International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 8 Aug. 2022, pp: 677-681 www.ijaem.net ISSN: 2395-5252

A Review on radio Frequency Energy Harvesting Techniques

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Submitted: 05-08-2022 Revised: 11-08-2022 Accepted: 15-08-2022

ABSTRACT:This research present a review of different techniques used in maximizing the energy harvested at the receiver.Recent research is aimed at developing algorithms that can maximize the amount of energy harvested for user consumption in wireless sensor networks (WSN). The energy constrained wireless networks such as WSN are powered by batteries which have limited lifetime that results in low amount of energy harvested. Also, long-lasting batteries have a limited lifespan which largely confines the network performance of radio frequency (RF) devices. Researchers focus on using the lagrangian methods which rely on the balance between descents in objective space and ascents in the Lagrangian multiplier in order to arrive at equilibrium points. Without good balance, the search trajectory may converge very slowly, oscillate forever and diverge. The convergence speed and solution quality can be affected by adjusting the weight of the objective function and it is difficult to select a proper static weight for each problem instance. This paper also makes possible suggestion on how to maximize the energy harvested by receiving antennas in order to power devices.

KEYWORDS: Review, WSN, RF, SDP, Energy harvesting

I. INTRODUCTION

In recent times, radio-frequency (RF) signals radiated by ambient transmitters becomes a sustainable new source for wireless energy harvesting. A general architecture of an RF energy harvesting device is shown in figure 1.(Lakshmi, 2015). Ever since RF signals carry energy as well as information at the same time, simultaneous wireless information and power transfer (SWIPT) enables efficient resource allocation at transceiver designs and thus has careworn an important attention in wireless communications (Liu, 2016).Energy harvesting (EH) is an attractive solution for enabling self-sustainable wireless devices in communication networks. Thus, the inconvenience of recharging and replacing batteries can be avoided by harvesting energy from different energy sources, such as solar and wind. Recently, wireless power transfer (WPT) via radio frequency signals has received considerable attention as it provides a ubiquitous, relatively stable, and controllable source of energy (Grover and Sahai, 2010; Krikidis et al., 2014).

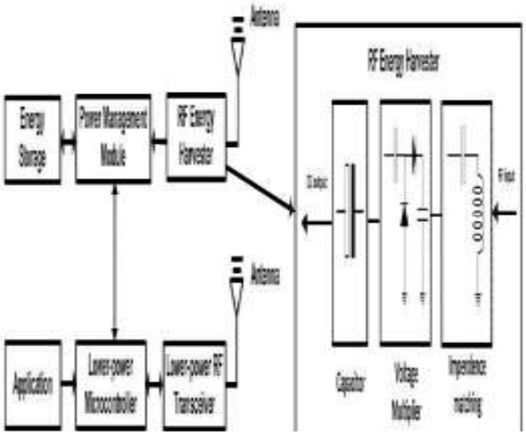

Figure 1: General architecture of an RF energy harvesting device(Lakshmi, 2015).

Furthermore, other benefits can be reaped by employing information carrying signals for WPT, which enables simultaneous wireless information and power transfer (Varshney, 2008).

The SWIPT system, introduces a paradigm shift for system, receiver, and resource allocation algorithm design for communication systems due to the newly imposed challenges in delivering information and energy concurrently. In particular, there is a fundamental trade-off between EH and information decoding (ID) (Varshney, 2008). Thereby, resource allocation plays a particularly important role for improving the system performance of SWIPT networks (Boshkovska et al., 2016a). In Grover and Sahai (2010) the power allocation algorithm for near-field communication systems was proposed. However, assumption was made that the receivers

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are able to harvest energy from the received signal, while simultaneously decoding the embedded information, which is not feasible in practice, yet, due to practical limitations of EH circuits. Consequently, hybrid power splitting receivers and separate receivers were proposed for SWIPT (Zhang & Ho, 2013; Zhou et al., 2013). Additionally, a simple time-switching receiver was proposed for alternating between ID and EH across different time slots (Zhou et al., 2013). For multiuser downlink SWIPT systems, suboptimal order-based scheduling schemes to balance the trade-off between the ergodic achievable rates and the average amounts of harvested energy of the users were proposed in Morsi et al. (2015). The optimization of beamformers with the objective to maximize the sum of total harvested energy under the minimum required signal-to-interference-plus-noise ratio (SINR) constraints for multiple information receiver was considered in Xu et al., (2013). A multiuser scheduling schemes, which exploit multiuser diversity for improving the system performance of multiuser SWIPT systems. Besides, SWIPT has also been considered in cooperative system scenarios, where the performance of SWIPT systems was analyzed by considering different relaying protocols (Krikidis et al., 2014; Nasir et al., 2015).

