An Energy Sustainable CPS/IoT Ecosystem

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Abstract. This paper provides a short overview on methods and technologies necessary to build smart and sustainable Internet-of-Things (IoT). It observes IoT systems in a close relation with data centered intelligence and its application in cyber-physical systems. With the current rate of growth IoT devices and supporting CPS infrastructure will reach extremely high numbers in less than a decade. This will create an enormous overhead on world's supply of electrical energy. In this paper, we propose a model extension for estimation of energy consumption by IoT devices in next decade. The paper gives a definition of CPS/IoT Ecosystem as a mutually codependent heterogeneous multidisciplinary structure. Further we explore a set of methods to reduce energy consumption and make CPS/IoT Ecosystem sustainable by design. As a case study we propose energy harvesting sensor node implemented as a wildfire early detection system.

Keywords: Internet-of-things · Energy consumption · Sensor networks · Energy harvesting

1 Introduction

The rapidly expending world of internet-of-things (IoT) is changing technological landscape for civil, industrial and social projects. It is projected that the number of IoT devices is going to reach 100 billion until year 2025 [40]. An average energy consumption of Raspberry Pi 3 devices is between 1 Wh and 5 Wh [37]. To approximate average energy consumption of IoT application to about 4 Wh in the next 10 years we used following estimation formula, based on the models described in [7].

$$E_{IoT} = (E_{IoT_a} \times AR + E_{IoT_p} \times (1 - AR)) \times T \times D_{IoT} \times (\frac{100\% - ER\%}{100})^n \quad (1)$$

(E_{IoT_a}, E_{IoT_p}) are projected average consumption per device for an active and passive (i.e. sleep mode) operation.

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(AR) provides the ratio between active and passive operation of a device, we chose three arbitrary cases as best, average and worst.
(D_{IoT}) is projected number of IoT devices.
(ER) is projected energy efficiency increase as proposed by [7].
(T) is time in operation over a year.
(n) provides projection period in years.

Table 1. Different case scenarios depending for IoT device activity related to energy consumption. With the energy consumption projection of IoT devices in 2030.

Case	AR	D_{IoT} (10^9)	$ER(\%)$	$T(h)$	Period	$E_{IoT_a}(Wh)$	$E_{IoT_p}(Wh)$	$E_{IoT_{2030}}(TWh)$
Best	0.01	100	5%	8640	10	4	2	**532**
Avg	0.3	100	4%	8640	10	4	2	**1493**
Worst	1	100	1%	8640	10	4	1	**3125**

IoT revolution will bring enormous influx of devices that are not always designed in energy efficient way as they are not considered as major energy consumers. However, if the quantity of these devices reaches the levels mentioned above it could create enormous overhead in energy consumption. Table 1 also provides three projections of energy consumption based on the Eq. 1 in year 2030. In addition, there is energy consumed by cloud infrastructure as the number of cloud applications will increase accordingly. Cloud server infrastructures are already consuming enormous amounts of electrical energy, with up to 1.5% of total worldwide consumption [35]. With the influx of new IoT applications, data and emerging applications as a result it is evident that the cloud server capacity needs to be increased. Authors in [7] provide an estimate of cloud infrastructure energy consumption in range of 1000 TWh up to 8000 TWh. In addition there is a consumption required for communication. This approximation intends to show possible scale of the IoT energy consumption overhead. It is evident that energy efficiency of new devices will improve but the quantity of possible devices is still overwhelming. To put this in a perspective an average energy production of European Union (EU) is not around 3400 TWh over past couple of years [8]. Sustainability of the IoT applications and infrastructure depends on an energy efficient methodological design of IoT devices and applications, optimizing existing devices and applications, communal use of infrastructure, and energy harvesting capabilities.

In this paper, we are exploring energy aware design of IoT devices as a requirement for constitution of sustainable CPS/IoT Ecosystems. We define CPS/IoT Ecosystem as “a heterogeneous structure of hardware devices, and corresponding software components distributed over tree intertwined scopes of operation: cloud, fog/edge, and sensor/actuator nodes” [30]. These systems are distributed over different platforms and infrastructural facilities such as a power grid, the Internet, or a mobile grid. It is extremely difficult to maintain oversight on energy consumption over the whole composition. We propose technologies and methods that can be used to ensure energy efficient and sustainable design from the perspective of sensor nodes. First, we will explore a set of methods that can be applied from the hardware design and up to ensure most beneficial performance to energy consumption ratio. Further, we will show examples on how to design a sensor node for IoT with low or completely neutral energy signature. Finally we will show how to optimize existing systems by introducing methods such as hardware acceleration.

