RESEARCH ON WIRELESS POWERED COMMUNICATION NETWORKS SUM RATE MAXIMIZATION BASED ON TIME REVERSAL OFDM

Wei Liu[1]、Fang Wei Li[2]、Hai Bo Zhang[3]、Bo Li[4]

[1] School of Communication and Information Engineering, Chongqing University of Posts and Telecommunications, Chongqing, China

[2] Chongqing Key Laboratory of Public Big Data Security Technology, Chongqing, China

[3] School of Communication and Information Engineering, Chongqing University of Posts and Telecommunications, Chongqing, China

[4]Chongqing Key Lab of Mobile Communications Technology，Chongqing University of Post and Communications

ABSTRACT

This paper studies a wireless power communication network(WPCN) based on orthogonal frequency division multiplexing (OFDM) with time reversal(TR). In this paper, the " Harvest Then Transmit " protocol is adopted, and the transmission time block is divided into three stages, the first stage is for power transmission, the second stage is for TR detection, and the third stage is for information transmission. The energy limited access point (AP) and the terminal node obtain energy from the radio frequency signal sent by the power beacon (PB) to assist the terminal data transmission. The energy limited AP and the terminal node obtain energy from the radio frequency signal sent by the PB to assist the terminal data transmission. In the TR phase and the wireless information transmission (WIT) phase, the terminal transmits the TR detection signal to the AP using the collected energy, and the AP uses the collected energy to transmit independent signals to a plurality of terminals through OFDM. In order to maximize the sum rate of WPCN, the energy collection time and AP power allocation are jointly optimized. Under the energy causal constraint, the subcarrier allocation, power allocation and time allocation of the whole process are studied, and because of the binary variables involved in the subcarrier allocation, the problem belongs to the mixed integer non-convex programming problem. the problem is transformed into a quasiconvex problem, and then binary search is used to obtain the optimal solution. The simulation results verify the effectiveness of this scheme. The results show that the proposed scheme significantly improves the sum rate of the terminal compared to the reference scheme.

David C. Wyld et al. (Eds): SIGEM, MLTEC, SEAPP, ITCON, NATL, FUZZY, CSEA - 2022
pp. 23-40, 2022. CS & IT - CSCP 2022 DOI: 10.5121/csit.2022.122002

KEYWORDS

Wireless Powered Communication Network, Ttime Reversal, OFDM

1. INTRODUCTION

In recent years, the rapid development of connected devices has led to the rise of Internet of Things (IoT) applications, which are used in smart homes, smart transportation, medical monitoring, and disaster warning information [1][2]. In a traditional network, node devices are powered by a fixed energy source such as a battery, and the network life is limited due to power exhaustion, thereby affecting the performance of the network. In order to extend the runtime of the network, the battery needs to be replaced or replenished after the battery power is exhausted.However, in some applications, it is not technically and economically feasible for wireless nodes to be deployed in large-scale sensor networks or implanted into the human body to cause regular replacement or charging[3][4]. Energy harvesting (EH) is considered to be a promising technology to replace traditional energy sources such as batteries because it provides more cost-effective energy for wireless networks [5]. Especially, because radio frequency (RF) signals have dual purposes of wireless information transmission (WIT) and wireless energy transmission (WET), the EH of RF signals has attracted great attention [6]. RF power transmission is an EH technology. Wireless network nodes collect energy from RF signals and convert them into electrical energy [7]. Among various energy transmission systems, wireless power supply communication network (WPCN) has been widely studied [8]. For WPCN, WET and WIT are completely separate. Compared with the traditional wireless network whose terminal devices are powered by batteries, WPCN is more suitable for small wireless networks and can provide permanent energy for small wireless sensors and other terminal devices. In [9],a “harvest-then-transmit” protocol was proposed for a multi-user WPCN, where users first harvest energy from RF signals broadcast by a single antenna hybrid access point (AP) in the

DL and then transmit information to the AP in the UL.