Recently, SWIPT system has drawn more attention on maximizing either the throughput or the harvested energy. The EH has provided solutions for the limitations introduced by energy-constrained mobile devices.

Emphasis on this works will be place on maximizing the harvested energy in SWIPT systems. And a non-linear model will be adopted for the work of Boshkovska et al., (2016b), which the semi-definite programming algorithm will be improve using dynamic weight adaptation algorithm for effective convergence speed.

1.1Radio frequency energy harvesting network

A lot has been written about the benefits of wireless sensor and potential of energy harvesting to provide a reasonable power for the life of some devices.

In wireless sensor application, disposable, long life batteries will continue to be used until the technologies of energy harvesting gets matured, creating a shift in the usage from disposable to rechargeable batteries for applications that would need higher power over the life time of the device (Basagni et al., 2013). However, this potential lies in the new class of device that are batteries – free which enables the applications which would have been expensive due to the maintenance cost of repeated batteries replacement (Basagni et al., 2013).

Technology has been developed in the energy harvesting technology taking advantage of varied sources of micro-power (power measured in milliwatts) which includes solar, vibration, thermal energy and radio frequency energy. Hence, for some specific installation there is a clear choice for optimal energy harvesting technology to be used, but depending on the application, there all capable of providing the required micro power needed for wireless sensor applications (Ostaffe, 2009)

The typical architecture of a radio frequency (RF) energy harvesting network which comprise of three major components such as information gateways, RF energy sources and network nodes/devices is shown on Figure 2(Lakshmi, 2015).

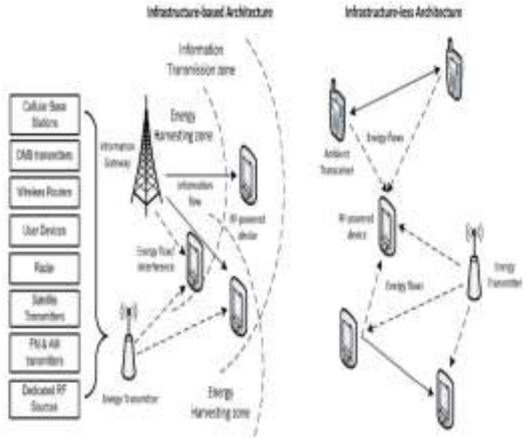

Figure 2: RF energy sources and network nodes

II. REVIEW OF SIMILAR WORKS

Leng **et al.,** (2016)studied the resource allocation algorithm design for energy efficient simultaneous wireless information and power transfer (SWIPT) systems. The considered system comprises of a transmitter, an information receiver, and multiple energy harvesting receivers equipped with multiple antennas. A multi-objective optimization framework was design for the trade-off between the maximization of the energy efficiency of information transmission and the maximization of wireless power transfer efficiency. The proposed problem formulation takes into account the per antenna circuit power consumption of the transmitter and the imperfect channel state information of the energy harvesting receivers. The adopted nonconvex multi-objective optimization problem is transformed into an equivalent rank-constrained semidefinite program (SDP) and

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optimally solved by SDP relaxation. The numerical results unveil an interesting trade-off between the considered conflicting system design objectives and also highlighted the benefits of multiple transmit antennas for improving system energy efficiency. However, on maximizing the harvested energy, the alternative approach to harvest as much energy as possible adversely affects information transfer, leading to the degradation of system quality of service (QoS).