In Sect. 1 we explore a problem of energy consumption overhead created by IoT devices and supporting CPS infrastructures. We propose an extended power consumption estimation model for IoT devices. Section 2 gives an overview of related activities on the topic. In Sect. 3 we provide a definition of CPS/IoT Ecosystem. Section 4 gives methodological steps towards energy aware CPS/IoT Ecosystem. Further, Sect. 5.5 proposes a sensor node that utilizes energy harvesting methods. Section 6 gives a short overview on a use case that can be realized with the described energy harvesting sensor node. Last two sections conclude the paper and provide due acknowledgements.

2 Related Work

The problem of the rapidly growing IoT market among with its energy needs, requires focussing on possible solutions for an efficient energy use on all the CPS/IoT Ecosystem's scopes. In this context, different approaches have been tried to reduce the energy consumption of sensor networks as, for example, trying alternative routing schemes to achieve a network lifetime increase as well [43]. Moreover, in traditional networks, the network configuration is not changed after initialization, but energy consumption improvements are noticed by adaptive network configuration where, if the distance between two sensors is calculated, the transmission power can also be adjusted avoiding the use of unnecessary power [48]. Further, analysing the architecture of a sensor, the main components that affect to their lifetime are identified so that aggressive energy optimization can be performed [38]. Nonetheless, the data centers used for cloud computing are an important point to consider regarding energy consumption. These centers can host up to several thousands of servers and they reach 1.1% to 1.5% of the total electricity use worldwide and is likely to rise [35]. In this context, an efficient cloud computing is crucial for which diverse hardware and software strategies can be adopted in all the levels that compose a data center [17,25,32]. An efficient operation can also be achieved for the Edge scope's components such as cloudlets balancing the workload across the nodes or adapting their configuration to manage latency and energy consumption [47].

In addition to managing the energy consumption, a wide range of energy harvesting methods can be used as an extra power source [28]. One of the main energy harvesting techniques is based on vibration energy scavenging. Its applications range from railway vehicles [26] to supplying hearing aids [6]. Other main method focuses on the solar energy which can be used to power sensors on both outdoor and indoor environments [22,27,39]. However, the energy source this paper focuses on is the thermal by using thermoelectric generators. The usages cover industrial applications to recover waste heat from engines and increase the vehicle's overall efficiency [16,24,31] as well as using an aircraft's fuselage varying temperature to power autonomous sensors and perform diverse measurements [41]. As a human body constantly generates heat, several studies have also been carried out to take advantage of it to power autonomous wearable electronics like watches, medical devices or other types of sensors [12,33,34]. However, the need to make the energy scavenging unobtrusively limits the power that can be obtained.

These autonomous sensors can be placed in inaccessible places where battery replacements are not possible so they only rely on the temperature gradient across the thermoelectric generator to work. Additionally, a wireless transmission module can be added to their structure to track the measurements remotely [9,14,15]. These sensors will perform the programmed tasks as long as a minimum temperature gradient is achieved. Nevertheless, alternative storage elements like supercapacitors can be employed to manage the generated power and keep the system working even if this power is discontinuous [42]. A similar approach is presented in this paper, but an event detection circuit is introduced so the measurements are performed only under certain circumstances and the generated energy is just stored otherwise.

3 CPS/IoT Ecosystem

In Sect. 1 we structurally defined CPS/IoT Ecosystem, in this section we will give a motivational overview and functional description of this concept. The IoT allows us to connect physical environment with a digital infrastructure, collect its data and store it for the purpose of later or runtime analysis. CPS is a collection of practical and theoretical methodologies that allow us to interpret physical data, create models of physical environments using this data, recognize and extract emerging behaviours and use them to optimize system in question. We observe two concepts as separate disciplines but highly dependent on each other. We conceptualize CPS/IoT Ecosystem structurally in three scopes of operation:

Cloud. The cloud infrastructure provides the ability to construct computational units based on computational performance or storage requirements in an automated and scaleable fashion. It can compute and store enormous amounts of data and made it available to large number of users at the same time. This is an essential requirements for the large scale data analysis. Cloud servers are located at remote locations and accessible exclusively through internet.

Fog/Edge. The concept of fog and edge computing describes platforms with ability to perform computing and storage tasks in relative proximity to a physical environment and with extremely low response rates [11]. Fog hosts time sensitive tasks such as control loop execution where it is required to perform complex calculation based on historical data with low latency. Fog and edge devices are located within the same facility and are communicating using local area network from one side and the Internet to communicate with cloud level if necessary.