In order to meet the rapidly increasing demand for wireless data traffic, and rate maximization is considered as an important index, and resource allocation has been widely studied due to the trade-off between WET and WIT in wireless packet networks. In [10], a WPCN protocol is proposed, in which users first obtain energy through a hybrid access point (HAP), and then transmit data to the HAP through time division multiple access (TDMA). And then through the analysis for the wireless power transmission and the optimum time distribution of information transmission, to maximize the total throughput of all users. In [11], the optimal power allocation for downlink power transmission and uplink information transmission is derived for multiple access fading networks using TDMA or Frequency Division Multiple Access (FDMA). In [12], the joint power allocation of downlink power transmission and the time allocation of uplink information transmission are optimized for WPCN based on TDMA. In [13], considering the limited energy storage capacity of users, an optimal allocation algorithm of energy and time is proposed. In [14], a new model for simultaneous transmission of wireless information and energy in WPCN is proposed. In [15], various resource allocation problems of cognitive WPCN are studied, aiming at maximizing the performance of secondary users while satisfying the service quality of primary users. In [16], a full-duplex WPCN based on orthogonal frequency division multiplexing (OFDM) is considered, and the subcarrier allocation and power allocation under ideal and non-ideal self-interference cancellation are studied. The work in [17] all considers that the HAP is equipped with two antennas supporting full duplex and the users are half duplex. When the user supports full duplex, the performance of WPCN can be further improved by collecting more energy and selecting an appropriate antenna for uplink transmission. However, some practical scenarios located in toxic environments, underground, tunnels, remote areas, or disaster areas involve energy-constrained nodes that transmit information to IoT devices under limited power constraints, and environmental factors increase the difficulty of battery replacement. Hence, transmitters can harvest energy from dedicated RF signals to communicate with IoT devices [18]. Using power beacon (PB) as a dedicated wireless energy supply point, energy supply can be carried out for energy-constrained devices in the WET phase without the need for network communication [19]. The coverage probability of PB-based WPCN has been studied in [20], in which transmitters collect energy through PB during WET and then communicate with their corresponding receivers in WIT. In [21] proposes a new harvest-transmission scheduling method to maximize the total throughput of WPCN. In the designed method, multiple terminals can transmit information to AP nodes at the same time in one time slot. With single-user detection/decoding, only one of the composite signals can be successfully decoded at a time, and the other signals are treated as interference. Due to the existence of interference signal, the throughput performance is limited. In view of the above considerations, multiuser detection and continuous interference cancellation (SIC) are applied. Using the SIC algorithm, some interference signals can be decoded instead of being regarded as noise.

Based on the above discussion and literature review, the time reversal technique is used to suppress the interference of OFDM WPCN system in multi-terminal interference channel. By introducing PB, a WPCN model is constructed, which is composed of a single antenna PB, an energy-constrained AP and $k > 1$ single-antenna terminal devices.

AP and Internet of things terminals obtain energy from RF signals transmitted by PB to assist the downlink communication between AP and Internet of things devices. The goal is to maximize the total throughput of the system by jointly optimizing the time allocation and transmission power allocation of the system.

The main contributions of this paper are summarized as follows:

1. we propose a WPCN model, in which AP and IoT terminal nodes receive RF energy from PB, and then AP transmits information to IoT devices on the downlink. In the proposed WPCN, AP adopts the HTT protocol supported by PB in the WET phase, and uses OFDM to allocate transmission power in the WIT phase to transmit information to IoT devices.

2. For OFDM WPCN system, the time reversal technique is used to suppress the interference between transmission antennas, and the problem of sum rate maximization is solved by jointly optimizing EH time and transmission power. The resulting problems are all non-convex, and for WPCN of OFDM, because the subcarrier allocation involves binary variables, the mixed integer programming problem is transformed into a

quasi-convex problem, and then the optimal solution is obtained by binary search.

3. Finally, we give a large number of numerical results to prove that our proposed algorithm is effective in improving system sum rate.

The rest of this paper is organized as follows. A WPCN model is introduced in section 2. Section 3 investigate the system sum rate problem, respectively. Section 4 evaluates the performance of the presented algorithms by conducting numerical simulations and section 5 concludes the paper.

