RESOURCE ALLOCATION FOR WIRELESS POWERED MULTI-PAIR TWO WAY RELAY NETWORKS

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Abstract: We consider a wireless powered multi-pair two-way relay network in which the devices without batteries communicate with their partners assisted by a hybrid access point (HAP). For the network, half-duplex (HD) and full-duplex (FD) protocols are designed in a time division multiple access manner and power and time allocation problems are addressed. The problems optimize a generalized utility function taking into account the efficiency and fairness under the power constraints at the HAP and the energy storage constraint at the devices. We transform the problems for the HD and the FD with no self-interference (SI) into the convex problems while providing an iterative algorithm to solve the non-convex problem for the FD suffered from the residual SI. The results confirm the superiority of the FD over the HD in the throughput and the fairness.

Index Terms*:* Full duplex, resource allocation , two way relay, wireless powered communication

I. INTRODUCTION

Recent advances in microwave power transfer technologies have lead to the advent of wireless powered communication (WPC) which charges the devices remotely before communication [1]. The WPC expands the applications of the Internet of things by allowing devices sustainable without batteries and curtailing high costs in the battery replacement. In this context, existing communication systems are now being redesigned by introducing wireless powering and energy harvesting (EH) capabilities as observed in the references of [1].

Cooperative networks adopt harvest-and-transmit protocols for WPC in general, where the relays with the EH capability are powered by the signal to be relayed [2], [3], [4], [5], [6]. In these studies, only a pair of communicating devices is assisted by amplifyand-forward (AF) relays [2], [3], [4], [5] and decodeand-forward (DF) relays [6]. Although a full-duplex (FD) protocol for one-way relaying has come out in an initial stage [2], two-way relaying (TWR) is based on half-duplex (HD) protocols mostly [3], [4], [6] except for [5]. Notably, the relays in [2], [3], [4], [5], [6] are of similar complexity to the communicating devices.

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Unlike the studies in [2], [3], [4], [5], [6], we consider wireless powered TWR networks (WP-TWRNs) with a relay of similar complexity to an access point (AP). The relay not only takes a role of wireless powering to the EH devices, but also handles the bidirectional data of the multiple device pairs. This type of relays has been addressed in [7], [8] to support the WP-TWR protocol based on space division multiple access by using a large number of antennas. However, a large number of antennas is not always applicable due to a high cost.

In this context, we consider a relay equipped with a single antenna for the HD and two antennas for the FD as in the wireless powered uplink (WP-UL) based on time division multiple access (TDMA) [9], [10], [11]. For the WP-TWRN, we design TDMA-based HD and FD protocols exploiting the bidirectional data flows for wireless powering, unlike the TDMA-based FD protocol for the WP-UL which keeps transmitting the power signals. While the studies for the WP-UL in [9], [10], [11] aim at maximizing the sum rate only, this letter provides a more comprehensive study on resource allocation for the WP-TWRN by maximizing the generalized utility function reflecting a various level of the fairness in the throughput [12], and by encompassing the HD protocol, the FD protocol with no self-interference (SI), and the FD protocol with residual SI.

II. SYSTEM MODEL

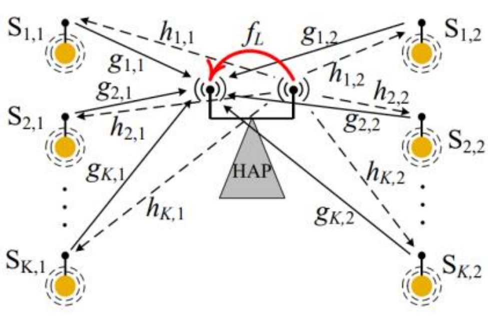

Fig. 1. System configuration

Consider a WP-TWRN with one hybrid AP (HAP) and K active device pairs $\{(S_{k,1}, S_{k,2})\}_{k=1}^{K}$, There are no direct links among the devices so that the HAP deployed at a vantage point assists the information transfer among the devices as in [13]. The HAP operates either in HD with a single antenna or in FD with two antennas while the devices always operate in HD with a single antenna. Fig.1