Sensor and Actuator. There are two basic types of devices that allow to interact with the physical environment, either by observing it or manipulating it. The sensors and actuators are implemented using low energy, low performance devices that are deployable in an imminent proximity to the observed object. The number of these devices is manifold of what is required on the upper levels and although they use less energy it needs to be considered based on the quantity. These devices are often placed in inaccessible locations with limited maintenance capabilities and their energy supply relies on energy storage devices such as batteries, or on their ability to harvest energy from the environment.

4 An Energy Aware CPS/IoT Ecosystem

CPS/IoT Ecosystem is a concept that allows to transform real data from a physical environment into valuable information, in order to increase efficiency of a system in different ways. This process requires number of layers of technology from hardware and software perspective. It relies on massive data collection and processing, learning statistical and mathematical paterns, applying optimizations and novel applications for forthcoming and legacy systems. The scale of this undertaking will require a massive number of devices from sensor to cloud level. In Table 1 possible energy consumption scenarios for IoT, plus overhead on Fog and Cloud infrastructure as shown in Sect. 1. This is why it is necessary to reduce its energy footprint by adopting various methods that increase overall efficiency and reduce energy consumption in all scopes of operation. In this section we will discuss methodological approach that would outperform commonly used approaches.

Energy aware design for CPS/IoT Ecosystem has multiple dimensions. It doesn't depend on hardware or software alone, it is rather a "full stack" problem starting from a system model to the final application artefacts.

Standardized IoT Model. One of the major obstacles in development of IoT systems is lack of standardization. IoT is building on top of embedded programming that has a significant number of libraries. A model based approach to development of IoT would ensure use of verified code that can be configured between energy and performance optimal instance. A model based approach would be realized in multiple aspects such as hardware platform model, service model, network model, application model and eventually wrapper model to unify all above mentioned cases. This would increase oversight and traceability of the system, reduce maintenance cost and increase resource utilization.

HW/SW Co-design. CPS/IoT Ecosystem applications are dependant on full range of devices from a cloud server with high-power CPU, to microcontrollers in embedded devices and custom designed hardware for networking solutions.

Use of FPGA or hybrid architectures is widely accepted, and its application in CPS/IoT applications is more than beneficial. Molding HW/SW platform to specific needs provides the advantages of a dedicated platform such as resource utilization and performance and flexibility of a COTS platform. Both IoT and CPS can profit from custom designed accelerators or IP blocks. Both ends of the CPS/IoT Ecosystem can benefit from a targeted application acceleration. Using hybrid architectures such as Intel Arria 10 [2] or Xilinx Znyq [3] applications have access to a standardized CPU architecture and FPGA device within the same platform. The FPGA is ideal for acceleration of mathematical tasks, network routing, security tasks or other application specific IP. Study presented in [29] showed massive acceleration for tasks such as matrix multiplication up to 5 times and reduced energy consumption up to 4 times. This comes with a cost of flexibility and programmability but with application of high level synthesis tools it can be significantly reduced.

Energy Harvesting. IoT is a leading industry in propagation of energy harvesting solutions from a piezzo electric auto-charging switches to solar driven fog and/edge stations. By adding energy harvesting capabilities use of electrical power from grid can be significantly reduced or completely neutralized as shown in Sect. 5.5. Environmental sources for energy harvesting are [10]: a) mechanical energy in form of vibration or movement with examples of piezzo-electric generators, wind and water turbines, b) Solar energy generated by the sun with examples of photo-voltaic generators or thermal generators, c) Thermal energy generated by environment with example of thermoelectric generator (TEG), electromagnetic energy generated by surrounding electromagnetic fields and converted into electricity by electromagnetic induction.

5 Energy Harvesting Sensor Nodes

In this section we propose an energy harvesting sensor node for remote data collection over narrow-band communication network. It is a sensor device that can use any of the above mentioned energy harvesting sources and can be deployed in a remote place with little to none maintenance. The sensor device is designed to track a specific event such as abrupt temperature rise or extreme kinetic forces in the environment. It is an environmental friendly device with no chemical batteries and low energy storage.

The sensor device shown in Fig. 1 is based on thermo-electric generator, which produces an electric power on a temperature gradient in the surrounding environment. It powers a microcontroller centered device over a power management unit (PMU). The power management unit uses a supercapacitor as an energy storage element and gives a stable regulated voltage necessary for MCU to perform its tasks. As an interface between MCU and PMU an event detection circuit is placed. It tracks outside event and releases power to the MCU when the stable voltage is reached. The MCU is further interfaced with a Sigfox transceiver and two sensors, a temperature sensor and a global positioning sensor. When