2. SYSTEM MODEL

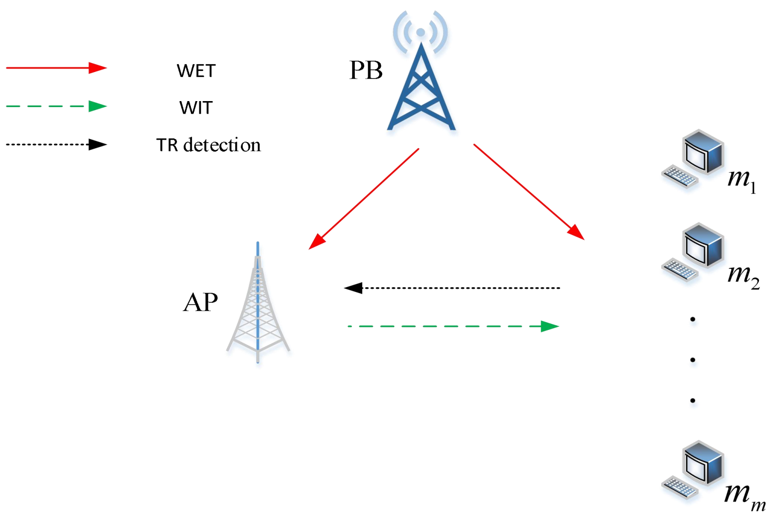

Figure 1. WPCN system model

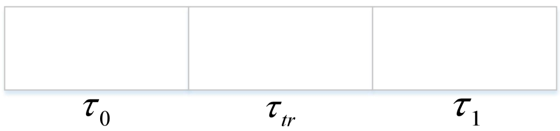

Figure 2. Frame structure of WPCN

In this paper, we consider a WPCN of OFDM based on time reversal, as shown in Figure 1. A single-antenna PB and an energy-constrained AP with N_T antennas and $k>1$ single-antenna Internet of things terminals are composed of WPCN. In the WPCN system, PB first carries out WET to the AP and the terminal node, and the AP and the terminal node receive the energy and store it in the rechargeable battery. Different from the traditional WPCN system, after the WET stage, the terminal node sends a time reversal probe signal to the AP. After the AP receives the probe signal, it performs WIT, Specifically, the data signal to be sent is sent to the terminal node after time reversal processing. All channels are assumed to have quasi-static flat fading and that the channel power gain remains constant during a transport block, but may vary between transport blocks. Without loss of generality, the time of a transport block is normalized to 1, which is represented by $T_{\max}$, that is, $T_{\max}=1$. Suppose in AP and all terminal channel state information (CSI) is perfectly known. In the IoT network, all transceivers, including AP, should be low-cost and low-power devices. Therefore, a transmission block is divided into three stages by adopting the HTT protocol [16]. The first stage is that PB transmits RF energy, and AP and terminal EH, and the duration is τ_0. In the second stage, the terminal sends the time reversal detection signal with a duration of τ_{tr}, and in the third stage, the AP node transmits the information to the terminal node with a duration of τ_1.

In the WET phase, the AP and the terminal EH from the PB, and the total power received by the AP is $P_T = P_B \left\| h_p \right\|^2$, where P_B is the transmission power at the PB and $h_p \in \mathbb{C}^{N_T \times 1}$ is the channel vector from PB to AP.

The energy collected at AP can be expressed as follows:

$$E = \eta P_T \tau_0 \tag{1}$$

Where $\eta \in (0,1]$ is the energy conversion efficiency.

In WPCN network, the system performance is affected by the interference caused by multipath environment. Time reversal technology is considered to be an effective technology to combat multipath and time-selective fading in the field of wireless communication. The time-space focus of time reversal technique in multipath channel is used to suppress the interference caused by multipath effect in OFDM transmission. It is assumed that the terminal channel gains are sorted from low to high. As shown in Figure 2, AP transmits data to the terminal through N orthogonal subcarriers using OFDM during the WIT phase with duration τ_1. A binary SC allocation variable $x_{k,n}$ is introduced in the WIT phase, and SC n is allocated to the mth terminal, $x_{k,n} = 1$; otherwise, $x_{k,n} = 0$. The channel impulse response of the jth antenna of the AP and the mth terminal on SC n is $h_{jm}^{(n)}$. Considering the influence of multipath effect on the system in practice, it is assumed that all terminals send signals to AP at the same time, and the channel impulse response $h_{jm}^{(n)}$ is:

$$h_{jm}^{(n)}[t] = \sum_{l=0}^{L-1} \delta_{jm,l}^{(n)} \delta\left[t - \tau_{jm,l}^{(n)}\right] \tag{2}$$

Where L represents the number of multipaths, $l \in \{1, 2, ..., L-1\}$; $\delta_{jm,l}^{(n)}$ represents the amplitude of the l th multipath; $\tau_{jm,l}^{(n)}$ represents the time delay of the l th multipath. Discretize $h_{jm}^{(n)}[t]$ As：

$$h_{jm}^{(n)} = \left\{ h_{jm}^{(n)}[0], h_{jm}^{(n)}[1], \ldots, h_{jm}^{(n)}[L-1] \right\}^T \tag{3}$$

When the channel impulse response is discretized in time domain, the mean value a is satisfied $E\left[h_{jm}^{(n)}[l] \right] = 0$.

In the time reversal stage, the terminal node sends a time reversal probe signal to the AP node by using the EH to obtain the channel state information. At this time, the AP records the probe signal and performs time reversal preprocessing on the obtained channel state, that is, reverses it in the time domain. After time reversal processing, the equivalent channel between the AP and the terminal node can be obtained, and the equivalent channel is:

$$g_{jm}^{(n)} = \left\{ g_{jm}^{(n)}[0], g_{jm}^{(n)}[1], \ldots, g_{jm}^{(n)}[L-1] \right\}^T \tag{4}$$

Where each element in the above matrix is the tap value after time reversal processing and normalization can be written as:

$$g_{jm}^{(n)}[p] = \frac{\overline{h}_{jm}^{(n)}[L-1-P]}{\sqrt{E\left[\left\| h_{jm}^{(n)} \right\|^2 \right]}} = \frac{\overline{h}_{jm}^{(n)}[L-1-P]}{\sqrt{E\left[\left| \sum_{l=0}^{L-1} h_{jm}^{(n)}[l]^2 \right| \right]}} \tag{5}$$

where $\overline{\bullet}$ represents conjugation.

After time reversal processing, the channel gain $h_{jm}^{(n)}$ becomes $h_{jm}^{(n)} * g_{jm}^{(n)}$, which is specifically expressed as:

$$\left(h_{jm}^{(n)} * g_{jm}^{(n)} \right)[p] = \sum_{l=0}^{L-1} h_{jm}^{(n)}[l] g_{jm}^{(n)}[p-l] = \frac{\sum_{l=0}^{L-1} h_{jm}^{(n)}[l] \overline{h}_{jm}^{(n)}[L-1+l-p]}{\sqrt{E\left[\left| \sum_{l=0}^{L-1} h_{jm}^{(n)}[l]^2 \right| \right]}} \tag{6}$$

Where $h_{jm}^{(n)} * g_{jm}^{(n)}$ represents the convolution operation, and $p \in \{0, 1, \ldots, 2L-2\}$. When $p = L-1$, the autocorrelation function is generated in the corresponding formula, and the above formula takes the maximum power center peak value at this time. According to the reference [21], most of the power of the signal will focus on the central tap, that is, the $L-1$ tap, so it is considered that the power on the $L-1$ tap is the transmission power of the ideal signal. The transmission power of the AP allocated to the SCn for transmitting information to the mth terminal is represented as $p_{m,n}$.