describes the system model for the FD WP-TWRN. The channel gain from the HAP to $S_{k,i}$ and from $S_{k,i}$ to the HAP is described by $h_{k,i}$ and $g_{k,i}$, respectively, by assuming flat fading. We denote by f_L the loop-back channel between the transmit and receive antennas at the HAP. The HD WP-TWRN can be rendered as a special case of the FD WP-TWRN by letting $g_{k,i} = 0$ and $f_L = 0$ for the single-antenna HAP with the channel gain $h_{k,i}$ subject to the channel reciprocity. The active devices scheduled in a time frame of length T (assumed to be T = 1) are powered by the HAP, and then exchange their information assisted by the HAP via the HD or FD protocol. In the protocol design, the devices have the energy storage constraint as in [9], [10], [11], which makes the energy harvested in the current frame unavailable in the future transmission time scheduled later.

A. HD Protocol

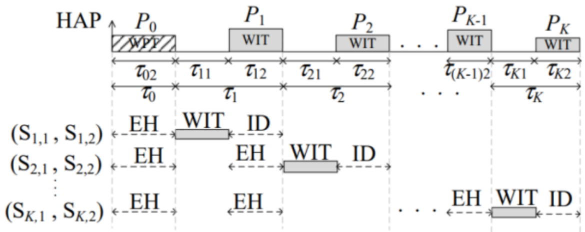

Fig. 2. HD protocol

Fig. 2 describes the HD protocol for the WP-TWRN, where a time frame is divided into $K+1$ time slots of durations $\{\tau_k\}_{k=0}^{K}$. Time slot k is split into two time phases (TPs) k_1 and k_2 of durations τ_{k1} and τ_{k2} for $k \in Z_0^K$, where Z_{l1}^{l2} denotes the set of integers from $l1$ to $l2$. Time slot 0 is devoted to the wireless power transfer (WPT) from the HAP with $\tau_{01} = 0$ and $\tau_{02} = \tau_0$. Time slot $k \in Z_1^K$ is assigned for the simultaneous wireless information transfer (WIT) from $(S_{k,1}, S_{k,2})$ to the HAP in TP k1 and for the WIT from the HAP to in TP k2. In TP k2, the HAP delivers the network coding of the messages received from $(S_{k,1}, S_{k,2})$ in TP k1. At the devices, the signal received in TP k1 for $k \in Z_1^K$ is utilized for information decoding (ID) at the desired pair $(S_{k,1}, S_{k,2})$ and for EH at the remaining devices $\{(S_{l,1}, S_{l,2})\}_{l=k+1}^{K}$. If we denote by P_k the transmit power of the HAP in TP $k2$ for $k \in Z_0^K$, , the energy harvested at $S_{k,i}$ up to its transmission under the energy storage constraint [9] is given by

$$Q_{k,i} = \varsigma_{k,i} |h_{k,i}|^2 \sum_{m=0}^{k-1} P_m \tau_{m2} \tag{1}$$

where $\varsigma_{k,i}$ is the EH efficiency at $S_{k,i}$ for $(k,i) \in I_D = \{(k,i) | k \in Z_1^K, i \in Z_1^2\}$. The transmit power of $S_{k,i}$ is determined as $p_{k,i} = Q_{k,i}/\tau_{k1}$ for $(k,i) \in I_D$.

Let $r_{k,i}$ denote the rate from $S_{k,i}$ to $S_{k,3-i}$ for $(k,i) \in I_D$. With the HD protocol, the achievable region of the rates $(r_{k,1}, r_{k,2})$ is formed by [6]

$$r_{k,i} \le min\{\tau_{k1} C(p_{k,i}\lambda_{k,i}), \tau_{k2} C(P_k \lambda_{k,3-i})\}, \quad i = 1,2 \tag{2a}$$

$$r_{k,1} + r_{k,2} \le \tau_{k2} C(p_{k,1}\lambda_{k,1} + p_{k,2}\lambda_{k,2}) \tag{2b}$$

for $k \in Z_1^K$, where $C(x) = log_2(1+x)$, $\lambda_{k,i} = |h_{k,i}|^2/\sigma^2$, and σ^2 is the noise variance at the receiver. By replacing $p_{k,i} = Q_{k,i}/\tau_{k1}$ in (2), we have