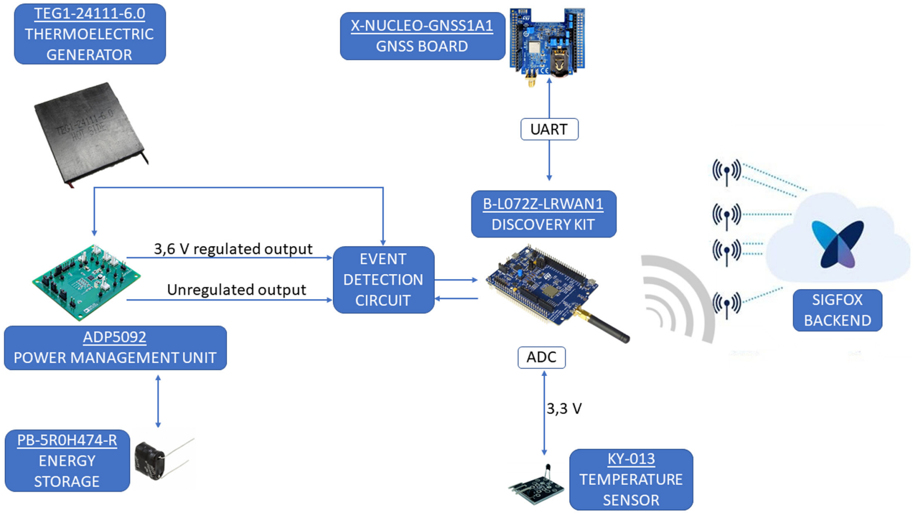

Fig. 1. Designed system's architecture

the temperature of the environment reaches threshold it will generate enough power to wake the MCU, acquire data from sensors and transmit the message over Sigfox network.

5.1 Thermoelectric Generator (TEG)

The selected TEG device for this application is the TEG1-24111-6.0 manufactured by Tecteg MFR [36]. As high temperatures may be reached during an event detection and its processing, it is important that the TEG module can work in that range so the chosen module is designed with high temperature bonding materials allowing it to withstand temperatures of up to 320 °C and offers superior performance when its hot side is over 150 °C.

5.2 Power Management Unit

The output obtained from the TEG module is a varying irregular voltage so that it cannot be used to power the MCU. Therefore, a treatment stage is added making use of the ADP5092 [19]. This is an ultralow power energy harvester PMU which offers a wide range of configurations so it can be configured in accordance with the energy harvesting source and the connected load requirements.

The board offers a Maximum Power Point Tracking (MPPT) control which can set the maximum power point ratio for the energy harvester obtaining the maximum available power from it. This is configured in its dynamic sensing mode and adjusted for a TEG harvester.

Rechargeable batteries, capacitors or other storage elements can be charged with the obtained energy so it can later be used to power the load when needed.

In this case we are using the Eaton's PB-5R0H474-R [23] supercapacitor with 0.47 F and 5 V. Less environmental friendly option would be a battery supported device that can easily be integrated in the device.

The PMU provides two power outputs, an unregulated power output for charging of the supercapacitor, and a regulated power output for direct supply of the microcontroller. The unregulated output is connected to the storage element so its voltage changes with the supercapacitor's charge. The regulated output with a current limit of 150 mA is available, which is sufficient to run the MCU as described in Sect. 5.4. The output voltage is set to 3.6 V but can be regulated from 1.5 V to 3.6 V. The regulated output is used to power the load in this approach while the unregulated output is directed to the event detection circuit as explained in Sect. 5.3.

Additionally, a couple of control features are used by the MCU to make a more efficient use of the PMU: RF interference are avoided by temporarily shutting down the boost regulator when a Sigfox message is going to be sent and the quality of the regulated output is checked before performing a cycle's actions.

In order to get an easy way to evaluate the ADP5092, the ADP5092-1-EVALZ evaluation board [21] has been chosen. This board provides a default working configuration which can be easily adjusted replacing any necessary component and making use of the provided jumpers.

5.3 Event Detection

As one of the key steps is the event detection to know when to perform the measurements and data transmission, a circuit has been designed to ensure a correct detection.

In this case event detection is fully corelated with the energy generation event. This means that the sensor node is triggered when the enough energy is generated. To start energy generation TEG device requires a temperature gradient between exposed and isolated side of the device. The design of the device provide us with physical means to ensure the gradient necessary to generate enough power. For the current version a required gradient is 50 °C. This will correspond to aproximate 2 V regardless of the working temperature, so this is the threshold of the desired event. Figure 2 represents the designed circuit to detect events over the defined threshold.

The thermoelectric generator is connected to the PMU and a 3.6 V regulated output is obtained to power the board. The board should be powered just when an event is detected and shut down otherwise so to control this, a comparator based circuit has been designed. This comparator compares the TEG output to the defined event threshold. To get this fixed voltage, the unregulated output of the PMU is directed through a low-dropout (LDO) regulator. The regulated output is used as the positive power supply for the comparator while the negative supply is connected to ground.