Zhang & Ho (2013) studied the simultaneous wireless information and power transfer (SWIPT) system for a multiple-input multiple-output (MIMO) wireless broadcast system. And this technique was implementable by various technologies such as inductive coupling, magnetic resonate coupling, and electromagnetic (EM) radiation, for various applications. The problem of the SWIPT is unable to decode information directly. Thus, a MIMO broadcast system were designed to mitigate the stated problem. The results showed that, for the case of separated receivers, the optimal transmission strategy to achieve different tradeoffs for maximal information rate versus energy transfer were obtained, which were characterized by the boundary of a so-called rate-energy (R-E) region. For the second case, the co-located receivers, showed an outer bound for the achievable R-E region due to the potential limitation that practical energy harvesting receivers are not yet able to decode information directly. However, results obtained were based on the overly optimistic assumption of perfect channel state information.

Ng **et al.,** (2014) studied the robust beamforming for secure communication in systems with wireless information and power transfer. More importantly, wireless energy harvesting technology facilitates the possibility of simultaneous wireless information and power transfer. Yet, this new technology introduces a paradigm shift in system and resource allocation algorithm design due to the imposed new challenges. Thus, a multiuser multiple-input single-output (MISO) downlink system with simultaneous wireless information and power transfer were considered to improve security on communication in the presence of passive eavesdroppers and potential eavesdroppers. A resource allocation algorithm was designed to minimize the total transmit power for the case, when the legitimate receivers were able to harvest energy from radio frequency signals. And the design was based on the dual used of both artificial noise and energy signals in providing secure communication and facilitating efficient wireless energy transfer. The algorithm was formulated as a non-convex optimization problem. To mitigate the stated problem, a non-convex probabilistic constraint was replaced with a convex deterministic constraint. Then, a semi-definite programming (SDP) relaxation approach was adopted to obtain the optimal solution for the reformulated problem. The suboptimal resource allocation scheme with low computational complexity for providing communication secrecy and facilitating efficient energy transfer was developed. Simulation results showed that, with increasing imperfectness of the channel estimation, the transmitter have to allocate more power to the artificial noise and the energy signal to prevent interception by potential eavesdroppers and to facilitate efficient energy transfer for fulling constraints. But assumption of linear harvesting model makes it imprecise and not capable of capturing the nonlinear behavior of the energy harvesting system.

Krikidis **et al.,**(2014) proposed a simultaneous wireless information and power transfer in modern communication systems. The energy harvesting technology was a promising field in wireless power transfer, where terminals harvest energy from electromagnetic radiation were harvested. Thereby, the energy may be harvested opportunistically from ambient electromagnetic sources or from sources that intentionally transmit electromagnetic energy for energy harvesting purposes. The interesting and challenging scenario arises when sources perform simultaneous wireless information and power transfer (SWIPT), as strong signals not only increase power transfer but also interference. The proposed technique focusses particular on the hardware realization of rectenna circuits and practical techniques that achieve SWIPT in the domains of time, power, antennas, and space. However, the RF model did not considered some aspects of nonlinearities of the model.

Khandaker & Wong, (2015)proposed robust secrecy beamforming with energy harvesting eavesdroppers, for simultaneous wireless information and power transfer (SWIPT) in multiple-input–single-output downlink systems, in which a multi antenna transmitter sends a secret message to a single-antenna information receiver (IR) with multiple single-antenna energy receivers (ERs). The technique maximize the harvested energy by the ERs while maintaining the signal-to-interference-and-noise ratio (SINR) threshold at the IR and keeping the message secure from possible eavesdropping by the ERs by suppressing their SINRs. The scenarios for the perfect and imperfect channel state information at the transmitter were considered. Which the semidefinite relaxation techniques was employed and it was observed that, there always exists a rank-one optimal solution for the IR (i.e., transmit beamforming was optimal for the IR). Simulation results showed that, the more CSI available at the transmitter, the more efficient the beamforming schemes and the higher power harvested. However, assumption that the actual channels lie in the neighborhood of the estimated channels available at the base station cannot guarantee that channel uncertainties bounded.