Therefore, the achievable rate of the mth terminal on the nth SC is:

$$r_{k,n} = \frac{B\tau_1}{N} x_{m,n} \log_2\left(1 + SINR_{m,n}\right) \tag{7}$$

The $SINR$ at the mth terminal is expressed as:

$$SINR_{m,n} = \frac{p_{m,n}\left|h_{jm}^{(n)} * g_{jm}^{(n)}\right|^2}{\left(B/N\right)\left[\sum_{\substack{i=1\\i\neq j}}^{N_T}\sum_{p=0}^{2L-1} p_{m,n,i}\left(h_{jm}^{(n)} * g_{jm}^{(n)}\right)+\sigma^2\right]} \tag{8}$$

Where $\sum_{\substack{i=1\\i\neq j}}^{N_T}\sum_{p=0}^{2L-1} p_{k,n,i}\left(h_{jm}^{(n)} * g_{jm}^{(n)}\right)$ represents the interference of the $i\left(i\neq j\right)$ th antenna of the AP to the jth terminal on the subcarrier n; σ^2 represents noise power; For the convenience of the following calculation commands:

$$A_{m,n} = \frac{\left|h_{jm}^{(n)} * g_{jm}^{(n)}\right|^2}{\left(B/N\right)\left[\sum_{\substack{i=1\\i\neq j}}^{N_T}\sum_{p=0}^{2L-1} p_{m,n,i}\left(h_{jm}^{(n)} * g_{jm}^{(n)}\right)+\sigma^2\right]}$$

Then, the sum rate of the WPCN scheme based on time reversal OFDM is calculated as:

$$R_{sum} = \sum_{m=1}^{M}\sum_{n=1}^{N} r_{mn} = \sum_{m=1}^{M}\sum_{n=1}^{N} \frac{B\tau_1}{N} x_{m,n} \log_2\left(1+SINR_{m,n}\right) \tag{9}$$

3. PROBLEM PLANNING AND ALGORITHM DESIGN

3.1. Problem Planning

The optimization goal of this paper is to maximize the system sum rate of TR-OFDM-WPCN. By jointly optimizing τ_0, $x_{m,n}$, and $p_{m,n}$, the optimization problem in this paper is expressed as:

$$\begin{aligned}
OP_1: &\max_{\tau_0, x_{m,n}, p_{m,n}} R_{sum} \\
s.t.\ & C_1: p_{m,n} \geq 0 \quad \forall m \in M \ \ \forall n \in N \\
& C_2: \sum_{m=1}^{M} x_{m,n} = 1 \quad \forall m \in M \ \ \forall n \in N \\
& C_3: x_{m,n} \in \{0,1\} \quad \forall m \in M \ \ \forall n \in N \\
& C_4: \left(1-\tau_0-\tau_{tr}\right)\sum_{m=1}^{M}\sum_{n=1}^{N} x_{m,n} p_{m,n} \leq E \quad \forall m \in M \ \ \forall n \in N \\
& C_5: 0 \leq \tau_0 \leq 1
\end{aligned} \tag{10}$$

Constraints C_2 and C_3 indicate that an SC is accurately assigned to each link. Constraint

C_4 means that the total energy consumed by AP in the WIT phase is less than the EH in the WET phase. In problem OP_1, the strong coupling between τ_0, $p_{m,n}$ and $x_{m,n}$ leads to the non-concavity of the objective function and the non-convexity of C_4. In addition, because there are binary assignment variables in this problem, OP_1 is a mixed integer nonconvex programming problem.

3.2. Algorithm Design

In this section, the joint energy acquisition time, SC and power allocation solution will be introduced to maximize the sum rate of WPCN of OFDM of TR. rewrite C_4 in OP_1 as:

$$\tau_0 \geq \frac{\left(1-\tau_{tr}\right)\sum_{m=1}^{M}\sum_{n=1}^{N} x_{m,n} p_{m,n}}{\sum_{m=1}^{M}\sum_{n=1}^{N} x_{m,n} p_{m,n} + \eta P_T} \tag{11}$$

Obviously the objective function in OP_1 is a non-increasing function of τ_0. Therefore, according to constraint C_4 in OP_1, for a given power allocation, the optimal τ_0 should hold the equation:

$$\tau_0 = \frac{\left(1-\tau_{tr}\right)\sum_{m=1}^{M}\sum_{n=1}^{N} x_{m,n} p_{m,n}}{\sum_{m=1}^{M}\sum_{n=1}^{N} x_{m,n} p_{m,n} + \eta P_T} \tag{12}$$