When the TEG output is higher than the threshold, the comparator gives a low output. Otherwise, when the TEG output is below the threshold, a high

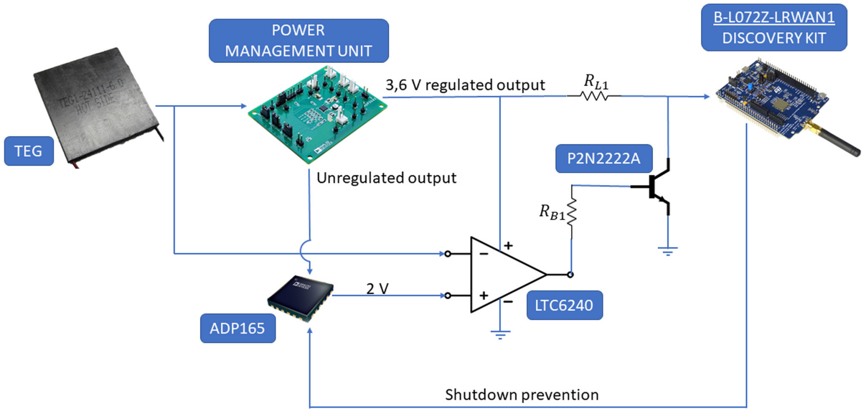

Fig. 2. Event detection circuit

output is generated. In order to control the board supply with this output, a transistor that acts as a switch is used. The comparator's output is connected to the transistor's base through a resistor (R_{B1}, so a low comparator output causes the transistor to work in its cut-off region leading to power the board, and a high output causes it to enter its saturation region resulting in a board shutdown.

Additionally, a shutdown prevention connection has been added to ensure the board is supplied until it finishes all its process. Otherwise, the TEG output could drop below the detection threshold causing a sudden board shutdown even if enough energy is still available in the PMU. This prevention is achieved by controlling the ADP165 voltage.

The ADP165 is a very low quiescent current, LDO, linear regulator [18]. Although an event detection threshold has been defined, the adjustable output option has been chosen over a fixed output to have some flexibility if any change is needed in the future. Figure 3 represents the used configuration.

To set the output voltage, R_1 and R_2 are adjusted. Additionally, the regulator can be enabled or disabled by means of the EN pin which is used for the board's shutdown prevention using a similar approach as before with a transistor. So, the regulator is working when the board is not powered but it is disabled after an event is detected. This means the regulator gives a low output forcing the TEG's comparator input to be always higher. The ADP165CP-EVALZ [20] evaluation board that simplifies the testing process has been used to try the configuration.

5.4 Microcontroller

The B-L072Z-LRWAN1 discovery kit [44] has been used in this project. It is a development tool which includes the CMWX1ZZABZ-091 open module by Murata allowing to use LoRa and Sigfox technologies. Being powered by an STM32L072CZ microcontroller which offers an ultra low power consumption makes it a great choice for IoT and energy harvesting applications.

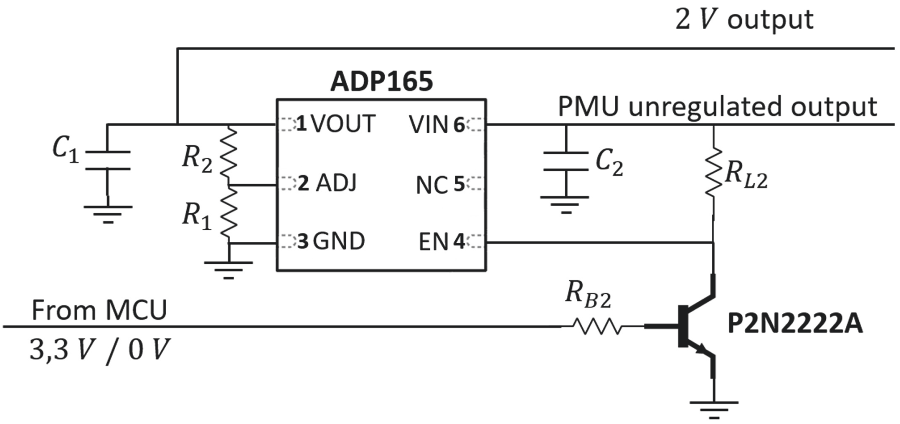

Fig. 3. ADP165 voltage regulator circuit

Location Acquisition. One of the relevant data to be acquired is the current location of the board for which the X-NUCLEO-GNSS1A1 module has been used which represents an easy-to-use, GNSS solution [46]. Both UART and I2C interfaces are available to establish a connection but UART is used in this case. It is compatible with the Arduino UNO R3 connector also present in the B-L072Z-LRWAN1 making it easy to connect them and allowing to stack extra components.

