send and receive information; 6) sensory equipment; 7) an A/D converter to convert the analog signals to digital which has been generated by the sensors and Provided for further processing to microcontroller, and 8) Memory for storage of sensing information, code and application data.

## 2 Different types of techniques and sources of energy

Figure 1.4 displays different energy types that can be harvested. In this section we provide their brief description and related references.

### 2.1 Mechanical energy harvesting

This represents the process of transforming mechanical energy into electrical energy by using vibration, mechanical stress and pressure, sensor level stress, high voltage motor, waste rotary movement, fluid and power. The principle behind harvesting of mechanical energy is to transform the spring mounted mass component's oscillations and displacements energy inside the harvester into energy of electricity [7, 8]. Mechanical energy harvesting can be: *Piezoelectric*, *electrostatic* and *electromagnetic*.

#### 2.1.1 Piezoelectric energy harvesting

It is based on the piezoelectric effect, and for this mechanical energy from vibration, pressure or force is converted into electrical energy by deforming the piezoelectric material. The piezoelectric harvester technology is generally established on a beam structure with an unstable bulk is connected into a piezoelectric beam that has attached on both sides of the piezoelectric stuff [8]. Specifically, piezoelectric produces stress on digestive material, which creates an electrical field that proportionate the voltage of the stress generated voltage [3]. Voltage changes based on stress and time and produce unorganized AC signals. Piezoelectric energy transformation has the benefit of directly generating a basic voltage without the need for an independent voltage point of supply. However, Piezoelectric Material Breaks are capable and may be affected by leakages [9], [10], [8]. Piezoelectric energy harvester's examples and references can be found in [11], [12], [13], [14], [15].

The principle of electrostatic energy harvesting is based on vibration based on the ability of a variable capacitor to change [16, 17]. To achieve mechanical energy, variable capacitors developed by variable plates, a plate has been stable, a other is moving, and initially charged. When the plates are separate by vibrations, by the capacitance change electrical energy is generated from mechanical energy. This type of harvesters can be added to microelectronic devices due to the compatibility of its integrated circuits. [18]. However, primarily requires an additional voltage source to charge the capacitor [10]. Recent attempts to collect prototype sensor sized electrostatic energy can be found in [19, 20].

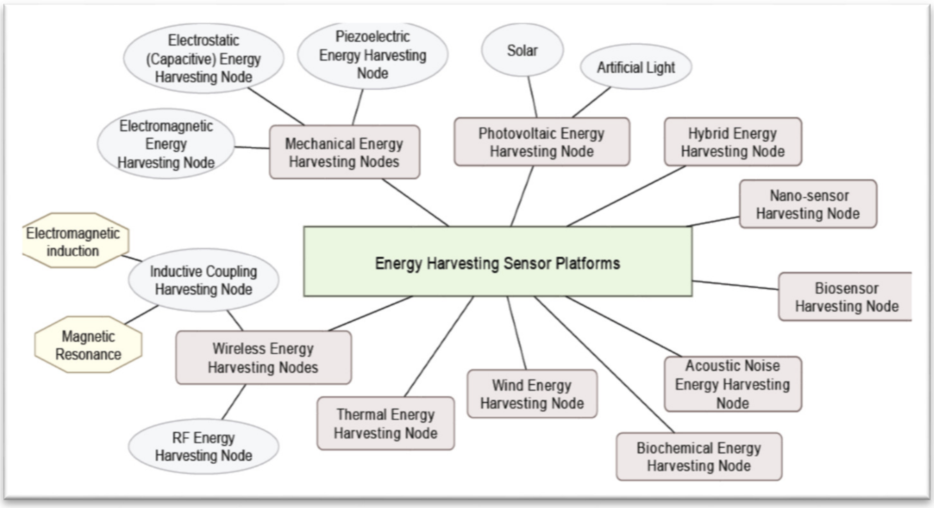


*Figure 2. Different energy types (rectangles) and sources (ovals)*

### 2.1.2 Electromagnetic energy harvesting

It is based on the form of electronic magnetic deployment of the faraday's law. Electromagnetic magnet transforms mechanical energy into electrical energy using a inductive spring mass system. It moves the voltage by moving a large quantity of magnetic materials through the magnetic field generated by fixed magnet. Specifically, the spring-connected magnetic vibration of the coil changes the magnetic flow inside the coil and generates an enthusiastic voltage. [16], [8], [21]. The advantages of this approach are not included in mechanical contacts between the part and the individual voltage source, which increases the reliability of the customer and reduces mechanical dumping [9, 17]. However, due to large scale electromagnetic materials, it is difficult to integrate them into the sensor nodes. [9]. some examples of electric power harvesting system are given in [22, 23].

