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Highly Efficient Energy Harvesting WPCN Using Dynamic Antenna Method

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Abstract

This paper deals with a bi-directional full duplex WPCN equipped with a dual function information and energy access point, and a group of energy harvesting wireless sensor nodes. The access point is equipped with two antennas,one for downlink which broadcast energy to the sensor nodes and the other for uplink. In the uplink,TDMA method is used to receive information from users. Throughput rate maximization and energy harvesting time minimization is achieved in the WPCN system utilizing the optimal time allocation algorithms. In the proposed system,the use of a dynamic antenna pattern is investigated. Here the antennas are flexible,each can can be used either for transmission or reception. The transmit-receive antenna combination is selected whose channel has the maximum power. Thus the dynamic configuration of antennas yield a higher throughput rate then the fixed antenna systems.

Keywords:
Throughput maximization,Wireless power transfer, Dynamic antenna

1 Introduction

In conventional sensor networks, the wireless sensor devices are powered by batteries,either rechargeable or replaceable. But their operation time is limited due to the need for recharging the batteries every now and then. The replacement or recharging of batteries is impossible in the devices located in dangerous environments or in medical sensors implanted inside human bodies. In such cases,we opt for energy harvesting,which can provide an intermittent power supply. This can extend the wireless network's lifetime.
The several energy harvesting sources include sun and wind. Another main source for harvesting energy is the wireless signals. The wireless signals carry both information and energy. This method of information and energy transfer is called Wireless Power Transfer(WPT). The networks evolved using the wireless power transfer is called Wireless Powered Communication Networks(WPCN). The wireless power is harvested from from television broadcast signals.

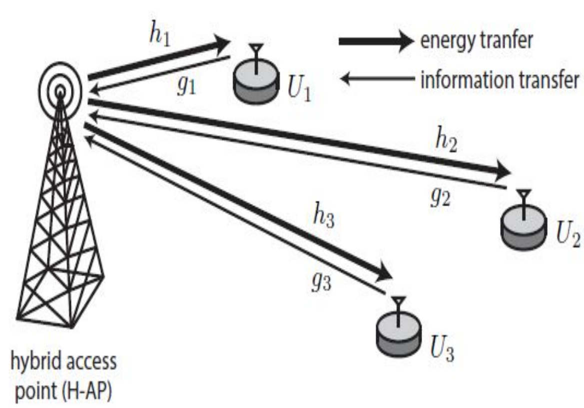

Fig 1:System Model

In a WPCN,energy nodes(EN) transmit wireless power to the sensor devices in downlink and the wireless sensor devices use the harvested energy to transmit the information to the information access point(AP) in the uplink. The energy node and access point can be separately located,or can also be grouped into pairs and each pair of energy node and access point are co-located and integrated as Hybrid Access Point(HAP). The energy causality model is considered here where it is assumed that the wireless users cannot use the harvested energy after its transmission slot;i.e,they can only use the harvested energy before its transmission slot.

In the earlier communication networks, the access point was limited to having one single antenna,hence it was able to perform downlink and uplink communication concurrently. Then the uni-directional antennas evolved where either uplink or downlink transmission was carried out. But the proposed system is based on bi-directional simultaneous wireless power transfer and information transmission where both uplink and downlink communication takes place simultaneously. Two fundamental problems are discussed here:(i)Maximizing the total throughput of the system and (ii)Minimizing the energy harvesting time.

It is found that the use of a dynamic antenna pattern can highly increase the performance of the wireless powered communication network efficiently. By dynamic behaviour of antenna,we mean the functions of antenna are not fixed. The system will decide which antenna are used for transmission or reception according to the present channel conditions like channel capacity,channel fading,power etc. Here each node is equipped with two antennas,one for transmission and other for reception.

Methodologies

In the WPCN system,the hybrid access point is proposed to have two flexible antennas,whose functions are not predefined and their functions are being decided by the system,based on the availability of better channel conditions and less channel fading. Initially the HAP is considered to be consisting of a fixed antenna pattern. The corresponding sum throughput is being calculated. The algorithms are implemented in MATLAB and the graphs are plotted. Then the energy harvesting time is calculated and the corresponding graphs are calculated. We find that the throughput maximization algorithm has increased the throughput to a great extend and the time minimization algorithm has decreased the energy harvesting time. This increases the efficiency of the system. The proposed WPCN system consists of a dynamic HAP which consists of a flexible antenna pattern which highly increases the throughput of the system than the earlier system. This will increase the efficiency of the system.

