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Low-power Renewable Possibilities for Geothermal IoT Monitoring Systems

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Abstract – Nowadays, humanity is facing a difficult challenge focused on the sustainability of further years. One of the major ways is the usage of renewable energy as a sustainable and reliable source of electric power. This trend is also obvious in the field of the Internet of Things, where research teams are increasingly focusing on renewable energy and its improvement. This paper aims to map current research on the use of renewable resources on the Internet of Things with a focus on use in geothermal applications. Information concerning renewable energy sources and individual IoT platforms is summarized.

Keywords – Internet of Things, Renewable energy, Low-Power, Geothermal, TEG

1. Introduction

Today, we are witnessing a huge increase in Internet of Things (IoT) devices around the modern world. Due to the global pressure to expand renewable energy sources, we are increasingly encountering these technologies within the IoT[1]. IoT monitoring systems consist of a big amount of one-purpose devices, which can monitor the actual condition of the environment or a specified device using sensors. The aim is also to provide a power supply wirelessly and make the device long-term self-sufficient. This can be solved by a battery, but we come across the term Energy Harvesting, ie obtaining electricity using innovative technologies using available renewable resources[2].

Typical limitations of the renewable energy sources are discontinuous energy providing, the total amount of energy, and energy-storing. It is possible to use a geothermal or heat-based energy generator, which does not depend on the sun, or weather, due to source discontinuities. The occurrence of usable water resources is also limited[3].

Geothermal energy is a source of renewable energy that uses available heat from the ground. There is no problem with the discontinuity of the geothermal heat source and ideally, it can last forever. The amount of harvested energy strongly depends on the performance of thermoelectric materials and the source of heat[3], [4]. Another big advantage of geothermal energy is energy generation without the need for moving parts such as turbines, which eliminates maintenance and extra cost[5].

This paper aims to present the results of actual research in the field of geothermal energy for IoT purposes. Different kinds of IoT communication technologies for geothermal monitoring systems are summarized. This review publication is also the basis for the following activities in the field of condition and temperature monitoring in heat exchanger installations.

2. The approach in Geothermal Renewable energy

In recent years, many researchers published their work in this field, due to the advantages of using geothermal energy or other heat sources as a source of power for supplying IoT devices[1], [3]–[15]. It is necessary to first consider the possibilities of available geothermal energy and choose the appropriate procedure and IoT equipment accordingly. Table 1 presents detailed information of selected papers.

Most researchers used a thermoelectric generator TEG as a power supply for the designed IoT monitoring system. TEG systems consist of three key elements such as heat exchanger, thermoelectric module, and heat sink[5]. The basic element is to create a difference in the temperature between the hot and cold sides of the thermoelectric module.

Jouhara et al. in their publication [5] deeply explain the basic principle of TEG and its applications and limitations. They also shared information about different materials of TEGs and discuss physical background. The case study is also presented with surrounding simulations of the heat flow. **Error! Reference source not found.** presents basic principle of TEGs and typical IoT sensor system.

