Futo Journal Series (FUTOJNLS)
e-ISSN : 2476-8456 p-ISSN : 2467-8325
Volume-4, Issue-1, pp- 127 - 134
www.futojnls.org

Research Paper July 2018

Harvesting RF Energy for Mobile Devices using Dynamic Weight Adaptive Techniques

Mshelia, Y. A.*, Usman, A. D. and Sani, S. M.
Department of Communications Engineering, Ahmadu Bello University, Zaria, Kaduna State, Nigeria
**Corresponding Author's Email: yalimshelia@yahoo.com.*

Abstract

Self-sustainable wireless devices in mobile communication networks is gaining fast attention. This is due to the need to charge and sustain these mobile devices without the use of wired chargers in order to meet user demand. A new source of wireless energy harvesting is gotten from the radio frequency (RF) signals that are radiated by transmitting antennas. This paper presented a modified Semi-definite Programming (mSPA) for RF harvesting. An adaptive dynamic weight technique was used to solve the Semi-Definite Programming (SDP). This is in order to obtain a faster convergence time for the optimal solution of the optimization problem so as to maximize the total amount of RF energy harvested at the receiver and in order to guarantee quality of service (QoS). Two different number of receiving antennas were considered and the results showed an improvement of 26.07% and 18.67%, for mSPA over Semi-definite Programming Algorithm (SPA) with number of receiving antennas N_R=3 and N_R=2, respectively. This showed that the developed mSPA performed more than the SPA which translates to more RF energy harvested.

Keywords: Energy harvesting, mSP, Radio frequency, SDP, Mobile communication.

1. Introduction

Energy harvesting is a process in which energy from external sources like solar power, thermal energy, wind energy etc., is captured and stored for small, wireless devices like those used in wearable electronics and wireless sensor networks (Visser & Vullers, 2013). Radio Frequency (RF) energy transfer and harvesting techniques have recently become alternative methods to empower the next generation wireless networks (Lakshmi, 2015).The broadcast nature of wireless channels facilitates one-to-many wireless charging, which eliminates the need for power cords and manual recharging, and enables the possibility of simultaneous wireless information and power transfer (SWIPT) (Ng, Lo & Schober, 2015).

In this research paper, emphasis will be place on maximizing the total average harvested power in simultaneous wireless information and power transfer (SWIPT) systems while guaranteeing the quality of service.

A semi-definite programming algorithm was modified using adaptive dynamic weight technique in order to obtain faster convergence speed for optimal solution that maximizes the amount of RF energy harvested at the receiver.

Dynamic weight adaptive technique is a strategy used to adjust relative weights of an objective function based on the behaviour of the dynamic system. The dynamic system gradually develops over time t, and reaches a feasible local minimum or maximum value of a function when it stops at equilibrium point where all the gradients vanish. The progress of the search trajectory can be monitored by dividing the time into non-overlapping windows of size N_u iterations

A lot of research has been carried out on maximizing the amount of RF energy harvested in SWIPT

Leng, Ng, Zlatanov and Schober, (2016) studied the resource allocation algorithm design for energy efficient simultaneous wireless information and power transfer (SWIPT) systems. However, the alternative approach to harvest as much energy as possible adversely affects information transfer, leading to the degradation of system quality of service (QoS). Proposing a joint antenna selection and spatial switching for energy efficiency in a multiple-input multiple-output (MIMO) simultaneous wireless information and power transfer (SWIPT) system, Tang, So, Shojaeifard, Wong and Wen, (2016) designed systems with the sole goal of spectral efficiency (SE) maximization which, however, constitutes an ever-rising network power consumption, which goes against global commitments for sustainable development.

Wu, Tao, Ng, Chen and Schober, (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. However, for a short transmission time, users can only meet the minimum system throughput requirement at the cost of sacrificing system energy efficiency. Earlier, Krikidis, Timotheou, Nikolaou, Zheng, Ng and Schober, (2014) had proposed a simultaneous wireless information and power transfer in modern communication systems. However, the RF model did not consider some aspects of nonlinearities of the model. Zhou, Zhang and Ho, (2013) had also studied the simultaneous wireless information and power transfer (SWIPT) system for a multiple-input multiple-output (MIMO) wireless broadcast system. However, results obtained were based on the overly optimistic assumption of perfect channel state information.

Studying the power allocation and scheduling for SWIPT systems with non-linear energy harvesting model, Boshkovska, Morsi, Ng and Schober (2016), reported that the optimal multiuser power allocation and scheduling policies depended only on the current time, which is not dynamic.