Substituting Equation (12) into (9), we get:

$$R_{sum} = \frac{\eta B P_T \left(1-\tau_{tr}\right)}{N\left(\sum_{m=1}^{M}\sum_{n=1}^{N} x_{m,n} p_{m,n} + \eta P_T\right)} \sum_{m=1}^{M}\sum_{n=1}^{N} x_{m,n} \log_2\left(1+SINR_{m,n}\right) \tag{13}$$

Rewrite OP_1 as:

$$\begin{aligned} OP_2 :& \max_{\tau_0, x_{m,n}, p_{m,n}} \quad R_{sum} \\ s.t. \quad & C_1 : p_{m,n} \geq 0 \quad \forall m \in M \quad \forall n \in N \\ & C_2 : \sum_{m=1}^{M} x_{m,n} = 1 \quad \forall m \in M \quad \forall n \in N \\ & C_3 : x_{m,n} \in \{0,1\} \quad \forall m \in M \quad \forall n \in N \end{aligned} \tag{14}$$

Lemma 1: Suppose g is a quadratic differentiable function. When ax+b>0, g(x)/(ax+b) is quasi-convex if y=g(x) is convex, and g(x)/(ax+b) is quasi-concave if y = g(x) is a concave function. (proof see Appendix A)

From Lemma 1, it can be observed that the objective function of OP_2 is a quasi-concave function with respect to $p_{m,n}$ given SC n .In order to solve OP_2 , the relaxation variable θ is introduced. Then OP_2 can be rewritten as:

$$\begin{aligned} &OP_3: \ \max \ R \\ &s.t. \quad C_1, C_2, C_3 \\ &\qquad C_6: \max_{x_{m,n}, p_{m,n}} R_{sum} \le \theta \end{aligned} \tag{15}$$

OP_3 is a convex optimization problem, so its unique optimal solution can be found by the Lagrangian dual method.

The Lagrangian function of the optimization problem OP_3 can be written as:

$$\begin{aligned} &L(p_m, \mu) = R_{sum} - \mu(R_{sum} - \theta) \\ &= \frac{(1-\mu)\eta B P_T (1-\tau_{tr})}{N} \sum_{m=1}^{M}\sum_{n=1}^{N} x_{m,n} \log_2(1+SINR) + \mu\theta\left(\sum_{m=1}^{M}\sum_{n=1}^{N} x_{m,n} p_{m,n} + \eta P_T\right) \end{aligned} \tag{16}$$

where $\mu \ge 0$ is the corresponding non-negative Lagrange multiplier. For a given SC allocation $x_{m,n} = 1$, the optimal power allocation on the SC in OP_3 can be solved by solving the above problem. According to the KKT condition, the analytical solution of optimal power allocation can be obtained(proof see Appendix B):

$$p_{m,n} = \left[\frac{(\mu-1)\eta B P_T (1-\tau_{tr})}{\mu\theta N \text{In} 2} - \frac{1}{A_{m,n}}\right]^+ \tag{17}$$

Where $[x]^+ = \max(0, x)$.

Substituting formula (17) into (16), we get:

$$L(p_{m,n}, \mu) = \sum_{m=1}^{M}\sum_{n=1}^{N} x_{m,n}\left[\frac{C}{N\text{In}2} - \frac{\mu\theta}{A_{m,n}}\right]^+ - \frac{C}{N}\log_2\left(1+\left[\frac{CA_{m,n}}{\mu\theta\text{In}2} - 1\right]^+\right) + \eta\mu\theta P_T \tag{18}$$

Where $C = (1-\mu)\eta B P_T (1-\tau_{tr})$

$$OP_4: \max_n L\left(p_{m,n}, \mu\right)$$
$$s.t. \quad C_2: \sum_{m=1}^{M} x_{m,n} = 1 \quad \forall m \in M \quad \forall n \in N \tag{19}$$
$$C_3: x_{m,n} \in \{0,1\} \quad \forall m \in M \quad \forall n \in N$$

Since each terminal only corresponds to one non-zero SC, the SC allocation function is defined as:

$$x^{op}_{m^{op},n} = \begin{cases} 1, & \text{m}=m^{op} \\ 0, & \forall m \neq m^{op} \end{cases} \tag{20}$$

Where $x^{op}_{m^{op},n}$ represents the optimal value of $x_{m,n}$ in the formula.

$$m^{op} = \arg\min_m \prod(m,n) \tag{21}$$

Where $\prod(m,n) = \left[\frac{C}{N\text{In}2} - \frac{\mu\theta}{A_j}\right]^+ - \frac{C}{N}\log\left(1 + \left[\frac{CA_j}{\mu\theta\text{In}2} - 1\right]^+\right)$

The best θ is determined by dichotomy. Algorithm 1 is the process of solving OP_1.