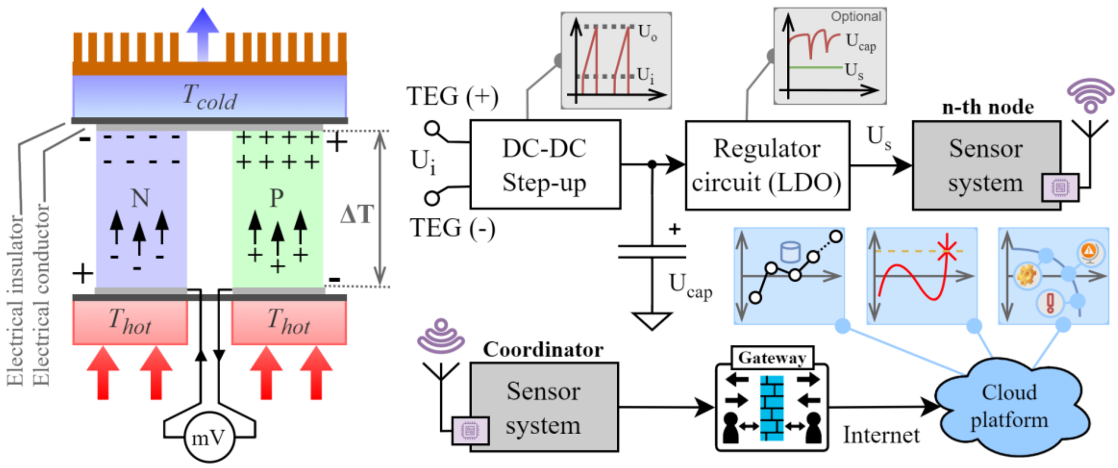

Figure 1. Seebeck effect - Principle of TEG[5]; Example of typical IoT sensor system[4], [16]

It is also necessary to be able to convert generated power in mV to a more suitable supply voltage with so-called DC-DC boosters[17]. Hou et al. [4] presented a novel paper about voltage booster circuits for wireless sensor networks with an energy conversion rate of up to 27%. Richelli et al. in their review [18] also discussed DC-DC boosters, which are fully integrated and embedded for IoT purposes.

The configuration chosen is an important factor when dealing with a solution with a higher number of TEGs. It allows reach higher density, smaller size, higher open-circuit voltage with higher internal resistance, and consequently small size of the P-N junctions themselves. Wan et al. in analyzed in their work[19] different architectures and configurations of TEGs. They were able to reach an efficiency of more than 88%.

Thermoelectric cells and generators are also used in utility networks. In their publication[20], Machacek et al. subjected several thermoelectric generators and Peltier cells to laboratory tests in order to find a suitable source of electricity to power flow measurement equipment. They also presented the measurement system and the concept of the flow meter. LoRa and SigFox were used to send the results.

3. Sustainable and reliable Internet of Things

Wireless communication technologies became preferred for many years due to their advantages (no wires, big distances, standalone)[21]. However, in the case of geothermal energy, various limiting factors should be considered, such as the total amount of generated energy, communication distances, IoT node consumption, different shield platform, total cost, technology availability, and environmental conditions[22]. **Error! Reference source not found.** presents the properties of the most used technologies for IoT.

IoT monitoring systems are increasing in shallow geothermal energy structures. IoT monitoring technologies in renewable energy are expected to increase due to their low cost, efficiency and sustainability. Moreover, these solutions offer advantages in remote areas where they can collect important data for many years for necessary analysis[22].

Table 1. Examples of heat sources, harvesting methods, and amount of generated energy

Article	Energy source	Harvesting technology	Power output	Size; ΔT_{avg}	Power delivery	IoT technology information, etc.
Mona **[1]**	Hot water (geyser)	Thermoelectric generator 20x	Up to 1,86 W; 12,4 V	Unknown; 65 °C	Continuous	Wi-Fi, Diff. temperatures and water flow, multiple TEGs
Tuoi **[3]**	Ambient air (fluctuations)	TEG #1 and #2	TEG #1: 0,2 mW/cm^2 TEG #2: 0,45 mW/cm^2	22 × 22 × 3,8 mm; 7 °C 40 × 40 × 3,8 mm; 7 °C	Continuous	33% efficiency of DC-DC circuit at ΔT = 6,3 °C
Hou **[4]**	Heater (experiment)	TEG TGM287-1.0-1.3	32,7 - 34,7 mW	40 × 40 × 3,6 mm 14 - 16 °C	Continuous	DC-DC and harvesting capabilities, feasibility study
Catalan **[16]**	Soil (heat) (volcano)	GTEG 2x TG12-8-01LS	Up to 0,34 W; 1,65 V	(2x) 40,1 × 40,1 × 3,5 mm 71,8 °C (T_H = 81,8 °C)	Continuous Better at night	LoRa (RFM95W), usecase information, T_{Cavg} = 10 °C

TEG – Thermoelectric generator**; GTEG** – Geothermal TEG; **TENG** - Triboelectric Nanogenerator; **T_C, T_H** – Temp. of cold/hot side

Table 2. Examples of suitable IoT communication technologies for geothermal energy

