Wireless Powering of Internet of Things Devices using Radio Frequency Harvesting

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ABSTRACT

Internet of Things (IoT) is tagging low power devices, miniaturized, with machine-readable identification tags, which are integrated with sensors to collect information and wireless technology to connect them with the Internet. These devices have a very low energy usage. Powering these devices with battery is very labor intensive, costly and tedious especially as number of nodes increases, which is in many applications, is the case. Hence the main objective of this research is to introduce new product called RF Collector, in the market such that IoT devices function independent of battery. Using the suggested approach they will be energized using Radio Frequency (RF) energy harvesting. RF Collector wirelessly capture the RF energy that is wasted in space, and re-use it again as the power source for IoT devices and hence making them autonomous of battery. The ability to harvest RF energy enables wireless charging of low-power devices in real time. This has resulting benefits to sustainability, cost reduction, product design, usability, and reliability.

Keywords

RF harvesting, IoT, Array Antenna, capture power.

INTRODUCTION

Internet of Things (IoT) is a technology of connecting devices through Internet, which has impact on communication, monitoring, business and many more. By the Internet of Things, devices gain intelligence behavior through sensing their surrounding; sharing the gather information with other devices through Internet or enabling them to make a decision to change their state [1]-[3]. These devices have a battery, micro-controller, sensor, possibly an actuator and a communication device. It is predicated that world will have 50 billion connected devices by 2020 using IoT [4]. Difficulties arise when a huge number of IoT devices are installed in one location such as office building, elderly home care, harbor, etc. For an office with 10,000 IoT devices it is required that the facility manager to change approximately 30 batteries each day. Hence powering these devices with battery is very labor intensive, costly and tedious. Consequently wireless powering of these low power devices becomes essential. The main objective of this research is to introduce new product called RF Collector, in the market such that IoT devices function independent of battery. Using the suggested approach they will be energized using Radio Frequency (RF) energy harvesting. RF Collector wirelessly capture the RF energy that is wasted in space, and re-use it again as the power source for IoT devices and hence making them autonomous of battery. RF energy is currently broadcasted from many radio transmitters around us, including Mobile Base Stations, mobile telephones, handheld radios, mobile-and WiFi base stations, and television/ radiobroadcast stations.

Since the RF energy is spread spherically in space and it is not localized, huge amount of energy is wasted. It is possible to harvest this energy and re-use it. The ability to harvest RF energy enables wireless charging of low-power devices in real time. This has resulting benefits to sustainability, cost reduction, product design, usability, and reliability.

The proposed solution is similar to that used in Photovoltaic (PV) systems except that it harvests energy at lower frequencies (a recycles man generated). Examining the power generated by PV systems is obviously much higher compare to the suggested technique. It is same concept except harvesting at lower frequencies. However there are number of advantages the RF harvesting can offer compare to the former one:

1. Harvesting does not depend on the nightfall or weather and it is continuous.
2. Harvesting device can be of any size and shape, mounted on every location, and integrated to other devices.
3. Installation is much easier and it does not have to be mounted on the roof (indoor usage possible).

To increase the efficiency of the system and due to the multi frequency nature of these wasted energies it is beneficial that the sensor of the harvester operate properly at the corresponding frequencies of the RF waves. In addition the direction finding of harvester plays a crucial role in the design and will be addressed in the section "proposed solution". A novel solution is proposed to increase the effective area of the receiver and simultaneously having direction finding capability to boost the captured power. Based on this novel idea a research proposal was granted by SIA.

SUGGESTED SOLUTION

Figure 1 shows the layout of RF collector for RF energy harvesting. It uses an antenna operating at the desired frequency to receive RF signals, RF harvester and IoT device. The proposed product concept is a ***RF Energy Harvester*** called **"**RF Collector**"**. "RF Collector" is based on multi frequency antenna array sensor technology as the inherent to RF energy capture mechanism. The device comprises a novel technology of appropriate miniaturized array of antenna sensor in matrix or linear fashion. Usage of array of sensor is two folded:

1. Direction finding to estimate the Angle Of Arrival (AOA), to orient the beam of IoT sensor toward the angle that maximizes the energy reception.
2. Effective area is increased and hence increases the capture power.

