Enabling High-Efficiency Far-Field Radiofrequency Energy Harvesting for 5G-Compatible IoT Applications

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***Abstract*—This report aims to summarize the latest progress of awardee's Ph.D. project in part supported by the 2019 IEEE MTT-S Graduate Fellowship Program. This project focuses on far-field radiofrequency (RF) energy harvesting for batteryless 5G-compatible Internet of Things (IoT) applications. To assess the feasibility of far-field ambient RF energy harvesting, a dynamic outdoor measurement of ambient RF energy density in Montreal was carried out. The main barrier for commercializing far-field RF energy harvesting technique lies in issues of limited dc output power and low harvesting efficiency. Thus, two measures have been taken to tackle these issues: (a) using dedicated beamforming wireless RF energy delivery; (b) simultaneously rectifying multi-physical ambient energy sources in the free space. The latest outcomes of this project are presented and discussed briefly in this report.**

***Index Terms*—backscattering, batteryless, far-field WPT, IoT, wireless power transfer (WPT)**

I. Introduction

FAR-FIELD radiofrequency (RF) energy harvesting is going through rapid development and has attracted vast attention recently [1]. With the roll-out of 5G and the internet of things (IoT), billions of sensors are being implemented all around the world, forming a global networking system. Far-field RF energy harvesting can be an ultimate powering solution for such sensors in urban and suburban areas and make them fully self-sustainable.

As the very first step of far-field RF energy harvesting, measuring and understanding how much ambient RF energy in the free space is of great importance. An outdoor ambient RF signal density mapping of Montreal was carried out [2]. Since available ambient input RF energy is often limited, far-field RF energy harvesting usually has low efficiency. As a result, the total dc output of far-field ambient RF harvesting is small, which is related to the input energy and rectifying efficiency. The first solution to the above problem is to introduce dedicated beamforming wireless RF energy delivery. A reconfigurable energy harvester with harmonic backscattering feature is designed to operate in this case [3]. Moreover, other ambient energy sources have been combined with RF energy for an enhanced efficiency performance in rectification, such as vibration [4], [5], and thermal power [6], [7].

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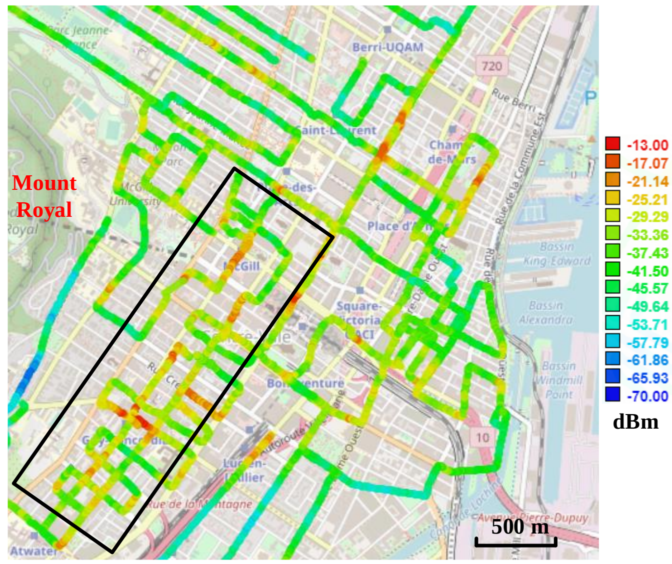

Fig. 1. Measured signal density of GSM/LTE-850 band in Downtown Montreal.

The remainder of this report is organized as follows. Section II presents the latest outcomes of this project. Section III discusses awardee's career plan and the impact of the MTT-S Fellowship Program on the decision. A brief conclusion is drawn in Section IV.

II. Major Outcomes

A. Ambient RF energy survey on the Island of Montreal

Different from previous ambient RF energy measurements, a dynamic outdoor testing of signal density on the Island of Montreal was conducted [2]. The measured results of the GSM/LTE-850 band in Downtown Montreal are presented in Fig. 1. The black box in Fig. 1 marks the major shopping pedestrian streets in downtown, where the ambient RF signal demonstrates relatively higher levels. The highest signal level is recorded to be about −13 dBm. Therefore, in a crowded area, far-field ambient RF energy harvesting is feasible and can have a satisfying efficiency.