Protocol	Data rate	Maximum range	Typ. power consumption	Available HW: Platform	Available HW: Module, SoC
NB-IoT	<127 kbps [23] <250 kbps [21]	<100 [22], [23] 35 [21]	14/**23** dBm @ 74 - **220** mA [22], [23]	SIM7020E-NB-IoT-HAT#; XBee#	SIM7020E; SARA-R4#; XBee#
LoRaWAN	<50 kbps [21], [23]	2 - 18 km [22], [23] 15 km [24]	**14**/22 - 30/20 dBm @ **28** mA [23] **14**/27 dBm @ <**28** mA [22]	WizzKit#	LORA-E5#; SX1276#
SigFox	0,1 kbps [24] 600 bps [23]	10 - 50 km [22]–[24]	**14**/22/30 dBm @ 10 - **50** mA [23] 12 - **14** dBm @ 10 - **50** mA [22]	WizzKit#	
ZigBee	<250 kbps [25]	10 - 100 m [21] 291 m [25]; 300 m [24]	0 dBm @ 9,3 mA [26] 0 dBm @ <30 mA [25]	CC2652P#; XBee#	CC2530#; XBee#; QPG7015M#
IQRF	<20 kbps [24], [25]	<1 km [25]	<**11** dBm @ 8,3 - **19** mA [27]	IQRF Click-2586#; IQRF-DS#	IQRF-TR-7x#

M – MCU with module; **D –** Only module/shield; # - Link, if available

Each communication technology has its specifics. When choosing a suitable communication technology, it is advisable to consider the amount of data sent, the communication distance, the total consumption, or the final price of the monitoring system. Communication distance and landscape profile play an important role in the selection[22]. The **Error! Reference source not found.** describes common IoT technologies and how they relate to each other in terms of transmission speed, range, or power consumption.

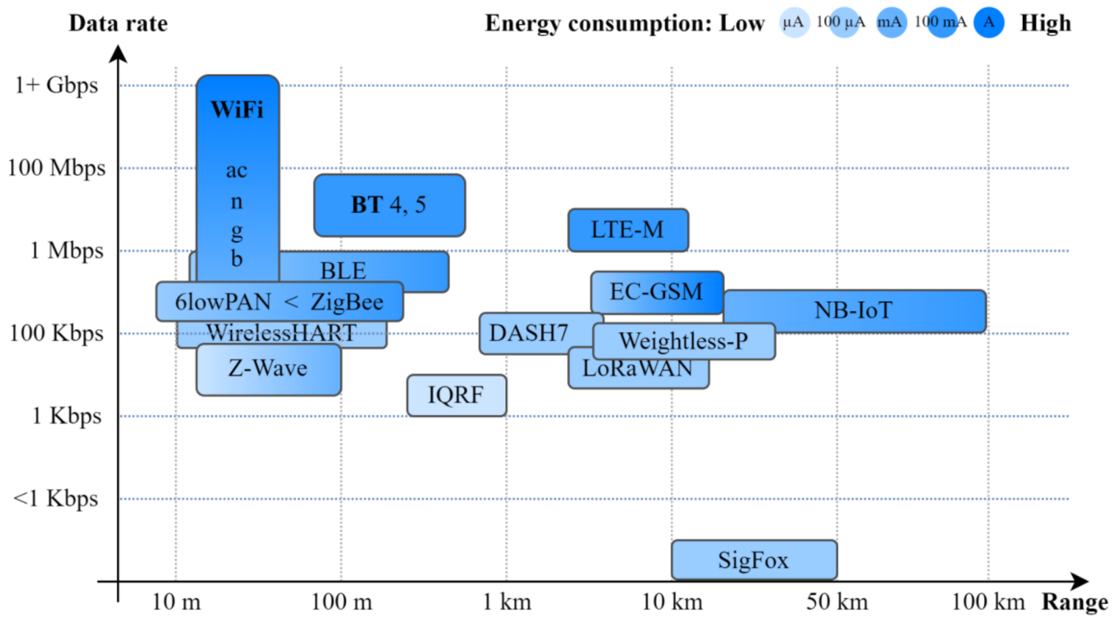

Figure 2. An overview of the features of available and common IoT technologies.