$$r_{k,i} \le \tau_{k2} C(P_k \lambda_{k,3-i}), i = 1,2, \tag{3a}$$

$$r_{k,i} \le \tau_{k1} C\left(\frac{\psi_{k,i}}{\tau_{k1}} \sum_{m=0}^{k-1} P_m \tau_{m2}\right), i = 1,2, \tag{3b}$$

$$r_{k,1} + r_{k,2} \le \tau_{k1} C\left(\frac{\psi_k}{\tau_{k1}} \sum_{m=0}^{k-1} P_m \tau_{m2}\right), \tag{3c}$$

where $\psi_{k,i} = \zeta_{k,i}\lambda_{k,i}^2\sigma^2$ and $\psi_k = \psi_{k,1} + \psi_{k,2}$.

B. FD Protocol

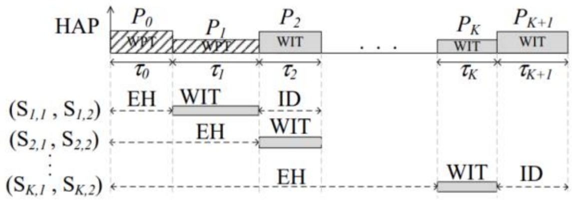

Fig. 3. FD protocol

Fig. 3 describes the FD procol for the WP-TWRN, where a time frame is split into $K+2$ time slots of durations $\{\tau_k\}_{k=0}^{K+1}$. The HAP transmits the signal $x_{k,bc}$ at transmit power P_k, for the WPT at time slot $k \in Z_0^1$, and for the WIT at time slot $k \in Z_2^{K+1}$. Meanwhile, in time slot $k \in Z_1^K$, $S_{k,i}$ transmits the WIT signal $x_{k,i}$ at transmit power $p_{k,i} = Q_{k,i}/\tau_k$ for $i = 1,2$, where $Q_{k,i}$ is the energy harvested at $S_{k,i}$ up to its transmission.

The received signal at $S_{l,i}$ is modeled as

$$y_{S_{l,i},k} = \sqrt{P_k} h_{l,i} x_{k,bc} + n_{S_{l,i},k}, \tag{4}$$

in time slot $k \in Z_0^{K+1}$, where $n_{S_{l,i},k}$ is the complex Gaussian noise of mean zero and variance σ^2 the and the signal transmitted by $(S_{k,1}, S_{k,2})$ is not included since the direct links among the devices are not available. Meanwhile, the received signal at the HAP in time slot $k \in Z_1^K$ is modeled as

$$y_{H,k} = \sum_{i=1}^{2} \sqrt{p_{k,i}} g_{k,i} x_{k,i} + \sqrt{P_k} f_L x_{k,bc} + n_{H,k}, \tag{5}$$

Which suffers from the loop-back interfernece $\sqrt{P_k} f_L x_{k,bc}$ and the noise $n_{H,k}$ of mean zero and variance σ^2. Note that $x_{k,bc}$ for $k \in Z_0^1$ contains no information while $x_{k,bc}$ for $k \in Z_2^{K+1}$ contains the network coding of the messages in $x_{k-1,1}$ and $x_{k-1,2}$ decoded in the preceding time slot.

All the devices harvest the energy in time slot 0, whereas $(S_{k,1}, S_{k,2})$ transmit their signal to the HAP and the other devices harvest the energy in time slot 1. In time slot $k \in Z_2^K$, $(S_{k-1,1}, S_{k-1,2})$ decode $x_{k,bc}$ from (4), $(S_{k,1}, S_{k,2})$ transmit their signal to the HAP, and $\{(S_{l,1}, S_{l,2})\}_{l=k+1}^{K}$ harvest the energy. In time slot $K+1$, $(S_{K,1}, S_{K,2})$ performs the ID from (4). Therefore, from (4), the energy harvested at $S_{k,i}$ is obtained as $Q_{k,i} = \zeta_{k,i} |h_{k,i}|^2 \sum_{m=0}^{k-1} P_m \tau_m$ for $(k,i) \in I_D$ under the energy storage constraint constraint and the achievable rates from the HAP to $(S_{k,1}, S_{k,2})$ are bounded as