$\theta_l = 0$ and $\theta_u = \omega$ are respectively expressed as the lower limit and upper limit of binary search, and ε is the accuracy of binary search. Define the upper bound ω of binary search as:

$$\omega = BM \log\left(1 + \eta P_T \max_{m,n}\left\{A_{m,n}\right\}\right) \tag{22}$$

Table 1. Joint Time Power Allocation Scheme

Algorithm for solving OP_1
1. Calculate τ_{tr} using the given d and v_0.
2. initialization: $\theta_l = 0$, $\theta_u = \omega$, $m = 0$, ε is the error threshold.
3. Repeat steps (1)-(5) until step 4 is established
(1) $\theta(m) = (\theta_l + \theta_u)/2$;
(2) Obtain the optimal $p_{m,n}$ according to formula(4.16);
(3) Obtain the optimal $x_{m,n}$ according to formula(4.19);
(4) Substitute the obtained A and B into (4.11), if $L(p_{m,n}, \mu) > 0$, $\theta_u = \theta$; else $\theta_l = \theta$;
(5) $m = m + 1$;

4. Judge whether $\theta_u - \theta_l < \varepsilon$ is established, if established Output $p_{m,n}$ and $x_{m,n}$;

4. SIMULATION RESULTS

In this section, the sum rate of WPCN of time reversal OFDM is simulated and analyzed, and compared with the traditional optimization algorithm. Assuming that all channels conform to Rayleigh fading characteristics, the channel gain model is $10^{-3} d_m^{-\alpha}$, where d_m represents the distance from the mth terminal to the AP node, and $\alpha = 3$ is the channel fading index. Suppose PB is placed in (0,0),AP is placed in (0,5), and the terminal is placed in area of (-5,-20) and (-5,20). The bandwidth of the system is 180KHz, the number of subcarriers is 11, the energy efficiency is 0.8, and the noise power is -50dBm.

Figure 3 is a comparison of different algorithms for system sum rate convergence performance. It can be seen from Figure 4.3 that as the number of iterations increases, the sum rate of the three algorithms also increases gradually. Finally, the algorithm proposed in this paper has the maximum sum rate after convergence. The reason is that when the energy transmitting node and the information receiving node are placed together to form a hybrid node, a double-far and near phenomenon will occur, resulting in a larger path loss. In this paper, because the time reversal technology can make full use of multipath to focus the signal energy on the target point, and improve the receiving power of the target user when the transmit power of the terminal node is the same, the algorithm proposed in this paper has better system sum rate.

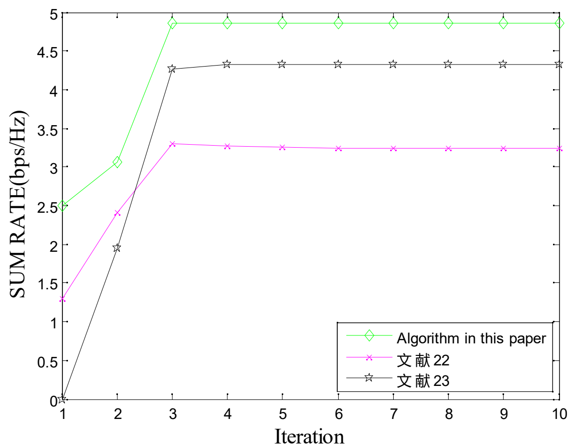

Figure 3 Graph of iterative algorithms for different schemes

Figure 4 shows the functional relationship between system sum rate performance of WPCN with respect to time allocation factor τ . It can be seen from the three-dimensional diagram that the sum rate changes with energy transmission time τ_0 and time reversal detection stage τ_{tr} . It can be clearly seen from Figure 4 and Figure 5 that in order to make the system and rate large enough, the TR detection time τ_{tr} should be as short as possible while ensuring that the farthest terminal can complete TR detection. This is because when τ_{tr} is small, the time allocated to the energy transfer phase can be as much as possible, and the AP node can obtain enough energy from the RF signal transmitted by the PB node during the duration of the energy transfer. From Figure 4 and Figure 5, it can be seen that the τ_0 of the proposed OFDM WPCN algorithm is about 0.5s;