### 2.2 Photovoltaic energy harvesting

It is the process of transforming electromagnetic waves coming from different sources like artificial light or solar light into electricity. Through photovoltaic (PV) cells photovoltaic energy can be used. These include two different types of semiconductor materials called P-type and N-type. Between these two materials, a power field is formed in the contact area called PN junction. Electron will releases by a photovoltaic cell when dealing with light. Photovoltaic energy conversion has mature, conventional, and commercially consumed energy consumption technologies. It offers high power output levels compared to other energy-saving techniques for a large power plant. However, this power and system performance depends largely on the availability of light and environmental conditions. Other factors, including material used in photovoltaic cells, affect the electrical efficiency and level produced by photovoltaic energy harvesters. [9, 24]. Some recent photovoltaic harvester's prototypes are characterized in [25], [26], [27], Known implementations of solar energy harvesting sensor nodes include Envenomate, Everlast, Trio, Solar Biscuit and Fleck.

### 2.3 Thermal energy harvesting

It is achieved by thermoelectric energy harvesting and pyroelectric energy harvesting.

#### 2.3.1 Thermoelectric energy harvesting

It is the process of using thermoelectric power generators (TEGs) to transform temperature difference (thermal gradients) to electric energy. The main element of a TEG is a thermopile formed by arrays of two different multiple conductors, namely P-type and n-type-type semiconductor (thorcup) attached to a hot and a cold plate and in the series.

The thermoelectric collector removes the energy according to the see beck effect, indicating that the voltage is generated when two different metals connected to two genes are kept at different temperatures. [28]. this is because the difference between the metal temperature difference, the heat flows through the thermometer generator. It generated a voltage difference which is balanced with the temperature difference between cold and hot plates. When thermal patient is born, thermal energy is converted into electricity. As long as temperatures are maintained, energy can be obtained.

#### 2.3.2 Pyroelectric energy harvesting

This is the process of generating voltage by heat heating or cold breaks. This material does not require the same rating of the thermocouple. Rather, it needs a temperature change that changes over time. Temperature change transforms atomic position in crystal structure of thermoelectric material, thus generating a voltage. To maintain the power generation, the entire crystal should be affected by temperature changes. Otherwise, due to leak current, the generated vector voltage generated gradually disappears. [29].

In contrast of thermoelectric harvesting higher efficiency is achieved by pyroelectric energy harvesting. It supports collections from high-temperature sources and is easy to operate with a limited level of heat transfer. On contrary, greater energy levels harvesting is provided by thermoelectric energy harvesting. The Carnot cycle restrict thermal energy harvester's maximum efficiency [16]. Due to different sizes of thermal deposits, they can put on structure, equipment and human body. Some examples of such deposits are described for the WSN nodes [30, 31].

There are two broad categories of Wireless energy consumption techniques: RFC energy shortage and resonance energy shortage.

#### 2.3.3 RF energy harvesting

It is the process of using rectenna or rectifying antenna to transforming electromagnetic waves into electricity. Energy either is harvested from ambient RF power sources like cellphones, television and radio broadcasting, microwaves and Wi-Fi communications, or from of particular wavelength EM signals. Though there is a large number of possible RFC power, the current EM waves are extremely low, because the signal travels away from the source, the energy is fast. Therefore, in order to effectively remove RF energy from existing environmental waves, the harvester must be kept adjacent to RF source. One more possible way to produce more energetic EM signals only for strengthen sensor nodes is to use a special RF transmitter. Relay upon the range between the harvester and the RF transmitter powers from micro-watts to few milliwatts are efficiently delivered by alike RF energy harvesting.

### 2.3.4 Resonant energy harvesting

Resonant inductive coupling is the second name of resonant energy harvesting, is the process of harvesting and shifting electrical energy in the couple of coils, which are greatly profound at the same frequency. Specifically, an external ratio transmission device, which comes with a basic coil, can send electricity from a secondary coil to an instrument through the air. Basic coil produces different magnetic flows of a time that passes secondary coil to generate voltage. Generally, there are two possible processions of resonant inductive coupling: Weak inductive coupling and strong inductive coupling. In the first case, there should be very minimum space between the coils (few centimeters).

However, if the received coil is appropriately set to satisfy the external power supply coil, a strong pair can be established between the electromagnetic resonance devices, and power can be supplied over long distance power. Note that the resonance of metallurgical pair is considered to be a wireless energy-saving technique because the primary and secondary components are not physically connected. In [32], [33], [34] the latest wireless power planting techniques can be processed.