$$r_{k,1} = \tau_{k+1} C(P_{k+1}\lambda_{k,2}) \tag{6a}$$

$$r_{k,2} = \tau_{k+1} C(P_{k+1}\lambda_{k,1}) \tag{6b}$$

On the other hand, the HAP decodes $x_{k,1}$ and $x_{k,2}$ from (5) for $k \in Z_1^K$, which leads to the achievable region of the rates $(r_{k,1}, r_{k,2})$ from $(S_{k,1}, S_{k,2})$ to the HAP as

$$r_{k,1} = \tau_k C\left(\frac{p_{k,1}\mu_{k,1}}{P_k\xi+1}\right), \quad (7a)$$

$$r_{k,2} = \tau_k C\left(\frac{p_{k,2}\mu_{k,2}}{P_k\xi+1}\right), \quad (7b)$$

$$r_{k,1} + r_{k,2} = \tau_k C\left(\frac{p_{k,1}\mu_{k,1} + p_{k,2}\mu_{k,2}}{P_k\xi+1}\right), \quad (7c)$$

where $\mu_{k,i} = \frac{|g_{k,i}|^2}{\sigma^2}$ and $\xi = \frac{|f_L|^2}{\sigma^2}$.

Finally, the achievable rate region of the FD protocol is formed by (6) and (7) with $p_{k,i} = Q_{k,i}/\tau_k$ as

$$r_{k,i} \le \tau_{k+1} C(P_{k+1}\lambda_{k,3-i}), i = 1,2, \quad (8a)$$

$$r_{k,i} \le \tau_k C\left(\frac{\omega_{k,i}}{\xi P_k\tau_k+\tau_k}\sum_{m=0}^{k-1} P_m\tau_m\right), i = 1,2, \quad (8b)$$

$$r_{k,1} + r_{k,2} \le \tau_k C\left(\frac{\omega_k}{\xi P_k\tau_k+\tau_k}\sum_{m=0}^{k-1} P_m\tau_m\right), \quad (8c)$$

where $\omega_{k,i} = \zeta_{k,i}|h_{k,i}|^2\mu_{k,i}$ for $i = 1,2$ and $\omega_k = \omega_{k,1} + \omega_{k,2}$.

III. RESOURCE ALLOCATION

This section aims at maximizing the $\alpha-$fair utility function of the device rates $\boldsymbol{r} = [r_{1,1}, r_{1,2}, r_{2,1}, r_{2,2}, \dots, r_{K,1}, r_{K,2}]$ defined by [12]

$$U_\alpha(\boldsymbol{r}) = \begin{cases} \frac{1}{1-\alpha}\sum_{k=1}^{K}\sum_{i=1}^{2} r_{k,i}^{1-\alpha}, \alpha \ge 0, \alpha \ne 1 \\ \sum_{k=1}^{K}\sum_{i=1}^{2} \log(r_{k,i}), \quad \alpha = 1, \end{cases} \quad (9)$$

where $\alpha \in [0,\infty)$ is the parameter for the degree of fairness. Notably, (9) is concave in $\boldsymbol{r}$ for each value of α and $\alpha = 0,1, and\ \infty$ represents the maximum throughput, proportional fairness (PF), and max-min fairness, respectively. In the following, (9) is optimized through power allocation (PA) and time allocation (TA) under the constraints on the peak power P_P and the average power P_A in the achievable rate region for each protocol.