4. Case study – IoT consumption measurement

In order to be able to deploy a given platform in a measuring system, it is necessary to know its operating characteristics. This part of the paper is devoted to the power measurement of our selected IoT platform, which is based on the ESP32 chip and BLE communication interface used as a iBeacon transmitter. Programming code is based on mbedOS with DeepSleep mode. After a DeepSleep a simple program sequence is run:

DeepSleep -> WakeUp -> DS18B20 Read -> BTConfig -> Beacon (100ms) -> DeepSleep

Figure 1 contains a graph of the measured power consumption of three program sequences. Every sequence draw about 0,022217 mAh in total. Measurements were performed automatically using LabView, Agilent 34410A and U3606A digital multimeter.

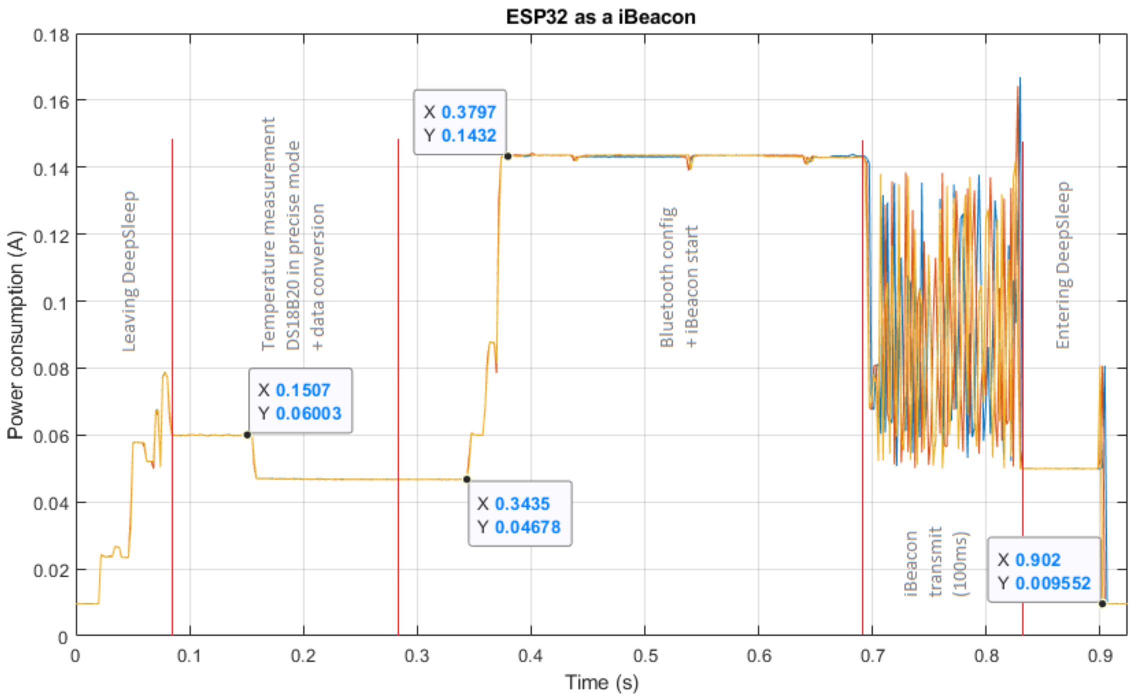

Figure 3 Three measurements of power consumption of described sequence.

5. Conclusion

Based on the literature review and articles found, low-cost, sustainable, and open standard IoT monitoring systems are used in the field of renewable geothermal energy. Most of the research is based on thermoelectric generators (TEGs), but there are different types of energy sources ranging from solar heating, wind cooling, or using available local heat source (volcano, geyser, hot springs). Careful consideration should always be given to the available environmental conditions and the objective of the measurement system being designed.

The field of geothermal renewable resources in IoT is still pushing its limits (lower consumption, longer endurance, cost, communication distance, etc.). Also, different types of TEGs are being experimented, which are additionally supported by further sub-experiments under different conditions.

When creating a low-power monitoring system, it is necessary to pay attention to the quality of the program code and libraries used. In our case there is still a lot of space for improvements in power consumption, especially DeepSleep mode requires around 9,541 mA to run. Ideally, DeepSleep consumption should be below 1 mA. The development kit with the ESP32 chip is also available from various manufacturers and here it is possible to encounter different limitations and operating conditions.

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