Temperature Sensor. The temperature is another important parameter to track as it conditions the performance of the whole system. The sensor chosen to read it is the analog low power consumption STLM20W87F by STMicroelectronics [45]. However, the analog KY-013 module has been used for testing purposes. It consists of a NTC thermistor whose resistance changes with the temperature leading to an output voltage variation. The sensor is connected using the Arduino UNO R3 [1] connector of X-NUCLEO-GNSS1A1 since it is stacked. Then, the real temperature is obtained using the ADC.

Operating Mode. Different possible operating modes for the board have been identified. The chosen operating cycle is shown in Fig. 4.

Increase in outside temperature creates a temperature gradient that generates electrical potential. When the power management unit detects this event it releases current and activates the board. This could be a short term event and take up to few seconds at most, so the energy is stored in the supercapacitor. The power management unit releases the energy from supercapacitor to power up the board.

Once powered up, the quality of the supply voltage is checked making use of the REG_GOOD pin in the PMU. If a high signal is read, the board reads the

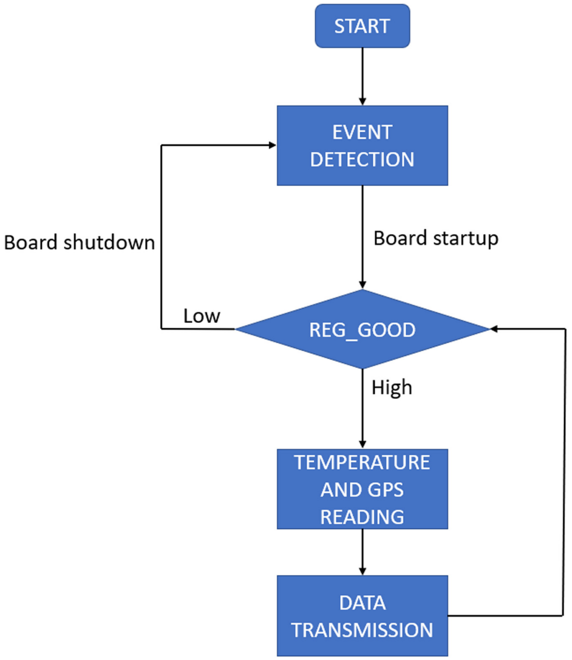

Fig. 4. Flowchart of the MCU's operating cycle

temperature and location measurements to, finally, send the data. Otherwise, the board is powerd down and until next event.

As the detected event may still be active after the first data is transmitted, and some energy may be available yet, the measurement and data transmission steps are repeated until there is not enough energy to repeat the process or a low signal is read in REG_GOOD. Like that, a complete event tracking and analysis is done.

Another option that we considered is to enter the standby mode and stay there until an event is detected. At that point, an interruption that wakes up the device is triggered, and the measurements are performed before the device goes back to standby mode. The main reason for the cycle selection is the uncertainty of the available harvested energy amount. As it is not known when an event will happen, the amount of time the device can stay in standby mode is undefined and, although its power consumption is very low, it needs a continuous supply which may not be available. Taking this into account, the selected mode fits better, powering the board just to track an event once it is detected.

Power Consumption. A rather pessimistic estimation for the power consumption of each step as well as the time spent on it is shown in Table 2. It is worth noting that the estimation has been done considering a supply voltage of 3.3 V.

Table 2. Execution cycle steps' power consumption.

Power mode	Stage	Power consumption	Time	CPU/Bus frecuency
Run	Board start-up, REG_GOOD checking	8.12 mA	500 µs	32 MHz
Run	Location acquisition	33.11 mA	8 s	32 MHz
Run	Temperature reading	18.11 mA	25 µs	32 MHz
Run	Signal Tx	128.11 mA	2.1 s	32 MHz

Taking this data into account, an average current consumption of 52.86 mA is obtained.

5.5 Sensor Node Evaluation

Energy harvesting sensor node was implemented in an experimental setup. It was used to test individual behaviour of components and the sensor as a whole. However, the TEG output was simulated making use of a power supply.