It can be seen from the literature reviewed that maximizing the amount of RF energy harvested is important, because it provides a way of sustaining lifetime and charging mobile devices. This paper presents an improved technique for maximizing the total harvested energy harvested at the RF receiver

2. Methodology

The step by step process for the development of the improved SDP algorithm using the dynamic weight adaptive technique for Lagrangian multipliers on the beam formers are as follows:

i. Initialize the maximum number of iteration L_{max} and iteration index n
ii. Estimate initial weight w(t=0)
iii. Measure the performance metric of search trajectory (X(t),λ(t),μ(t)) periodically
iv. Adapt w(t) to obtain efficient convergence time
v. Update the optimal solution to the optimization problem until iteration index n= L_{max}

The maximum number of iteration,$L_{max},$ and the iteration index are first initialized. The inner loop problem is solved via the SDP relaxation for vectors ϒ and α. The optimal solution to the optimization problem is updated until iteration index, n =$L_{max},$

Equation (1) represents the inner loop non-convex optimization problem. In each iteration, the inner loop non-convex optimization problem of estimating the performance of the RF receiving antennas was solved. The constraint C defines the variables that can affect the quality of the transmitted signal.

$$\underset{\mathrm{X,z}\in H^{N}T,\tau}{\max imize} \quad \sum_{j=1}^{J}\gamma_j{}^{*}[\mathrm{M}_j-\alpha_j{}^{*}(1+\exp(-a_j(\tau_j-b_j)))]$$

$$C_1 : T_r(\mathrm{X}+Z) \leq P_{\max}$$

$$C_2 : \min_{h\in\wedge} \frac{T_r(\mathrm{X}H)}{T_r(\mathrm{Z}H)+\delta_s^2} \geq \Gamma_{req,}$$

$$C_4 : \min_{G_j\in\Xi_j} T_r((\mathrm{X}+Z)G_jG_j^H \geq \tau_j, \forall_{j,}$$

$$C_3 : \mathrm{Z} \succeq 0, \mathrm{C}_5 : Rank(\mathrm{X}) = 1, C_6 : \mathrm{X} \succeq 0 \qquad 1$$

$X = xx^H$ Is a new optimization variables matrix and $\tau = \tau_1, \tau_{2,} - - - \tau_j$ is a vector of auxiliary optimization variable.

where:

M_j = Maximum harvested power at energy harvested receiver

$P_{r_{\max}}$ = Maximum radiated power at one time slot

T_r = Transmitter section

α_j and γ_j = Vectors

a_j = Non-linear changing rate with respect to the input power

b_j = Minimum turn on voltage of an energy harvesting circuit

Z = Constrain matrix

$X = xx^H$ Is a new optimization variables matrix and

$\tau = [\tau_1, \tau_2 .....\tau_j]$ is a vector of auxiliary optimization variables.

Equation (2) defines the unique optimal solution (ϒ,α) that can be obtained. This optimal solution can only be obtained only if equation (2) satisfied.

$$\varphi(\gamma, \alpha) = [\varphi_1, \varphi_2, ...\varphi_{2J}] = o \qquad 2$$

Therefore the RF transmission energy vectors γ^{n+1} and α^{n+1} are updated in the iteration algorithms as:

$$\gamma^{n+1} = \gamma^n + \zeta^n q^n{}_J + 1:2J \text{ and } \alpha^{n+1} = \alpha^n + \zeta^n q^n{}_{1:J} \qquad 3$$

where:

$$q^n = [\varphi'(\gamma, \alpha)]^{-1} \varphi(\gamma, \alpha) \qquad 4$$

and $\varphi'(\gamma, \alpha)$ is Jacobian matrix of $\varphi(\gamma, \alpha)$

ζ^n is the largest $\in'$ satisfying $\|\varphi(\gamma^n + \in^l q^n{}_J + 1:2J, \alpha^n \in^l q^n_{1:J})\| \leq (1 - \eta \in^l) \|\varphi(\gamma, \alpha)\|$ 5

2.1. Improved SDP Algorithm

The SDP algorithm is improved using dynamic weight adaptive technique which is a strategy in order to adapt weight. An estimated initial weight, w (t) = 0 is first obtained. The search trajectory (X (t), λ (t), μ (t)) is measured periodically. The weight factor, w (t) is adapted dynamically to obtain an efficient convergence time. The optimal solution to the optimization problem is updated until the maximum number of iterations. Table 1 shows the simulation parameters for the development of mSAP.