Wu **et al.,** (2016)proposed energy-efficient resource allocation for wireless powered communication networks (WPCN). Such that, multiple users harvest energy from a keen power station and then communicate with an information receiving station. The aimed was to examine the maximum realizable energy efficiency of the network through joint time allocation and power control while taking into account the initial battery energy of each user. The energy efficiency maximization problem for the WPCN without any system throughput requirement was considered. It was established that, energy efficiency maximization problem for the WPCN can be cast into energy efficiency maximization problems for two simplified networks via exploiting its special structure. The non-convex problem was transformed into a standard convex optimization problem using the fractional programming theory through the analysis of the Karush-Kuhn-Tucker (KKT) conditions, the optimal structure of time allocation and power control were characterized., which help in obtaining the optimal solution of joint time allocation and power control for the case of throughput-constrained WPCN and to derive an efficient iterative algorithm for obtaining the optimal solution. The Simulation results demonstrated the effectiveness of the proposed joint time and power optimization and that for a sufficiently long transmission time, the system energy efficiency is maximized by letting each user achieve its own maximum user energy efficiency. However, for a short transmission time, users can only meet the minimum system throughput requirement at the cost of sacrificing system energy efficiency.

Liu (2016) proposed a wireless information and power transfer for multi-relay assisted cooperative communication. In the work, the simultaneous wireless information and power transfer (SWIPT) in multi-relay assisted two-hop relay system were considered, where multiple relay nodes simultaneously assist the transmission from source to destination using the concept of distributed space-time coding. It was formulated that each relay applies power splitting protocol to coordinate the received signal energy for information decoding and energy harvesting. The optimization problems of power splitting ratios at the relays were formulated for both decode-and-forward (DF) and amplify-and-forward (AF) relaying protocols. Simulation results showed that, the effectiveness of the proposed technique outperform the traditional best relay selection schemes. Moreover, the power splitting is better in high signal-to-noise ratio (SNR) region and time switching is favored in low SNR region in relay networks.

Boshkovska **et al.,** (2016a) Studied power allocation and scheduling for SWIPT systems with non-linear energy harvesting model. The design of a resource allocation algorithm for multiuser simultaneous wireless information and power transfer systems for a realistic non-linear energy harvesting (EH) model was developed. The algorithm design was formulated as a nonconvex optimization problem for the maximization of the long term average total harvested power at EH receivers subject to quality of service requirements for information decoding receivers. To obtain a manageable solution, the non-convex sum of ratios objective function was transform into an equivalent objective function in parametric subtractive form. This result to a computationally efficient iterative resource allocation algorithm for the non-linear energy harvesting model. The simulation results showed that, the numerical results reveal a significant performance gain that can be achieved if the resource allocation algorithm design was based on the non-linear EH model instead of the traditional linear model. However, the optimal multiuser power allocation and scheduling policies depend only on the current time, which is not dynamic.

Boshkovska**et al.,** (2016b) proposed a robust beamforming for simultaneous wireless information and power transfer (SWIPT) Systems with Non-linear Energy Harvesting Model. The main issue with the SWIPT systems has to do with the problem of imperfect channel state information (CSI) and also the quality-of-service (QoS) of information transfer are not guarantees. The resource allocation algorithm design was formulated as a nonconvex optimization problem for the maximization of the total harvested power, which was formulated to mitigate the stated problems. The proposed technique obtains the global optimal solution for the non-convex optimization problem. Which in each iteration, a rank-constrained semidefinite program (SDP) was

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solved optimally by SDP relaxation, to get an optimal solution. And the average total harvested power versus the maximum channel estimation error, for different numbers of transmit antennas and resource allocation schemes were considered. The proposed algorithm was compared with the baseline scheme designed for perfect CSI and the conventional linear energy harvesting model which showed more robustness. However, the slack variable introduced in the semi-definite programming to handle inequalities constraints are not dynamically selected, this can affect the convergence speed.

III. CONCLUSION

This paper reviewed and discussed different RF harvesting techniques. All the individual approaches are aimed at increasing the amount of energy harvested at the receiver generally by power allocation or scheduling. For better performance of these techniques in terms of the energy harvested.

IV. RECOMMENDATION

1. Improve the sensitivity of the RF energy harvester by putting into consideration the type of antenna constellation and using a metaheuristic algorithm to select efficient constellations.
2. Designing an antenna with high sensitivity merging and relative diversity to detect and harvest more RF power from the spurious signals available in the environment.
3. Developing an algorithm that can optimize the processing time of harvesting this energy. E.g. improving the operation of SDP algorithm.

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