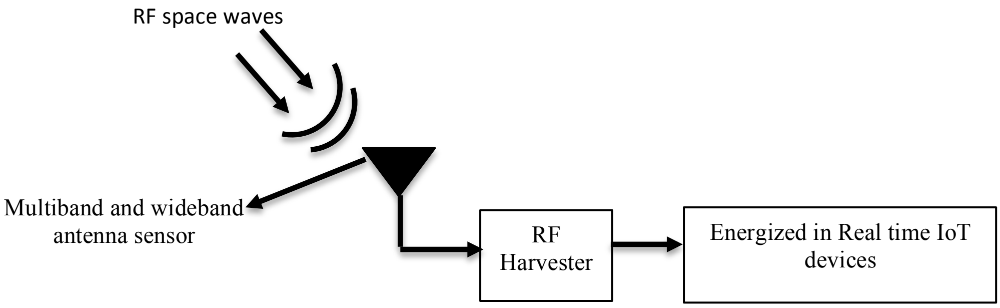


Figure 1. RF Collector.

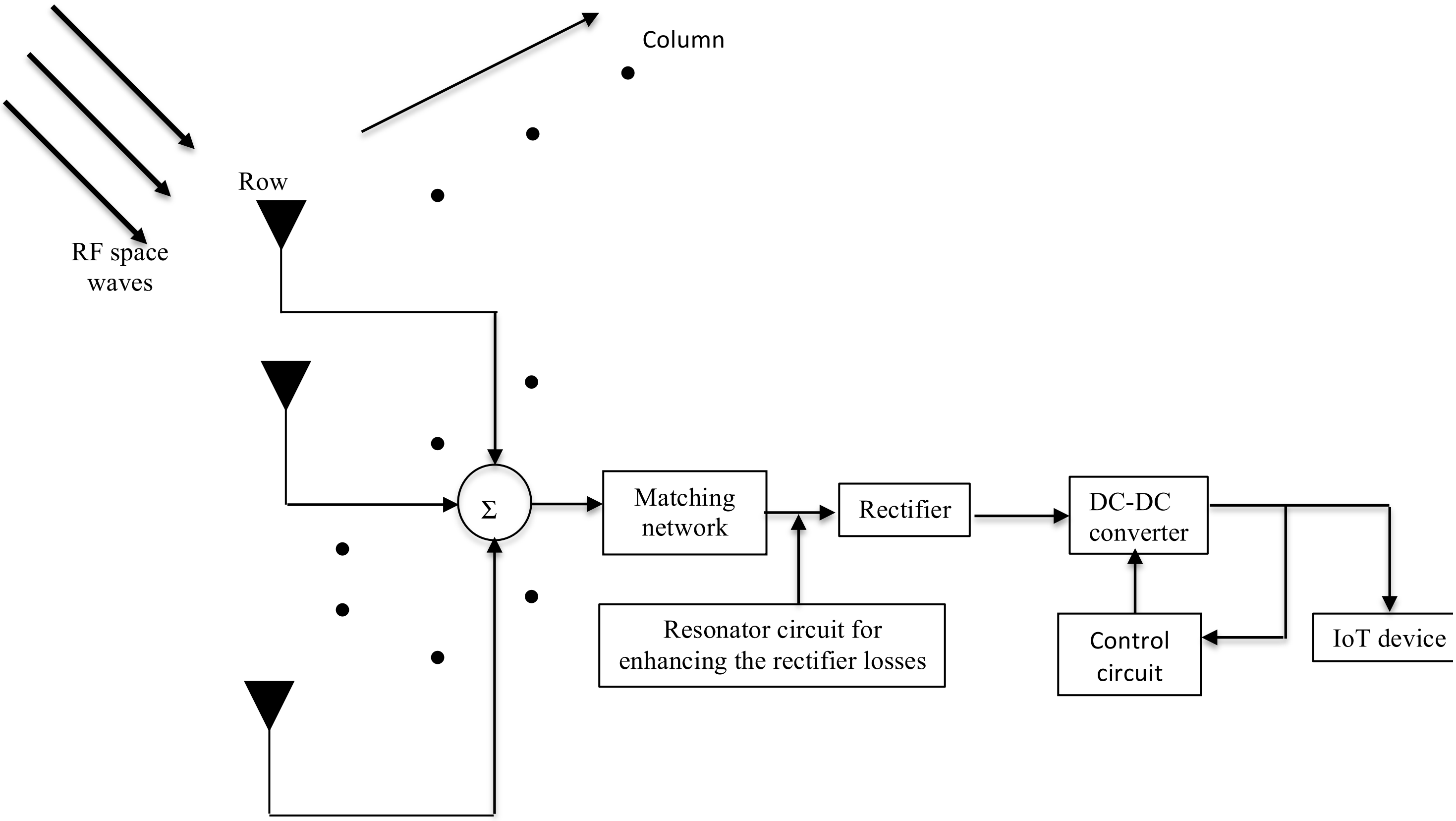
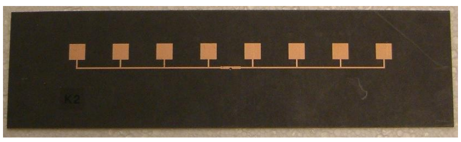