Table 1: Simulation Parameters

PARAMETER	VALUE
Simulator	Matlab 2016
Carrier center frequency	915MHz
Bandwidth	200Khz
Number of Time slots T	100
Reference and maximum service distance (w.r.t pmax)	10 Meter
Reference and service distance (w.r.t distance)	10-30 meter
Constraints on average radiated power Pav	0.2 pmax
Maximum transmit power Pmax (w.r.t distance)	30 dBm
Maximum harvested DC power for rectifying circuits –Mj	20mW
EH circuit parameter a	6400
EH circuit parameter b	0.003
Minimum required data rate per user Creq	0.5 bit/s/Hz
Number of Transmitting Antenna (N_T)	4
Number of Receiving Antenna (N_R)	3 and 2

3. Results and Discussion

The modified Semi-definite programming algorithm (mSPA) was simulated and implemented on MATLAB R2016b simulator with the results obtained compared with SPA based on average total harvested power in terms of maximum transmit power as performance metric

The results for different numbers of receiving antennas (N_R) obtained show the relationship between the average total harvested power and maximum transmit power. The maximum transmit power was taken to be P_{max} = 30dbm and the number of receiving antennas (N_R) = 2 and 3 in separate cases. The percentage improvement for the developed technique was estimated using equation 6.

$$\frac{av\sum ISPA - av\sum SPA}{av\sum ISPA} X100\% \qquad 6$$

Figure 1 is a plot of average total harvested power versus the maximum transmit power when the number receiving antennas N_R=2 and total number of transmitting antennas N_T=4. Figure 2, on the other hand, is a plot of average total harvested power versus the maximum transmit power when the numbers of receiving antenna N_R=3 , It is evident from Figures 1 and 2 that the total average harvested power increases non-linearly as the maximum transmit power increases and when the maximum transmit power is small as $P_{max} \leq 12.5dBm$, similarly the total harvested power increases slowly as the transmit power increases because the received power at the energy harvesting receivers are usually insufficient enough to switch the energy harvesting circuit. But at transmit power level of, $12.5dBm \le P_{max} \le 25dBm$, the total harvested power increase rapidly with respect to maximum transmit power.

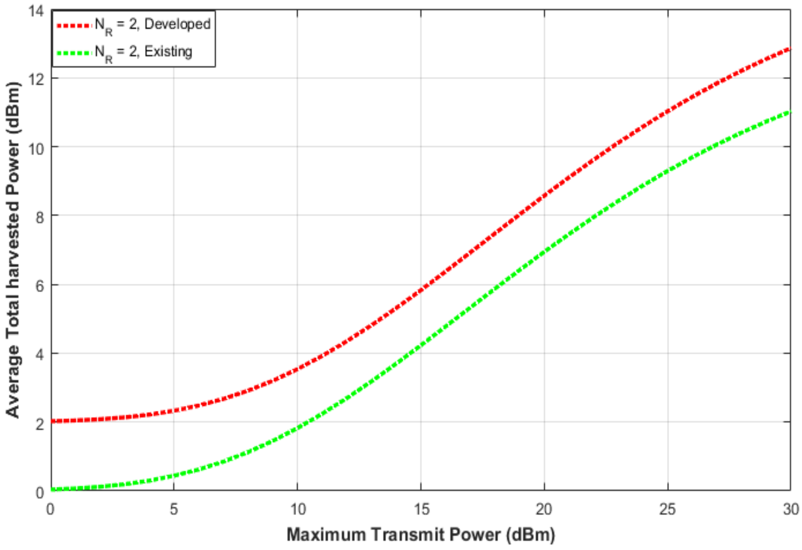

Figure 1: Plot of SAP against mSAP when N_R=2 and N_T=4

And at$P_{max} \ge 27dBm$, the total harvested power increases as the maximum transmit power increases but with diminishing return because exceedingly large transmit power can cause saturation in some of the energy receivers.

Fig. 2 shows that there is an increase in average harvested power when the number of receiving antennas was increased to N_R=3 as compared to Fig. 1 when N_R=2. Result shows how an extra receiving antenna can act as additional energy collector to enable a more efficient energy transfer.