## 2.4 Wind energy harvesting

It is the process of airflow change (for example, air) power in electrical energy. Shaped air turbine is used properly to use electric linear movement to generate electricity. There are small wind turbines that produce enough energy to power the WSN nodes [35]. However, the overall effectiveness of the air-scale air-conditioning continues to be a continuous study, subject to very low flow rates, flow of wind power, and unexpected potential of flow sources. In addition, although the efficiency of large air turbines is efficient, small air turbines perform less due to relatively small viscous drag on the blades at low Reynolds numbers [36, 7]. Examples of recent air-energy reserves systems designed for wireless sensor networks are [35], [37], [38], [39].

## 2.5 Biochemical energy harvesting

This is the way to convert oxygen and physical substance through electric chemical reaction to electric energy [40, 41]. Specifically, biophilic cells can be used as active enzymes and catalysts to collect biological energy from biological fluid to electrical energy. There are many substances with the ability to harvest fluid in human body [42]. Of them, glucose is the most common source of fuel. In principle, when carbon dioxide and water is oxidized, 24 electrons per molecule are released. Although biochemistry can be better than energy-efficient energy production and other energy harvesting techniques, [40] its performance depends on the type and availability of fuel cells. The advantages and losses of using anti-ferrous fuel cells to generate energy are described in [43]. Investigation work such as 49 [44], [40], [41] is an example of a recent prototype that uses biochemical power shortage for electricity to microelectronic devices.

### 2.6 Acoustic energy harvesting

It is a process of converting high and continuous sound waves from the environment into electrical energy by using an acoustic transducer or resonator. The harvestable acoustic emissions can be in the pattern of transverse, longitudinal, hydrostatic, and bending waves starting from very minimum to maximum frequencies [45]. Usually, sound energy is stored for situations where local long-term power is not available, such as remote or isolated places, or when cables and electrical accuracy is difficult to use, such as system entrance sealing or rotating [45, 46]. However, the power of the harvesting is unbearable and this energy can be achieved in noisy environment. Acoustic wave's harvestable energy theoretically yields 0:96W=cm3, this is much lower than what other energy harvesting technologies can achieve. In this case, limited research has been conducted to study this kind of harvesting. Such examples of the sound energy collection system can be found in [47, 48].

*Table 1. Power density and efficiency of energy harvesting techniques.*

| Energy harvesting technique | Power density | Efficiency |
|---|---|---|
| **Photovoltaic** | Outdoors (direct sun): 15 $mW/cm^2$<br>Outdoors (cloudy day): 0.15 $mW/cm^2$<br>Indoors: <10 $\mu$W=cm2 [9, 9, 10, 49] | Highest: 32 _ 1:5%<br>Typical: 25 _ 1:5% [50] |
| **Thermoelectric** | Human: 30 $\mu$W=cm2<br>Industrial: 1 to 10 mW=cm2 [59, 49] | ± 0:1%<br>±3% [49] |
| **Pyroelectric** | 8.64 $\mu$W=cm2 at the temperature rate of 8:5° C/s [52] | 3.5% [53] |
| **Piezoelectric** | 250 $\mu$W=cm3<br>330 $\mu$W=cm3 (shoe inserts) [9, 10] | *A* |
| **Electromagnetic** | Human motion: 1 to 4 $\mu$W=cm3 [38]<br>Industrial: 306 $\mu W=cm^3$ [54], 800 $\mu W=cm^3$ [38] | *A* |
| **Electrostatic** | 50 to 100 $\mu$W=cm3 [21] | *A* |
| **RF** | GSM 900/1800 MHz: 0.1 $\mu$W=cm2<br>WiFi 2.4 GHz: 0.01 $\mu$W=cm2 [9] | 50%b [55] |
| **Wind** | 380 _W=cm3 at the speed of 5 m/s [13, 56] | 5% [13] |
| **Acoustic noise** | 0.96 _W=cm3 at 100 dB<br>0.003 _W=cm3 at 75 dB [57, 24] | C |

*a* Noise power density are theoretical values
b Maximum power and efficiency are source dependent.
c Excluding transmission efficiency
The first described techniques can be combined and can be used together on the same platform (mixed energy deficiency). Table 1.1 gives a bird's eye view of different sources of energy. For every energy-saving technology, we show its power density and conversion efficiency. The harvested energy per unit area, mass, or volume expressed by the power density. Watts per square centimeter and watts per cubic centimeter are the common unit for measurement of power density. Conversion efficiency is defined as the ratio of harvested electrical power to harvestable input power. Performance of energy conversion is a latitude number between 0 and 100%.

## 3. Main open research issues

Although some great research has been done on the development of wireless HE intervention, there are still some open investigative challenges that will be solved in the future. We will discuss some of these in this section.

### A. Effective interference management with low complexity

Using intervention in the SWIPT system, information can also be transmitted with energy, and interference affected the QoS of IT. Thus, interference management issue is a key challenge for the interference-based wireless EH that must be solved. As described in Section III-D, there are two main ways to implement intervention management, i.e., interference alignment and beamforming optimization.