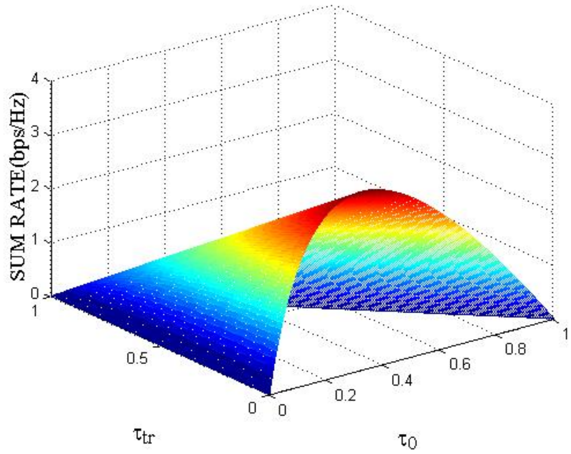

Figure 4 Sum rate and time relation diagram

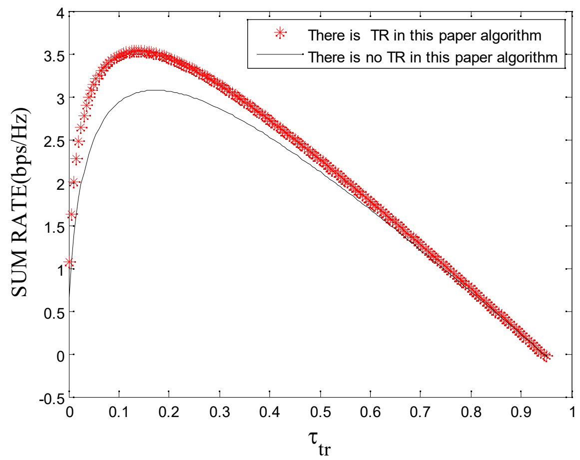

Figure 5 Sum rate and time reversal stage relation diagram

Figure 6 shows the curve of the system sum rate varying with the transmission power.Figure.6 is a simulation diagram of the variation of different scheme sum rates with power when the number of AP node antennas is 4. Figure 7 is a graph showing the variation of the system sum rate with the transmit power of the scheme in this paper when the number of multipaths in the system is different. It can be seen from Figure 6 and Figure 7 that the system sum rate of the proposed scheme and the comparative scheme both increase with the increase of the transmit power. This is because when the transmit power increases, the power received by the receiver is greater than the noise power, so the signal-to-interference-to-noise ratio of the receiver also increases, so the sum rate of the system increases with the increase of the transmit power. And because the space-time focusing of time reversal can make full use of the multipath to make the signal energy coherent superposition at the receiver, the signal strength received by the terminal is greatly increased, so the scheme in this paper can effectively improve the system sum rate. It can be seen from figure 7 that with the increase of the number of multipaths, the system and rate also increase. The reason is that with the increase of the number of multipaths, the time reversal technique uses multipaths to provide additional spatial degrees of freedom for the system. The richer the multipath, the better the focusing effect, the stronger the energy of the received useful signal, and the better system and rate are obtained, so the effectiveness of the algorithm in this paper is verified.

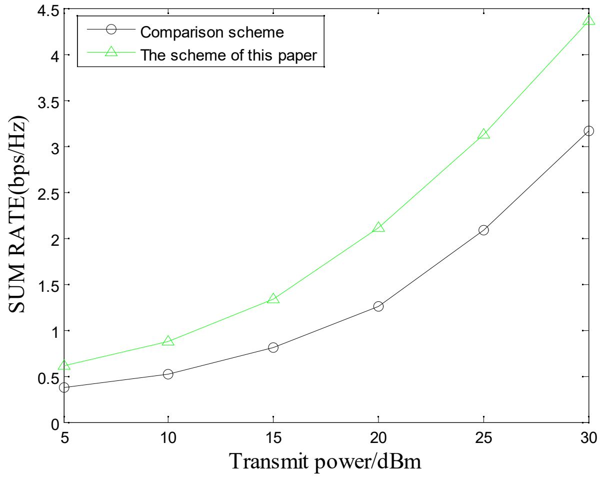

Figure 6 Diagram between sum rate and transmission power

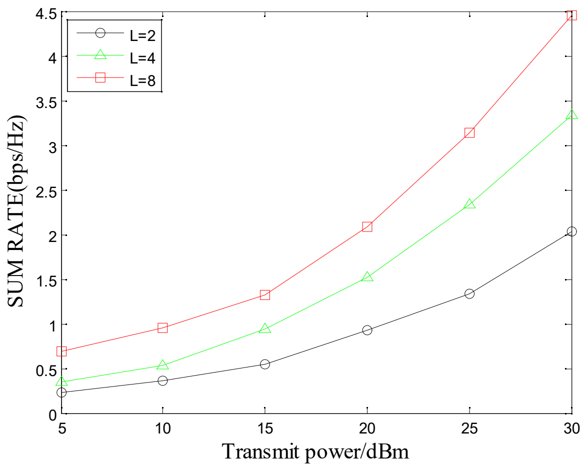

Figure 7 Diagram of sum rate with transmission power for different multipaths

Figure 8 shows the effect of the distance from the AP to the terminal on the sum rate of different algorithms when Pmax=30dBm, assuming that other parameters are the same. The sum rate of the two algorithms decreases with the increase of distance, because the path loss of WET and WIT increases with the increase of distance. The performance of the proposed algorithm is significantly better than that of the comparison algorithm. After the signal is processed by TR technology, most of the energy of the signal is focused on the AP node, combined with the algorithm proposed in this paper can effectively increase the system sum rate. The system sum rate will decrease with the increase of distance, because the larger the distance, the more power consumption of the system, which leads to the lower system sum rate.