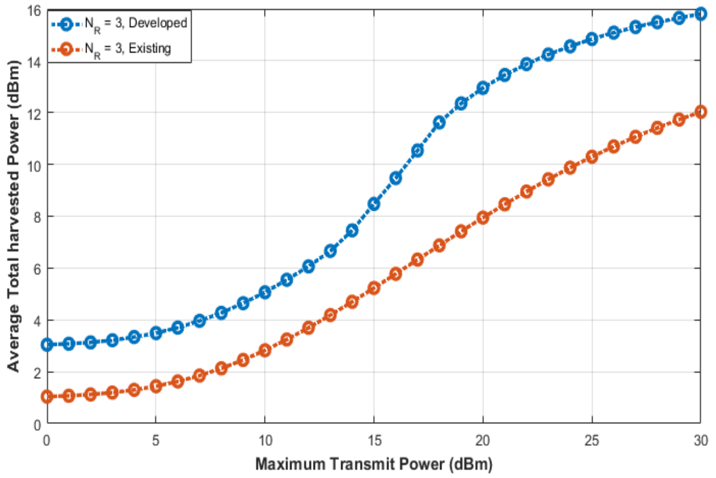

Figure 2: Plot of SAP against mSAP when N_R=3 and N_T=4

Fig. 3 is a comparison plot of average total harvested power for SPA and mSAP algorithms when N_R=2 and N_R=3. However the performance of mSAP is better than the S-PA by 26.07% and 18.67% using equation (6) when, N_R= 3, and N_R=2 respectively and is as a result of maximizing the amount of received signal power by IS-PA.

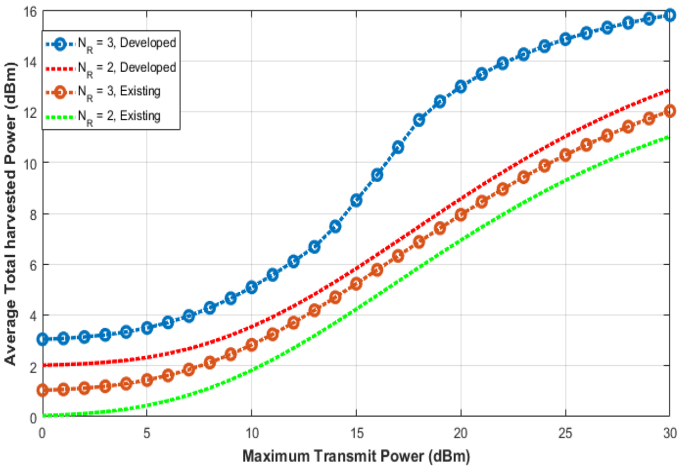

Figure 3: Comparison of the SDP with mSDP Algorithm for different number of Receiving Antenna

4. Conclusion

In this paper, a modified semi-definite programming algorithm (mSPA) using dynamic weight adaptive technique was presented considering different number of receiving antennas. The developed technique shows an improvement in the total average harvested power and also guarantees the quality of service of the information transfer.

5. Recommendations

The sensitivity of the RF energy can be improved in order to extract RF energy located far away from the RF transmitter by adopting meta heuristic algorithms for better convergence..

Devising a high gain antenna by using Hilbert matrix for a wide range of frequency can be tested to improve energy harvesting efficiency

References

Boshkovska, E., Morsi, R., Ng, D. W. K., & Schober, R.(2016). Power allocation and scheduling for SWIPT systems with non-linear energy harvesting model. Paper presented at the Communications (ICC), 2(3), 22-33.

Krikidis, I., Timotheou, S., Nikolaou, S., Zheng, G., Ng, D. W. K., & Schober, R. (2014). Simultaneous wireless information and power transfer in modern communication systems. *IEEE Communications Magazine, 52*(11), 104-110.

Lakshmi, R. S. (2015). RF energy harvesting for wireless devices. *International Journal of Engineering Research and Development, 11*(4), 39-52.

Leng, S., Ng, D. W. K., Zlatanov, N., & Schober, R. (2016). Multi-objective resource allocation in full-duplex SWIPT systems. Paper presented at the Communications (ICC), 5(6), 7-8.

Ng, D. W. K., Lo, E. S. & Schober, R. (2014). Robust beamforming for secure communication in systems with wireless information and power transfer. *IEEE Transactions on Wireless Communications, 13*(8), 4599-4615.

Tang, J., So, D. K., Shojaeifard, A., Wong, K.-K. & Wen, J. (2016). Joint antenna selection and spatial switching for energy efficient MIMO SWIPT system. *arXiv preprint arXiv:1611.00277*.

Visser, H. J., & Vullers, R. J. (2013). RF energy harvesting and transport for wireless sensor network applications: Principles and requirements. *Proceedings of the IEEE,* 101(6), 1410-1423.

Wu, Q., Tao, M., Ng, D. W. K., Chen, W., & Schober,R. (2016). Energy-efficient resource allocation for wireless powered communication networks. *IEEE Transactions on Wireless Communications,* 15(3), 2312-2327.

Zhou, X., Zhang, R., & Ho, C. K. (2013). Wireless information and power transfer: Architecture design and rate-energy tradeoff. *IEEE Transactions on Communications,* 61(11), 4754-4767.