#### 1) Beamforming optimization

The first way is to deal directly with transceiver beamforming, especially in the wireless HE system. The beamforming design is usually customized with PS ratio. The combined reform issue is a non-convex problem that is difficult to solve. Although many submitting algorithms have been suggested to solve the combined correction problem, e.g., linear programming, semi-definite programming, game, and second- order cone programming, the compulsory complexity of the original system is still high. Therefore, less complexity for joint mathematics and PS correction should be devoted to more efforts for the development of suboptimal algorithms.

#### 2) Interference alignment

IA Wireless Network is a passionate technology to interfere with interference and it can be used to interfere with the wireless EH system. Even though the IA-based wireless H-performance is the best, there are still some challenges, one of which has its virtual computational complexity. First, the closed-form solutions of IA cannot be derived when there exist more than 3 users in the network, and thus some iterative algorithms should be leveraged to obtain the solutions of IA with relatively high computational complexity. Second, the accurate channel state information (CSI) of the whole network should be available at each node to obtain the solutions of IA, which is surely a strict requirement. Although there are plenty of research works that focus on these aspects of IA, there is still a long road ahead. Therefore, we should pay much more attention on the directions that make IA more suitable and practical for wireless EH.

**B. Efficiency of wireless energy harvesting**

Another challenge is the efficiency of wireless EH. Although wireless signal can carry energy as well as information, which can be harvested as a power source, the power strength of the wireless signal is attenuated seriously as the distance of transmission becomes longer. For the resonant inductive coupling and magnetic resonance coupling [58]– [59], the power strength is attenuated 60 dB per decade of distance, which means the power strength is decreased by 106 times with the increase of distance by 10 times. Thus, these two methods are only suitable to be utilized for the near-field applications of wireless EH with limited distance. For the wireless RF energy harvesting, it is suitable for the far-field applications of wireless energy transfer with relatively longer distance.

Nevertheless, the power strength of wireless RF energy harvesting is also attenuated 20dB per decade of distance, and it is not efficient or even not suitable when applied to the scenarios with much longer distance [8]. Besides, due to the regulations of government, e.g., the federal communications commission (FCC), the radiated power is limited, and the wireless EH is thus limited to be applied within a very small area. Thus, wireless EH is only suitable to be utilized in some low-power small-area networks, such as wireless sensor networks and wireless body networks. In the future research of this direction, much more efficient wireless EH schemes should be derived, in order to expand its applications. For example, the receive antennas for wireless EH with much higher gain and much better direction performance should be designed, and much more efficient RF-to-DC converters should be developed, etc.

**C. Energy-efficient algorithms**

The algorithms for the wireless EH system that exploits interference are usually very complex, due to the fact that the beamforming matrices should be optimized or the solutions of IA should be calculated to manage the interference as well as to optimize the perform of IT and EH. In addition, in the existing algorithms, the global CSI of the interference network is usually required by the nodes, which is also not easy to obtain.

On the other hand, the harvested energy is usually limited, due to the path loss of the wireless channels and the conversion loss of the EH terminal. If the consuming power of obtaining CSI and performing the beamforming algorithm at the receiver is no less than the collected power through EH, there seems to have no need to perform EH. Besides, more antennas will consume more power, and the number of antennas at the wireless EH powered communication nodes should be limited to save energy. Thus, there exists a tradeoff between the power consumption of nodes supported by the wireless EH and the power harvested by these nodes. For the SWIPT users, information receiving is more sensitive than the energy receiving. When the users are far from the interference energy source, there may be no need to perform wireless EH with information transmission still performed. Thus, we should decide whether wireless EH should be performed for the SWIPT receiver adaptively. Therefore, in the future, more energy-efficient beamforming algorithms should be developed to save energy at the receivers of the wireless EH system that exploits interference, which is essential to the wireless EH systems and thus will surely become one of the key challenges.

**D. Stability of the interference energy resource**

In the wireless, EH systems that mainly depend on the ambient interference, the energy source is not stable all the time, which will surely affect the stability of the wireless EH. At the peak time, e.g., the day time, more active users may exist in the network, the resource of interference for wireless EH is sufficient, but the transmission requires more energy too; while at the off-peak time, e.g., midnight, fewer active users exist in the network, the resource of interference for EH is insufficient, but the information transmission also requires less energy. Thus, it is a key problem to balance the wireless EH between the peak time and the non-peak time, and schedule the power utilization and storage adaptively.

In addition, the power resource of the interference can change dynamically in a short time, because some strong interference may disappear suddenly. Therefore, it is a challenge to perform the wireless EH from dedicated energy source or from the ambient interference according to the requirements of the systems adaptively.

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