A. Resource Allocation for the HD WP-TWRN

The optimization problem is formulated with $\boldsymbol{P} = [P_0, P_1, \dots, P_K]^T$ and $\boldsymbol{\tau} = [\tau_{02}, \tau_{11}, \tau_{12}, \dots, \tau_{K1}, \tau_{K2}]^T$ as

$$\max_{\boldsymbol{P}\succcurlyeq 0, \boldsymbol{\tau}\succcurlyeq 0} U_\alpha(\boldsymbol{r}) \quad (10a)$$

$$subject\ to\ (3a), (3b), (3c), k \in Z_1^K, \quad (10b)$$

$$\|\boldsymbol{\tau}\|_1 \le 1, \boldsymbol{P}^T\boldsymbol{\tau}_2 \le \mathrm{P_A}, \boldsymbol{P} \preccurlyeq \mathrm{P_P} \quad (10c)$$

where $\succcurlyeq$ and $\preccurlyeq$ denote the element-wise inequality, $\|.\|_1$ denotes the L_1 norm of a vector, and $\tau_2 = [\tau_{02}, \tau_{12}, \dots, \tau_{K2}]^T$. The optimization problem (10) is not convex in $\boldsymbol{P}$ and $\boldsymbol{\tau}$ since the constraints (3b)-(3c) on $\boldsymbol{r}$ and $P^T\tau_2 \le \mathrm{P_A}$ are non-convex although the objective function is concave in $\boldsymbol{r}$ for each $\alpha \in [0,\infty)$. By transforming the power $\boldsymbol{P}$ to the energy $E = [E_0, E_1, \dots, E_K]^T$ with $E_k = P_k\tau_{k2}$, we recast the problem (10) into

$$\max_{\boldsymbol{E}\succcurlyeq 0, \boldsymbol{\tau}\succcurlyeq 0} U_\alpha(\boldsymbol{r}) \quad (11a)$$

$$s.t. r_{k,i} \le \tau_{k2} C\left(\frac{E_k\lambda_{k,3-i}}{\tau_{k2}}\right), (k,i) \in I_D \quad (11b)$$

$$r_{k,i} \le \tau_{k1} C\left(\frac{\psi_{k,i}E_{0:k-1}}{\tau_{k1}}\right), (k,i) \in I_D \quad (11c)$$

$$r_{k,1} + r_{k,2} \le \tau_{k1} C\left(\frac{\psi_k E_{0:k-1}}{\tau_{k1}}\right), k \in Z_1^K \quad (11d)$$

$$\|\boldsymbol{\tau}\|_1 \le 1, \|\boldsymbol{E}\|_1 \le \mathrm{P_A}, \boldsymbol{E} \preccurlyeq \boldsymbol{\tau}_2\mathrm{P_P} \quad (11e)$$

where $E_{l1:l2} = \sum_{m=l1}^{l2} E_m$. The objective function of (11) is concave and the constraints in (11e) are linear. The other constraints (11b)-(11d) are also convex since their left hand side (LHS) is linear and their right hand side (RHS) is the perspective $\tau_{ki}f(\boldsymbol{E}/\tau_{ki})$ of a concave function $f(\boldsymbol{E})$ with $\tau_{ki} > 0$ which is also concave in $(\boldsymbol{E}, \tau_{ki})$. Therefore, (11) is a convex optimization problem which can be solved by an existing convex optimization solver.

B. Resource Allocation for the HD WP-TWRN

The optimization problem is formulated with $\boldsymbol{P} = [P_0, P_1, \dots, P_{K+1}]^T$ and $\boldsymbol{\tau} = [\tau_0, \tau_1, \dots, \tau_{K+1}]^T$ as

$$\max_{\boldsymbol{P}\succcurlyeq 0, \boldsymbol{\tau}\succcurlyeq 0} U_\alpha(\boldsymbol{r}) \quad (12a)$$

$$s.t. (8a), (8b), (8c), k \in Z_1^K, \quad (12b)$$

$$\|\boldsymbol{\tau}\|_1 \le 1, \boldsymbol{P}^T\boldsymbol{\tau} \le \mathrm{P_A}, \boldsymbol{P} \preccurlyeq \mathrm{P_P} \quad (12c)$$