B. Reconfigurable energy harvester design

Ambient RF energy is often scarce and unpredictable. Far-field RF energy harvesting based on ambient power is suitable for low-power devices/sensors working in a low duty

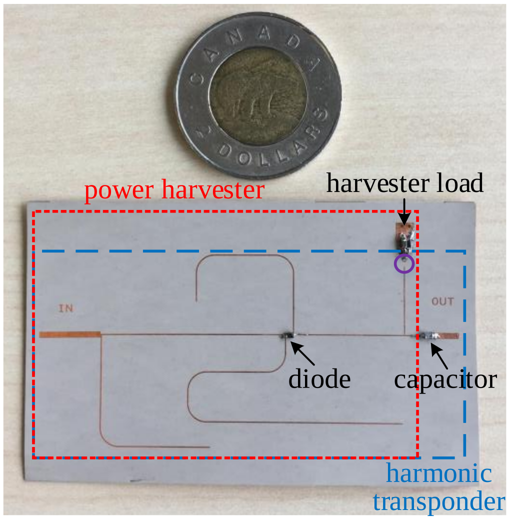

Fig. 2. Reconfigurable energy harvester able to work in tow modes: energy harvesting and harmonic backscattering.

cycle. Whereas, for specific applications requiring a consistent and stable power supply, far-field RF energy harvesting needs a more reliable RF source. Therefore, a dedicated beamforming RF energy transmitter is an intriguing solution. A reconfigurable energy harvester is designed specifically for this case, as shown in Fig. 2 [3]. It can work in two modes, i.e., power harvester and harmonic backscattering. A switch is required to control this circuit and determine operation modes. It is worth noting that the energy harvester and harmonic backscattering transponder share more than 90% of the circuit space.

C. *Cooperative multi-physical energy harvester*

Ambient RF energy sometimes only provides limited input power, so different types of ambient energy sources can be introduced in energy harvesting [4, 5, 7]. The first advantage of cooperative multi-physical energy harvesting is obvious, which can lead to larger dc output. Moreover, the harvesting efficiency, related to input power level, can also be leveraged greatly. Thus, a cooperative multi-physical energy harvester is a preferred option. Fig. 3 shows a typical example, which is a cooperative vibration and RF energy harvester. The efficiency enhancement of more than 50% is observed when input power is lower than −35 dBm for the reported multi-physical energy harvester.

III. Career Plan

I would like to continue my research on Batteryless IoT in academia after my Ph.D. study. I enjoyed inspiring discussions and idea exchanges with colleagues and researchers. The freedom and flexibility in academia give me more motivation to overcome challenges in research.

The recognition of the IEEE MTT-S Graduate Fellowship Award has strengthened my confidence greatly to pursue a career in academia. Moreover, the financial support of this fellowship has offered me an opportunity to attend the 2019 IMS in Boston. Through this valuable experience, I met many leading researchers from all over the world and learned the

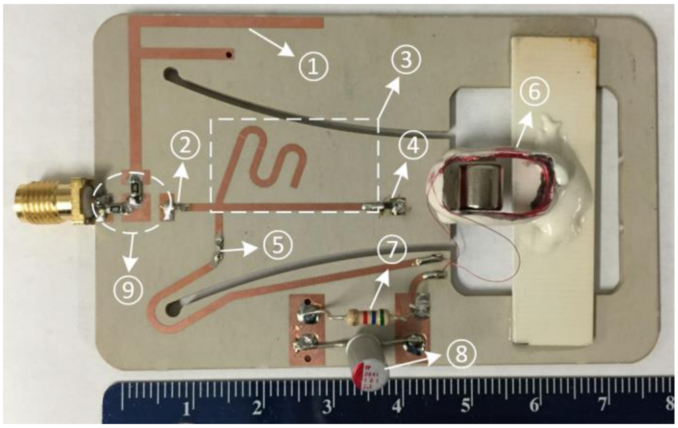

Fig. 3. Cooperative vibration and RF energy harvester.

state-of-the-art in fields of interest, like far-field WPT, backscattering, and batteryless IoT.

IV. Conclusion

This report briefly presents the latest progress of awardee's Ph.D. project in part supported by the MTT-S Graduate Fellowship Program. Ambient RF energy density measurement was finished, acting as a feasibility study of far-field RF energy harvesting. Prototypes of a reconfigurable energy harvester and a cooperative vibration and RF energy harvester are presented. All these efforts pave a way towards the high-efficiency far-field RF energy harvesting.

Acknowledgment

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