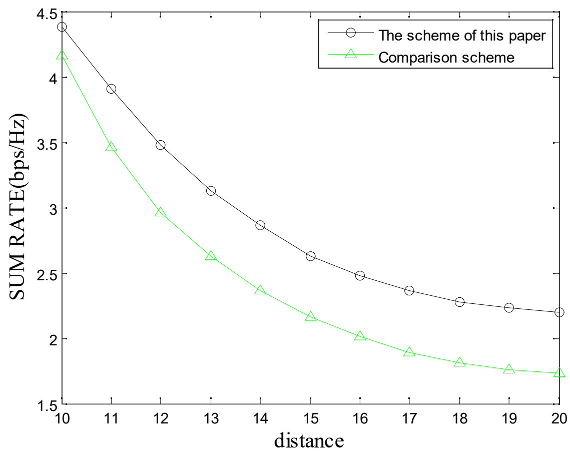

Figure 8 Diagram between sum rate and distance between transceiver and transceive

5. CONCLUSIONS

This paper studies the WPCN of OFDM, where APs and terminal nodes EH from the RF signal of the PB, and then use the harvested energy to transmit independent signals in the downlink to multiple terminal nodes. After introducing the time reversal technology to suppress the interference of the system, the transmit power, energy transmission time and subcarrier allocation of AP nodes are jointly optimized, and a maximizing system sum rate algorithm is proposed. Using the quasi-concave form of the proposed problem, the energy transfer time and optimal transmit power are obtained based on a dichotomy search. The numerical results show that the algorithm proposed in this paper is effective. And the influence of transmit power, AP-to-terminal distance and multipath on the system sum rate is analyzed. The simulation results prove that the scheme proposed in this section can suppress interference and help to improve the sum rate of the system. The WPCN system has broad application prospects and can be used in wireless sensor networks. Future research can allocate and optimize resources for multi-antenna HAP and multi-user complex multi-cell environments and vehicle networking environments. The focusing intensity of time reversal technology depends on channel estimation. When there is an error in channel estimation, it will affect the focusing of time reversal. The scheme of this paper assumes that the channel state information is perfect, but in practice, the channel estimation will be affected by many factors in the wireless environment. Therefore, when there is an error in channel estimation, the performance of the system will be affected.

ACKNOWLEDGEMENTS

This work is supported by the Natural Science Foundation of China (NSFC) grant funded by the China government (61771084).

APPENDIX A
PROOF OF LEMMA 1

Existence function $h(x)=\frac{g(x)}{ax+b}$

$$\frac{dh}{dx}=\frac{(ax+b)g'(x)-ag(x)}{(ax+b)^2} \tag{23}$$

Because $ax+b>0$,if $h'(x)=0$ is satisfied at this time, then $(ax+b)g'(x)-ag(x)=0$

$$\frac{d^2h}{dx^2}=\frac{d}{dx}\left(\frac{dh}{dx}\right)=\frac{(ax+b)g''(x)-\left(2a(ax+b)\left((ax+b)f'(x)-af(x)\right)\right)}{(ax+b)^4} \tag{24}$$

$$\frac{d^2h}{dx^2}\bigg|_{h'(x)=0}=\frac{(ax+b)g''(x)}{(ax+b)^4} \tag{25}$$

It can be seen from the above that at any point where the slope is zero, when $g''(x)\le 0$ then the second derivative of $h(x)$ is nonnegative.当 $g''(x)\le 0$ 时， $h''(x)\ge 0$， When $g''(x)\le 0$, then $h''(x)\ge 0$, which means that when $g(x)$ is convex, $h(x)$ is quasiconvex. When $g(x)$ is concave, $h(x)$ is quasi-concave.

APPENDIX B

According to the KKT condition, the analytical solution of optimal power allocation can be obtained. According to the KKT condition, the partial derivative of $p_{m,n}$ is zero.

$$\frac{\partial L}{\partial p_{m,n}}=\frac{(1-\mu)\eta BP_T(1-\tau_{tr})A_{m,n}}{N\left(1+p_{m,n}A_{m,n}\right)\text{In}2}+\mu\theta=0 \tag{26}$$

$$p_{m,n}=\frac{(\mu-1)\eta BP_T(1-\tau_{tr})}{\mu\theta N\text{In}2}-\frac{1}{A_{m,n}} \tag{27}$$

Since the power cannot be negative, write the above formula as follows：

$$p_{m,n}=\left[\frac{(\mu-1)\eta BP_T(1-\tau_{tr})}{\mu\theta N\text{In}2}-\frac{1}{A_{m,n}}\right]^+ \tag{28}$$

Where $\left[a\right]^{+} = \max\left(a,0\right)$ and γ is constant.

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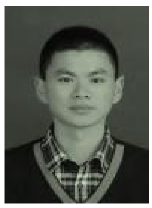
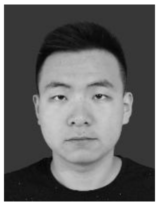
Authors

Wei Liu Born in 1994, from Inner Mongolia,China. Now he is a master's student of Chongqing University of Posts and telecommunications. His main research interests are wireless power communication network and time reversal.

Fang Wei Li Born in 1960 in Chongqing, China. Professor and doctor of Chongqing University of Posts and telecommunications. His main research interests are electromagnetic field and electromagnetic wave, wireless network security, wireless transmission theory and technology.

Hai Bo Zhang Born in 1979 in Chongqing, China. Associate professor and master's supervisor of Chongqing University of Posts and telecommunications. His main research interests are vehicle networking, security authentication, key negotiation and so on.





Bo Li received the B.S. degree from Shanxi Institute ofEngineering and Technology, China, in 2018.Currently studying for a master's degree inChongqing University of Posts and Telecommunication. His major is informationand communication engineering. His research interest covers Internet of Thingsand wireless power communication network.