Clearly, the problem (12) is non-convex in $\boldsymbol{P}$ and $\boldsymbol{\tau}$ since the constraints (8a)-(8c) and $\boldsymbol{P}^T\boldsymbol{\tau} \le \mathrm{P_A}$ are non-convex. By applying an approach similar to that adopted in the HD WP-TWRN, we now recast the problem (12) to

$$\max_{\boldsymbol{E}\succcurlyeq 0, \boldsymbol{\tau}\succcurlyeq 0} U_\alpha(\boldsymbol{r}) \quad (13a)$$

$$s.t. r_{k,i} \le \tau_{k+1} C\left(\frac{E_{k+1}\lambda_{k,3-i}}{\tau_{k+1}}\right), (k,i) \in I_D \quad (13b)$$

$$r_{k,i} \le \tau_k C\left(\frac{\omega_{k,i}E_{0:k-1}}{\xi E_k + \tau_k}\right), (k,i) \in I_D \quad (13c)$$

$$r_{k,1} + r_{k,2} \le \tau_k C\left(\frac{\omega_k E_{0:k-1}}{\xi E_k + \tau_k}\right), k \in Z_1^K \quad (13d)$$

$$\|\boldsymbol{\tau}\|_1 \le 1, \|\boldsymbol{E}\|_1 \le \mathrm{P_A}, \boldsymbol{E} \preccurlyeq \boldsymbol{\tau}_2\mathrm{P_P} \quad (13e)$$

where $\boldsymbol{E} = [E_0, E_1, \dots, E_{K+1}]^T$ with $E_k = P_k\tau_k$. With the perfect SI cancelation (SIC), or equivalently with $\xi = 0$, the problem (13) is convex due to the same reasoning provided for the HD WP-TWRN. We can thus solve the problem (13) with $\xi = 0$ by employing an existing convex optimization solver.

With the imperfect SIC, or equivalently with $\xi > 0$, the problem (13) is non-convex due to (13c) and (13d) so that the complexity of a brute-force search for (13) inicrease exponentially with the number K of the device pairs. To relieve the complexity, we apply the sequential parametric convex approximation (SPCA) framework [14] to find a solution of (13). In deriving convex approximations of (13c) and (13d) for the SPCA, we figure out the convex and non-convex properties hidden in (13c) and (13d) by applying the inequality

$$\tau C\left(\frac{y}{z+\tau}\right) = \tau C\left(\frac{y+z}{\tau}\right) - \tau C\left(\frac{z}{\tau}\right), \quad (14)$$

as

$$r_{k,i} + \tau_k C\left(\frac{\xi E_k}{\tau_k}\right) - \tau_k C\left(\frac{\xi E_k + \omega_{k,i}E_{0:k-1}}{\tau_k}\right) \le 0, \quad (15a)$$

$$\sum_{i=1}^{2} r_{k,i} + \tau_k C\left(\frac{\xi E_k}{\tau_k}\right) - \tau_k C\left(\frac{\xi E_k + \omega_k E_{0:k-1}}{\tau_k}\right) \le 0 \quad (15b)$$

for $k \in Z_1^K$. The non-convexity of (15a) and (15b) comes from $f(\boldsymbol{t}_k) = \tau_k C(\xi E_k/\tau_k)$ for $\boldsymbol{t}_k = [E_k, \tau_k]^T$, which is approximated to its first-order Taylor series expansion

$$f_1(\boldsymbol{t}_k; \boldsymbol{t}_{k,a}) = f(\boldsymbol{t}_{k,a}) + \nabla f(\boldsymbol{t}_{k,a})(\boldsymbol{t}_k - \boldsymbol{t}_{k,a}), \quad (16)$$

at a point $\boldsymbol{t}_{k,a} = [E_{k,a}, \tau_{k,a}]^T$ with $\nabla f(\boldsymbol{t}_k) = \left[\frac{\partial f}{\partial E_k}, \frac{\partial f}{\partial \tau_k}\right]$.