Figure 2. Detail layout of RF Collector.

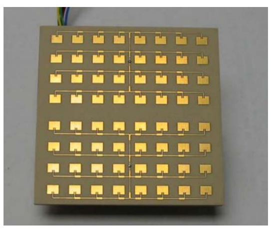
Figure 2 shows a more detail description of RF Collector using a novel array antenna. Each antenna sensor channel compromises a multi frequency or wideband; dual polarized antenna operational for different communication frequencies to increases the captured power. It is necessary and more appropriate to combine different RF signals just after the array antenna sensors. It then accommodates a matching network, rectifier, a DC-DC converter, and finally the IoT device.

The geometry of antenna surface is curial to increase the captured power density. Figure 3 shows the different type of array antennas.

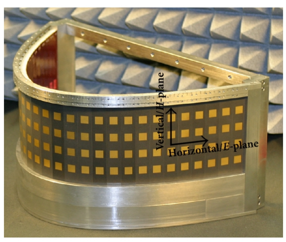
This approach is very curial for the RF Collector since the efficiency of the rectifier and DC-DC converter is very low in order of 30%. Hence array antenna improves the losses.



(a)



(b)



(c)

Figure 3. Different array antenna geometry: (a) Linear; (b) planar; (c) conformal.

Theoretical generated power

To demonstrate how much energy and power can be generated some examples are given to make the working principal of the "RF Collector" clearer. For simplicity let us assume that far field power density impinging on the "RF Collector" is 1µW/cm^2. Assume there are 100 elements in the array, and assume further that each antenna element to harvest at 5 different frequencies. This would give an instantaneous power density of about 5W/m^2. For antenna array with area of 1m^2 the total instantaneous power would be P = 5W. To have an indication of how much power instantaneously is captured, for example it takes Apple charger with 5V and 1A (P = 5W) about 2 hours (10Wh) to charge up an IPhone 5 from 5% to 100%. An "RF Collector" with a surface area of 1m^2 can generate the energy in the Apple example above in about 2 hours. If we double the area and number of antennas this amount of time will reduce with a factor of 4. Another example is a 6-inch E-paper with area of 0.024m^2 that needs 2Joule of energy to turn one page. Assuming the "RF Collector" powering the E-paper, the screen can be refreshed:

$$\frac{Time}{Turn} = \frac{2WSec}{5W} = 0.4\ \frac{sec}{Turn}$$

Cycle of day: IKEA bureau lamp uses solar panels and LED with 3 battery of 1.2V, 3.6V, and current of 800mAh. It charges up during the day to be used during the nightfall. This gives 2.8Wh. During one cycle of day the "RF Collector" harvester generate 5W×24h = 120Wh using an array area of 1m^2. The IKEA bureau lamp can be charge up 120/2.8 ≈ 43 times.
Taking photos doesn't consume much power. The DSLR Canon 600D camera (Canon, 2013), has a 1120 mAh battery operating at 7.2 V. This gives 8Wh. During one cycle of day the "RF Collector" can charge up the battery 120/8 ≈ 15 times.