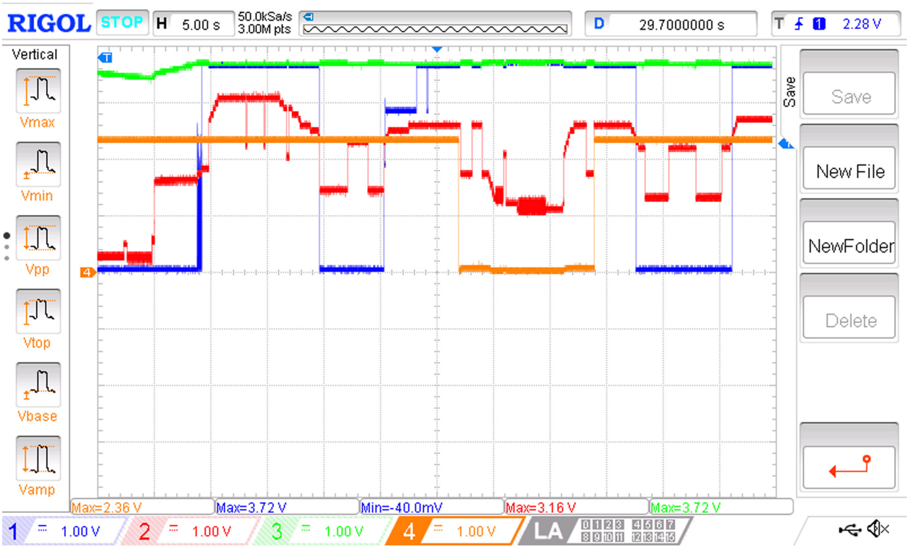

Fig. 5. System testing results

While testing the whole system, the following points were measured with an oscilloscope:

- Channel 1: Board power supply.
- Channel 2: TEG output simulation, V_{in}.
- Channel 3: Regulated output from the PMU.
- Channel 4: ADP165 output.

The captured results can be seen in Fig. 5. First, V_{in} increases until it gets higher than the ADP165 output. The comparator makes the transistor work in its cut off mode forcing a high board supply. Then, V_{in} gets lower than the ADP165 output, so the board's supply gets low. Later, the ADP165 output drops to a low voltage when the shutdown prevention is activated. At this point, as V_{in} is higher, a high board supply is obtained always. After the shutdown prevention is deactivated, it returns to its initial operation.

If the shutdown prevention is activated, because the board is working, and V_{in} drops to low, the supercapacitor's voltage will also start to drop. When it discharges enough, the regulated output will go low forcing a low board supply as well. Whether the supercapacitor is charged, a high output will be present again. This behaviour is shown in Fig. 6.