Since

$$\nabla f(\boldsymbol{t}_{k,a}) = \left[\frac{\xi\tau_{k,a}log_2 e}{\xi E_{k,a} + \tau_{k,a}}, C\left(\frac{\xi E_{k,a}}{\tau_{k,a}}\right) - \frac{\xi E_{k,a}log_2 e}{\xi E_{k,a} + \tau_{k,a}}\right], \quad (17)$$

and $f(\boldsymbol{t}_{k,a}) = \nabla f(\boldsymbol{t}_{k,a})\boldsymbol{t}_{k,a}$, (16) becomes

$$f_1(\boldsymbol{t}_k; \boldsymbol{t}_{k,a}) = \nabla f(\boldsymbol{t}_{k,a})\boldsymbol{t}_k. \tag{18}$$

The problem (13) is thus approximated to a convex problem

$$\max_{\boldsymbol{E},\boldsymbol{\tau}} U_\alpha(\boldsymbol{r}) \;\; s.t. (13b), (13e), \widetilde{(15a)}, \widetilde{(15b)} \tag{19}$$

where $\widetilde{(15a)}, \widetilde{(15b)}$ are the convex approximation of (15a) and (15b), respectively, attained by replacing $\tau_k C(\xi E_k/\tau_k)$ with $f_1(\boldsymbol{t}_k; \boldsymbol{t}_{k,a})$ defined in (18). The SPCA solves the convex problem (19) for given $\boldsymbol{t}_{k,a} = (E_{k,a}, \tau_{k,a})$ iteratively by updating $\boldsymbol{t}_{k,a}$ for a better approximation. The iterative algorithm finding a solution of (13) under the imperfect SIC is summarized in Table I. The algorithm converges to a Karush-Kuhn-Tucker (KKT) point as proved for any SPCA algorithm in [14]. The complexity of the algorithm with N_{it} iterations is $O(N_{it}(4K+4)^4)$ since a genertic convex problem solver with n variables has a complexity of $O(n^4)$.

Initialization: Solve (13) with $\xi = 0$ to obtain $(\boldsymbol{E}_a, \boldsymbol{\tau}_a)$
Repeat
1. Solve (19) with $(\boldsymbol{E}_a, \boldsymbol{\tau}_a)$ to find the solution $(\boldsymbol{E}^*, \boldsymbol{\tau}^*)$
2. Update $E_a \longleftarrow E^*$and $\tau_a \longleftarrow \tau^*$

Until the objective function converges

TABLE I – Joint PA-TA algorithm

IV. NUMERICAL RESULTS

We evaluate the sum rate of the WP-TWRN when $K = 5, \zeta_k = 0.8, \mathrm{P_A} = \mathrm{P_P}/2$ and $\sigma^2 = -90dBm$. The devices undergo an identical path loss of 30dB and independent Rayleigh fading. We adopt YALMIP with FMINCON solver in solving the generic convex problems.

Fig. 4 provides the sum rate of the WP-TWRNs when the utility function is optimized for $\alpha = 0, 1, \infty$ denoting the max-throughput $\sum_{k=1}^{5}\sum_{i=1}^{2} r_{k,i}$, max PF $\sum_{k=1}^{K}\sum_{i=1}^{2} ln r_{k,i}$, and max-fairness $\min(r_{k,i})$, respectively. The SI factor is set to $|f_L|^2 = -100dB$ for the FD WP-TWRN with the imperfect SIC. Here 'Scheme [10]' refers the TWR extension of the FD WP-UL with the perfect SIC in [10] by adding the downlink subframe for transmission of the network coded symbols. We also provide the Jain's fairness index [12] in Table II corresponding to $\mathrm{P_A} = 10\,dBm$ in Fig. 4. The sum rate of the WP-TWRN decreases as α, or equivalently the fairness level, increases. Clearly, the FD outperforms the HD and the scheme [10] both in the throughput and the fairness. In addition, the HD outperforms the scheme [10] by utilizing the WIT signals from the HAP for EH.

α	FD no SI	FD (SI = -100 dB)	HD	Scheme [10]
0	0.703	0.686	0.660	0.508
1	0.974	0.969	0.964	0.950
∞	0.998	0.998	0.998	0.998

TABLE II: Jain's fairness index

The sum rate of the FD WP-TWRN is also investigated as a function of the SI $|f_L|^2$ in dB in Fig. 5 when $\mathrm{P_A} = 20\,dBm$. The FD provides quite a large gain over the HD by reducing the number of time phases required for the WPT and WIT and by avoiding the adverse effect of the SI with resource allocation. As an example, the FD tends to allocation small values for $\{E_k\}_{k=1}^{K}$ at a high SI value to reduce the effect of the SI term $E_k\xi$ on the rate.