Preliminary measurements

Figure 4 shows the first measurements set-up to demonstrate the working principal of the RF collector.

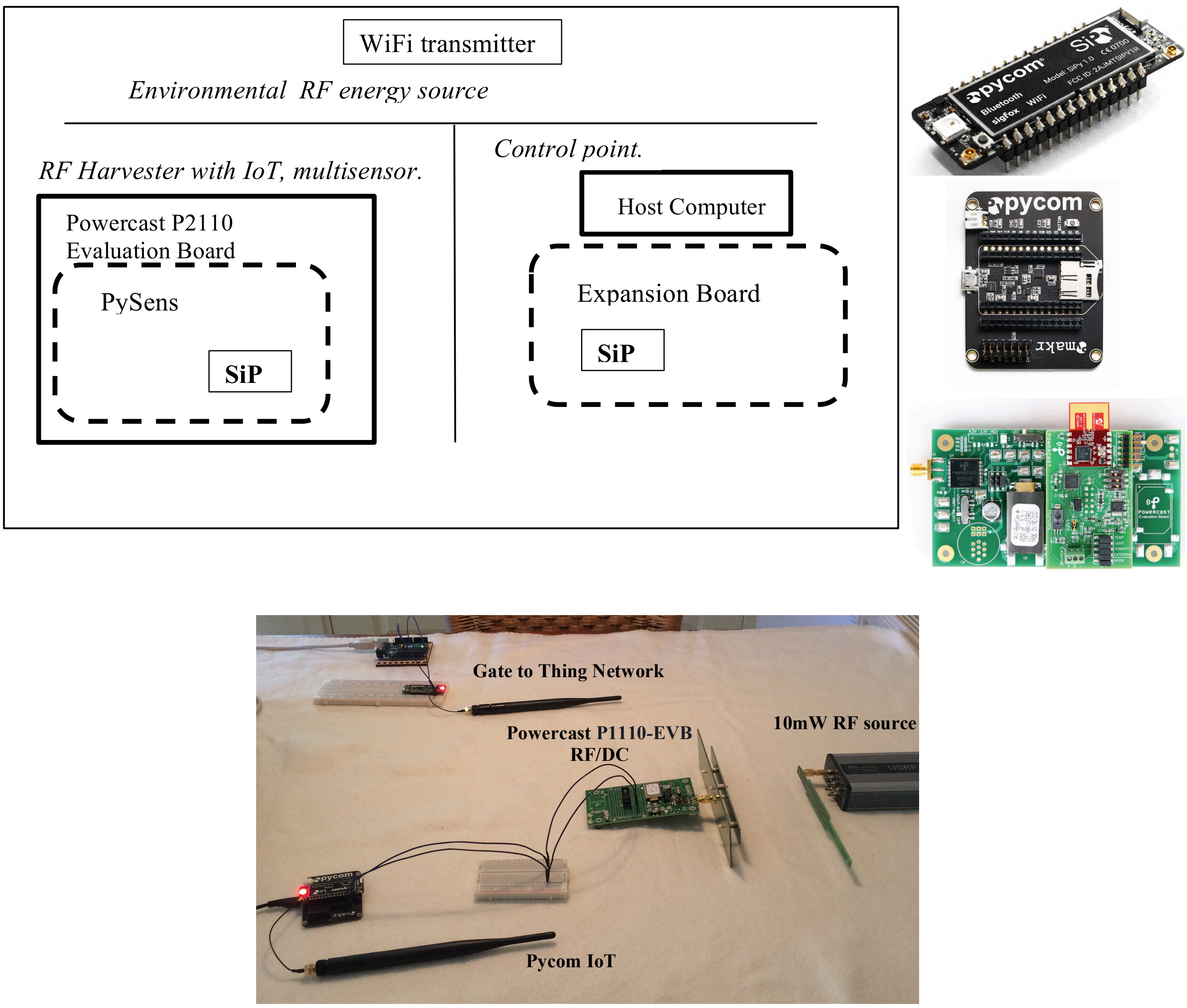


Figure 4. Measurement set to demonstrate the wireless harvesting.