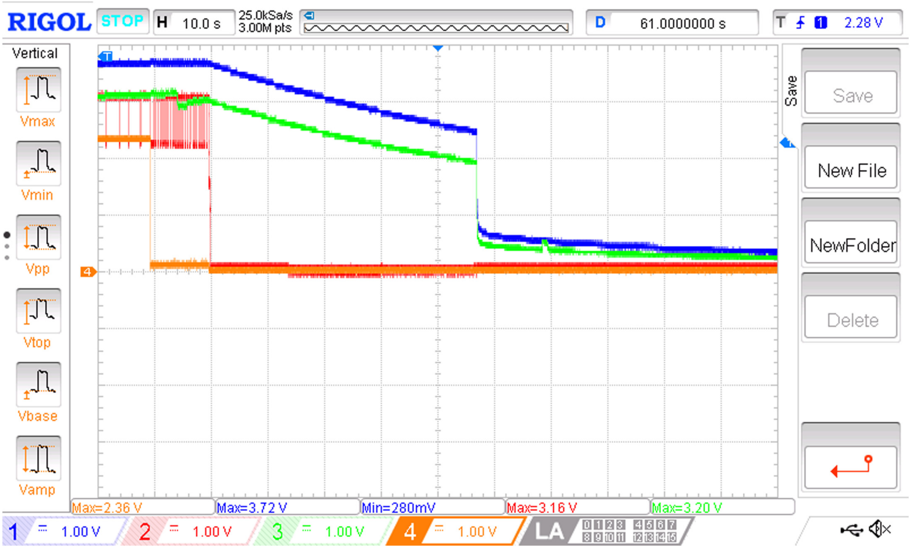

Fig. 6. System discharge testing

6 Energy Harvesting Use Case

The sensor node described in Sect. 5.5 can be applied in number of use cases. We are currently testing a prototype for a wildfire detection device. Despite all warning systems and services 100 people are confirmed dead during wildfires in Greece in 2018 [4]. In United States in the state of California an area of 7664,39 km^2 was caught in one of the largest recorded wildfires in the US, 89 people are confirmed dead [5]. In addition, the economic and environmental impact of these natural catastrophes is colossal. The damages to infrastructure, public and private properties are measured in billions. Furthermore, damages to wildlife and environment are enormous and areas affected will require years to recover. The proposed wild-fire detection device would provide both localized and global early warning system for wild-fires. When combine with current early warning systems it would be able to increase precision and timeliness of detected fires on a large scale. With approximately 800 sensors we would be able to cover up to 50 km^2. In addition to satellite based detection systems such as [13] this could be extended even further. To cover the area burned down in California it would take about 160000 devices. However, it is not necessary to cover the whole area, instead it would be enough to create a mash based on geographical parameters or protect residential, industrial or agricultural zones. The cost for the deployment of wildfire energy harvesting sensor nodes is almost insignificant to the amount of damage created by the fire. The devices showed in Fig. 7 can be placed on the endangered area with a distribution pattern that will complement other detection methods. This area should be covered with the low-band communication network, in this case we used Sigfox. The advantage of the radio based networks is the large coverage range and low power compared to other wireless communication networks. The device can stay dormant for years until a activation events occurs. In this case the activation event is a high temperature (or temperature gradient) generated by the fire. The sensor device will be triggered and sends a burst of alert messages containing temperature and location via narrow-band communication network to the cloud. Monitors in the

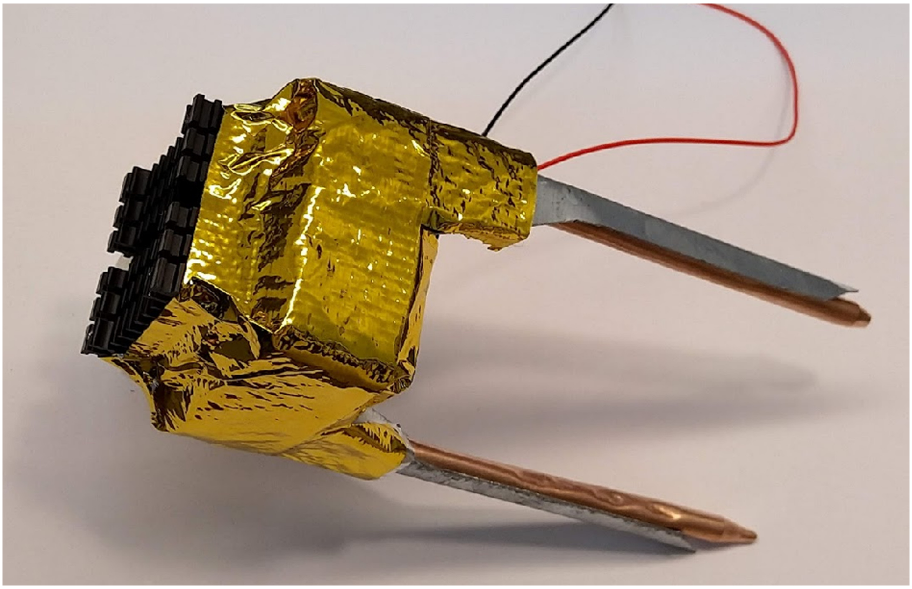

Fig. 7. Energy harvesting IoT node

cloud will notify authorities and provide them with the early detection necessary for a rapid response.

Table 3. Cost structure for the prototype.

Resource	Quantity	Unit cost (€)	Total (€)
TEG1-24111-6.0	1	50.00	50.00
X-NUCLEO-GNSS1A1	1	32.76	32.76
KY-013	1	1.00	1.00
B-L072Z-LRWAN1	1	43.52	43.52
ADP5092-1-EVALZ	1	44.00	44.00
ADP165CP-EVALZ	1	35.00	35.00
PB-5R0H474-R	1	4.47	4.47
LTC6240	1	1.89	1.89
P2N2222A	2	0.22	0.22
Various resistors	9	0.50	4.50
Case	1	25.00	25.00
Total			242.58

Figure 7 shows a package prototype of the energy harvesting node for the use case above. This design utilizes slow changing temperature of the ground in contrast to the air temperature, that changes rapidly in case of wildfire. The isolation layers divide hot and cold side of the TEG and ensure temperature gradient is achieved necessary to power up the sensor node. The cost of the prototype is given in Table 3 this can be reduced significantly in a serial production. This would make the platform highly viable and affordable considering the cost of the damages made by wildfires.

7 Conclusion

The number of IoT devices and supporting infrastructure used for CPSs is already affecting energy consumption and energy production models. This trend is continuing to grow and energy aware solutions are necessary to balance out the burden. In this paper, we proposed a model of estimating energy consumption for IoT devices and supporting infrastructure. We provided a set of methodological and design measures that could reduce energy consumption in CPS and IoT significantly. Finally, we proposed an energy harvesting method that is simple to produce and could be used to increase effectiveness of active early wildfire detection systems. They could be used by individuals to protect their property and also by official institutions to protect certain agricultural or forest resources.

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