2. Throughput Maximization

The total throughput,T(τ) of the system is

$$T(\tau) = \sum_{i=1}^{K} \tau_i R_i \qquad (1)$$

$$= \sum_{i=1}^{K} \tau_i \; ln\left(1 + \frac{\gamma_i \sum_{j=0}^{i-1} \tau_j}{\tau_i}\right) \qquad (2)$$

where γ_i is given by $\gamma_i = \frac{h_i \eta_i g_i P_H}{\sigma^2}$,

$$\forall\; i \in \{1,2, \dots \dots . . K\}$$

The sum throughput maximization involves maximizing the throughput of the system in a total time constant,T. The throughput maximization problem is formulated as:

$$max \sum_{i=1}^{K} \tau_i \, ln\left(1 + \frac{\gamma_i \sum_{j=0}^{i-1} \tau_j}{\tau_i}\right), \qquad (3)$$

$$\forall\; i \in \{1,2, \dots \dots . . K\}$$

2.1 Throughput Maximization Algorithm

- 1: Initialize : $c_1 = 0, x_0 = 0$
- 2: **for** i = 1: K **do**
- 3. $x_i = 1/\gamma_i\left(\left(e^{(W(\gamma_i-1))}/(e^{c_i}+1) + c_i + 1\right) - 1\right)$
- 4: $c_{i+1} = \sum_{k=1}^{i}\gamma_k \,/(\gamma_k\, x_k + 1),$
- 5: **end for**
- 6: Compute $\tau_k\ by\ \tau_k^* = 1/1 + \tau_K$
- 7: **for** i = K-1 : 0 **do**
- 8: $\tau_i^* = \left(1 - \sum_{j=1+1}^{K}\tau_j^*\right)/(1 + x_i)$
- 9: **end for**
- 10: Output: $\tau_0^*, \ldots\ldots, \tau_K^*$

3. Time Minimization

Each user has to send a particular amount of information to the HAP. Let the minimum amount of information be D_i. The following condition should be satisfied.

$$\tau_i\, ln\left(1 + \frac{\gamma_i \sum_{j=0}^{i-1}\tau_j}{\tau_i}\right) \geq D_i, \quad \forall\, i \,\epsilon\, \{1,2, \ldots. K\} \tag{4}$$

The aim of this problem is to reduce the energy harvesting time or the charging time of the users in the communication network.

Hence the time minimization problem can be written as:

$$\min\ \sum_{i=0}^{K}\tau_i, \quad \text{s.t}\ \ \tau_i \geq 0, \quad \forall\, i\,\epsilon\,\{0,1,2, \ldots\ldots..K\} \tag{5}$$

3.1. Time Minimization Algorithm

- 1: Initialize : $C_k^* = C_k^m$ and τ_k^m
- 2: Compute $C_{k-1}^* = C_k^* - \tau_k^m$
- 3: **for** i = k-1:-1:1 **do**
- 4: $C_{i-1}^* = C_i^* - \tau_i^*$
- 5: **end for**
- 6: for i= k+1: +1: K **do**
- **7:** $\tau_i^* = \text{Root}\left(\tau_i^*/\gamma_i\left(e^{(D_i/\tau_i^*-1)}\right) = C_{i-1}^*\right)$
- 8: $C_i^* = C_{i-1}^* + \tau_i^*$
- 9: **end for**
- 10: $\tau_0^* = C_1^* - \tau_1^*$
- 11. Output: $\tau_0^*, \ldots\ldots, \tau_K^*$

In the time minimization problem,the aim is to minimize the energy harvesting time of the users. The primary purpose of the access point is to obtain information from the user.

There should be a minimum information rate,D_i that should be obtained from the user. If it is not satisfied,there is no purpose for mere energy harvesting. Time minimization should start with the user with the minimum value of C. Minimizing time is equivalent to minimizing C.

4. Proposed System:

The proposed WPCN system consists of a dynamic HAP which consists of a flexible antenna pattern whose function is defined by the system according to the present channel conditions like fading. Here the bidirectional full-duplex(FD) communications occur between two nodes, where each node is equipped with two antennas, used for either transmission or reception.

The transmit and receive antenna combination is selected utilizing the selection combining diversity technique.The antenna with the maximum power is selected and the corresponding antenna pair is used for transmission or reception. This will highly increase the throughput of the system than the fixed antenna method. This also will inturn double the spectral efficiency of the system.

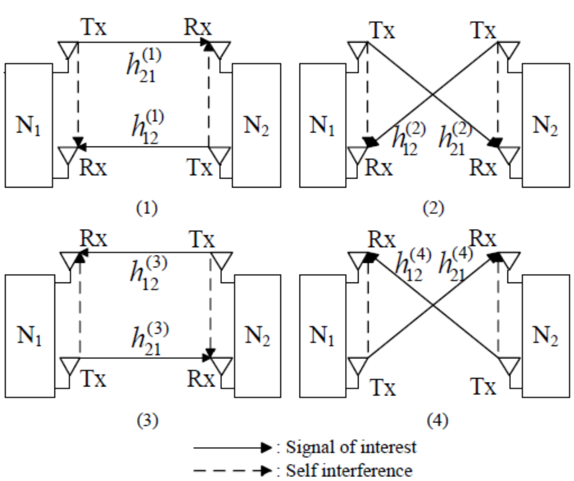

Fig 2: Proposed system model[4]

The fixed antenna pattern used in the earlier method have certain fixed function assigned to each antenna, i.e the antenna meant for transmission is used solely for that purpose and that meant for reception merely for reception. The system cannot predefine it. Hence a lot of time and power is wasted . But in the flexible method,the function of the antenna is decided by the system according to the channel conditions.