Company Powercast located in the USA, Pittsburgh has already a number of experimental kits in the market for harvesting [4]. Powercast P1110-EVB operating at 915MHz is used in our first measurements campaign. A wideband power source USRP E312 from company Ettus, with bandwidth of 70MHz–6GHz, and maximum transmit power of 10mW is used as the power source [5]. Pycom IoT has a temperature sensor on board and it was powered up using the wireless harvesting.
Thing network is used to transmit and receive the temperature in real time to our laptop. Thing Network: a cloud based hub for collection and dissemination of information, which is integrated with LoRa network. Figure 5 shows the received temperature data.

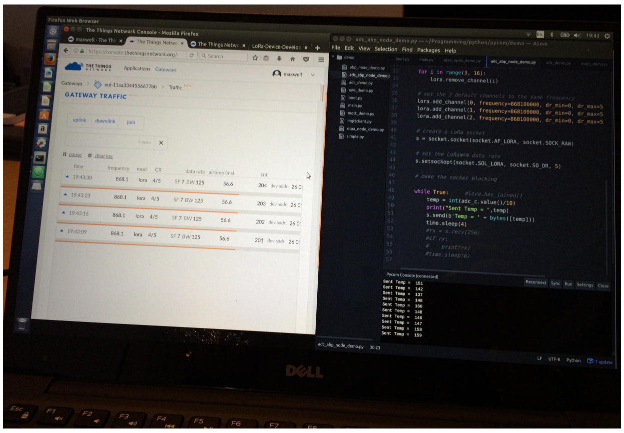


Figure 5. Received temperature as function of time.

Future work

Work is in progress to mature the system. Wideband antennas are designed to cover desired frequencies as depicted in Figure 6. Work is in progress.

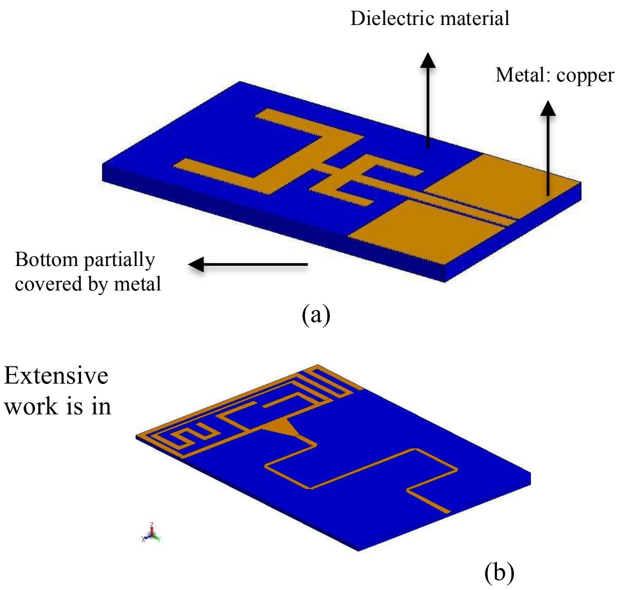


Figure 6. Typical multi-frequency antennas for RF harvesting: (a) 1.5GHz < f < 5.5GHz; (b) GSM, GPS, WiFi, 1.4GHz < f < 2.5GHz.

progress to design the system with multiple channels which each channel will be using Powercast's P110-EVB, combining circuit, and finally integrating with the antennas, see Figure 2.

CONCLUSION

A novel solution is proposed to improve and increase the capture power using wireless harvesting. Based on the suggested technique a grant is received to execute the project. Preliminary measurements are promising where using using wireless harvesting IoT sensor data is transmitted and received using Thing Network employing LoRA network. Work is in progress to design and built multiple channels with wideband antennas to tune the system.

ROLE OF THE STUDENT

Isay Konter is an undergraduate student studying technical computer science working under the supervision of Dr. ir. Mostafa Hajian when the research in this paper is performed. Mostafa proposed the research work. Measurements set-up and measurements, the processing of the results as well formulation of the conclusions and the writing were partially executed by the Isay.

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