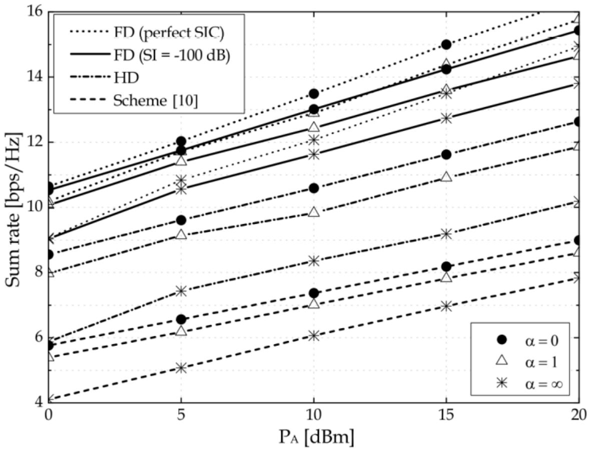

Fig. 4. Sum rate of the WP-TWRN as a function of $\mathbf{P_A}$

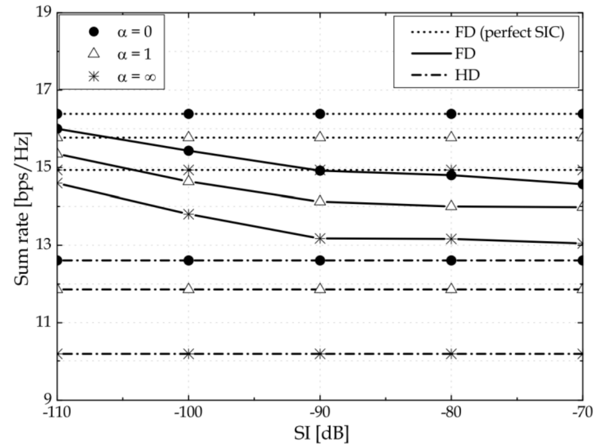

Fig. 5. Sum rate of the WP-TWRN as a function of the SI $|f_L|^2$ *when* $P_A = 20\,dBm$

V. CONCLUSIONS

This letter has designed the HD and FD protocols for a multi-pair TWRN with wireless powering capability. For each protocol, the problem of maximizing the generalized utility function is formulated with power and time allocation. We show the convexity of the problems for the HD and for the FD with perfect SIC to obtain the solution with a generic solver. In addition, we provide a feasible iterative algorithm for the problem of the FD with the imperfect SIC which is not convex. The results show that the proposed WP-TWRN outperforms the TWR extension of the existing WP-UL and the FD provides a significant gain over the HD.

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PHÂN BỔ TÀI NGUYÊN CHO MẠNG TRUYỀN THÔNG SONG HƯỚNG ĐA CẶP TIẾP SỨC VỚI NĂNG LƯỢNG KHÔNG DÂY

***Tóm tắt*:** Chúng tôi xem xét mạng truyền thông song hướng đa cặp tiếp sức trong đó các thiết bị không có pin giao tiếp thông qua một điểm truy cập hybrid. Đối với mạng này, các giao thức đơn công và song công được thiết kế theo đa truy cập phân chia theo thời gian và vấn đề phân bổ thời gian và công suất được xem xét. Bài toán hướng đến tối ưu hàm utility trong đó tính hiệu quả và công bằng với ràng buộc công suất tại điểm truy cập hybrid và ràng buộc năng lượng lưu trữ tại các thiết bị. Chúng tôi biến đổi bài toán cho giao thức đơn công và song công với không tự can nhiễu thành bài toán tối ưu lồi trong khi bài toán song công có tự can nhiễu chúng tôi cung cấp lời giải lặp. Kết quả mô phỏng chúng minh tính hiệu quả của giao thức song công so với đơn công cả về mặt lưu lượng thông tin và tính cân bằng

Từ khóa: song công, phân bổ tài nguyên, mạng chuyển tiếp song hướng, mạng thu hoạch năng lượng.

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