Hence the dynamic method of antenna configuration provides high efficiency and throughput than the earlier method.

4.1 Selection Combining

In "space diversity on receive," multiple antennas are used with the spacing between the adjacent antennas being chosen so that their respective outputs are essentially independent of each other. This requirement may be satisfied by spacing the adjacent receiving antennas by as much as 10 to 20 radio wavelengths or less apart from each other. Typically, an elemental spacing of several radio wavelengths is deemed to be adequate for space diversity on receive.

The much larger spacing is needed for elevated base stations,for which the angle spread of the elevated base stations is small since the spatial coherence spread is inversely proportional to the angle spread. Through the use of diversity on receive,a corresponding set of fading channels that are essentially independent are created. the issue then becomes of combining the outputs of these statistically independent fading channels in accordance with a criterion that will provide improved receiver performance.There are three diversity techniques of which selection combining technique is used in our paper.

The selection combiner structure consists of a logic circuit which selects the channel having the maximum signal to noise ratio. The selection combing method is the simplest form of space diversity on receive system. We assume that the channel is a frequency-flat,slowly fading Rayleigh channel. The selection combining procedure requires that we monitor the receiver outputs in a continuous manner and at each instant of time,select the receiver with the strongest signal(i.e the largest instantaneous SNR).

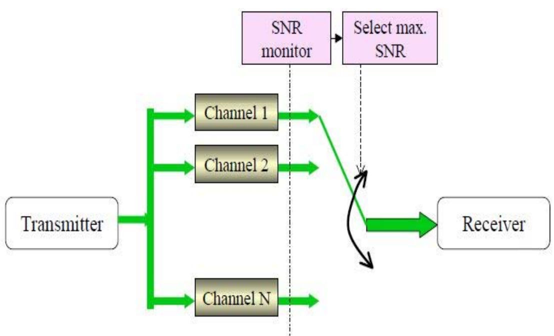

Fig 3:Selection Combiner

The combiner outputs the signal on the branch with the highest SNR. Since only one branch is used at a time,the selection combining requires just one receiver which is switched onto the active antenna branch.

A dedicated receiver on each antenna branch is needed for systems that transmit continuously to monitor SNR on each branch simultaneously. With selection combining,the path output from the combiner has an SNR equal to the maximum SNR of all the branches. Since only one branch output is used,co-phasing of multiple branches is not needed. Hence the selection combining can be used with either coherent or differential modulation.

5. Simulation results

The simulation is done in MATLAB and the graphs are plotted. The throughput maximization algorithm and the harvesting time minimization algorithms produced a higher throughput rate and the harvesting time is minimized. The proposed method of dynamic antenna pattern is found to produce a much higher throughput rate as well as less harvesting time as compared to the previous methods hence improving the efficiency of the system and the results are shown below.

5.1 Throughput Maximization method

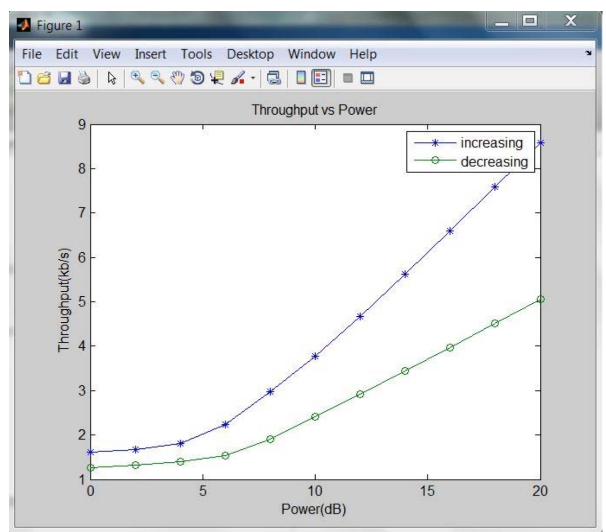

Fig 4:Throughput Vs Power

5.2 Time Minimization Method

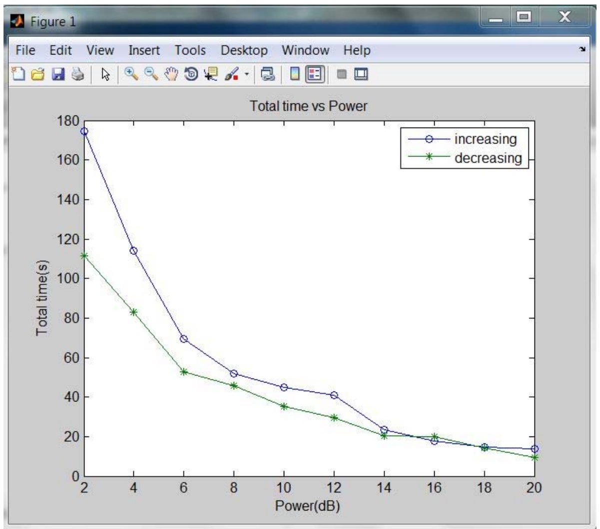

Fig 5: Total time Vs Power

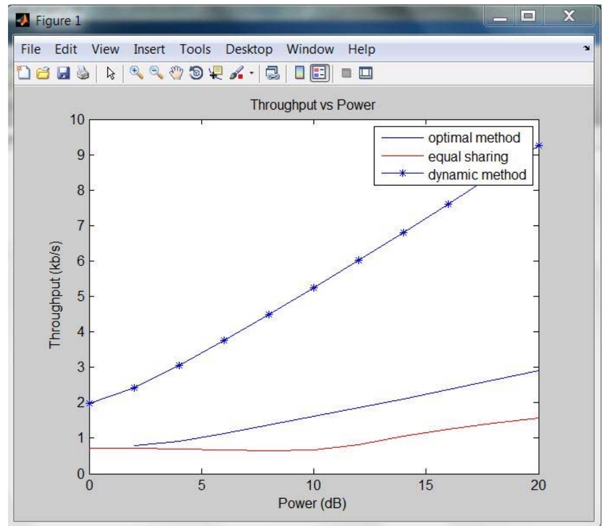

Fig 7:Comparison of dynamic method,optimal time allocation method and equal time allocation method

5.3 Dynamic Antenna Method

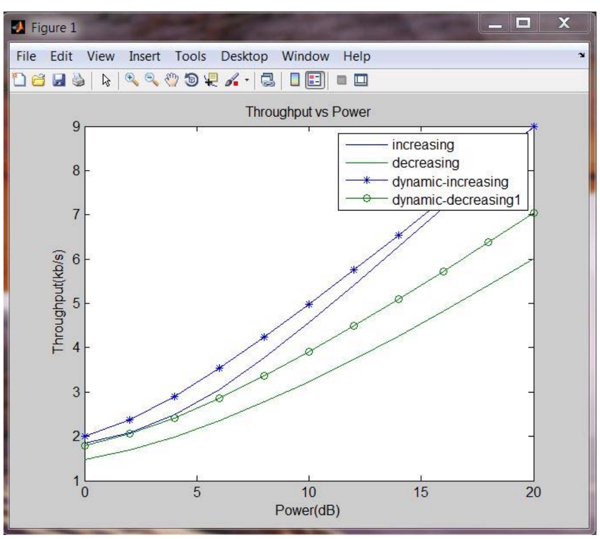

Fig 6: Comparison of the dynamic antenna method and optimal allocation method

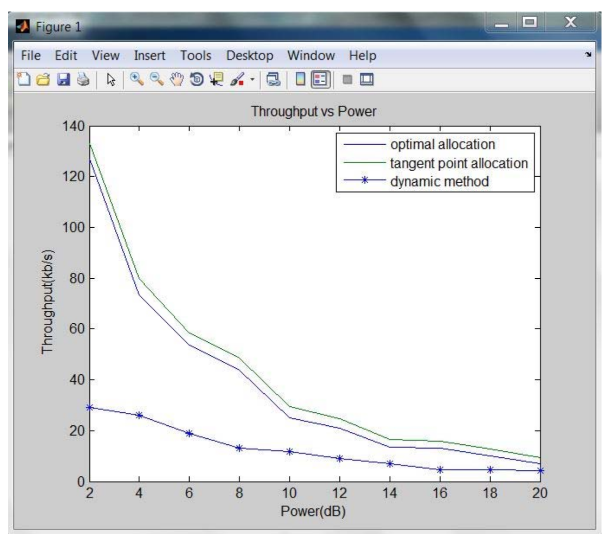

Fig 8: Comparison of total time minimization method and dynamic method

6. Conclusions

In the full-duplex bi-directional WPCN system,the flexible antenna pattern clears all the disadvantages of the fixed pattern. The fixed pattern system could not adjust to the channel conditions. patternHence it is not system friendly. Using the method of selection combining,we are creating flexibility to the antenna by selecting the channel with the maximum SNR. The throughput maximization and time minimization is achieved using the dynamic method of antenna configuration and it yields a higher performance than the optimal time allocation algorithms. Hence the efficiency of the system is also doubled.

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