Wireless Powered Communication Networks in Interference Channel

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***Abstract*—In this paper, we study a wireless powered communication network (WPCN) in a two-user interference channel, where two hybrid access-points (H-APs) support a user in each cell. In this two cell scenario, the H-APs first transmit the energy signal to charge both users in the downlink (DL) phase. Then, in the subsequent uplink (UL) phase, each user sends its information signal to the corresponding H-AP utilizing the harvested energy. Due to asynchronous time allocation of the DL and the UL between two cells, cross-link interference affects the overall performance. In this system, we aim to maximize the sum-rate by jointly optimizing the time durations for the DL and the UL phases of each cell, and the UL transmit power of all users. As the sum-rate maximization problem becomes non-convex, it is difficult to obtain an optimal solution. To solve this problem, we propose a new algorithm where the time allocation and the transmit power are alternatively updated based on the weighted sum-minimum mean square error criteria and the projected gradient method. In simulation results, we verify that the proposed algorithm for the asynchronous protocol outperforms conventional schemes.**

I. Introduction

Recently, energy harvesting (EH) techniques have been regarded as one of promising alternatives of energy sources because of the potential of endless energy supplies. Especially, harvesting energy from wireless radio frequency (RF) signals has attracted enormous amount of attention, and many researchers have studied RF EH techniques for wireless communication networks [1]–[11]. There are two main streams in RF EH based wireless communication systems, which are simultaneous wireless information and power transfer (SWIPT) [1]–[6] and wireless powered communication networks (WPCN) [7]–[13]. In the SWIPT, wireless energy transfer (WET) and wireless information transmission (WIT) are simultaneously conducted in the downlink (DL). In particular, the SWIPT in interference channels (IFC) was considered in [2]–[6] where users in each cell behave as either an information decoder or an energy harvester.

On the other hand, in the WPCN, an energy access point broadcasts the RF signals for the DL WET phase, and user nodes harvest those to transmit the WIT signals in the uplink (UL). The WPCN in single cell scenarios was studied in [7]–[11]. The authors in [7] introduced the optimal power allocation methods for sum-rate maximization in a single user WPCN. For the multi-user WPCN, a successive interference cancellation technique was adopted in [8] for information decoding, and precoding matrices were proposed for the downlik WET and the UL WIT. Also in [9]–[11], multiple access schemes were applied in the UL WIT to avoid interference. The work in [9] developed a harvest-then transmit WPCN based on time division multiple access (TDMA), where the DL WET and the UL WIT are carried out in a time division duplex (TDD) mode, and presented a resource allocation method to maximize the sum-rate. In addition, WPCN based on orthogonal division multiple access and space division multiple access were investigated in [10] and [11], respectively. However, different from the SWIPT, the WPCN in the IFC scenario has not been considered in the literature to our best knowledge.

In this paper, we study a WPCN in a two-user IFC where a hybrid-access points (H-AP) in each cell conducts the WET and the WIT in the TDD mode. When the WPCN is to be applied in the IFC, the DL and the UL should be jointly taken into account, since asymmetric time allocation between two cells generates cross-link interference [14]. In specific, the DL WET signal from one cell has detrimental effect on the information decoding at the other cell. On the contrary, the UL WIT signal helps the other user by providing EH signals. Thus, different from conventional one cell WPCN systems [9], in which the optimal time allocation depends only on the channel gain of users, for the two cell WPCN in this paper, interference in the DL and UL also needs to be considered in the time and the power allocation.

For this configuration, namely an *asynchronous* protocol, we propose a joint time and UL power allocation method to maximize the sum-rate. Owing to the WIT interference, the sum-rate maximization problem becomes non-convex in general. To tackle this problem, we provide an alternating algorithm which first optimizes power allocation utilizing the weighted sum-minimum mean square error (WMMSE) approach [15] with given time, and computes time allocation based on the projected gradient method with given power. Then, we repeat this procedure until convergence. From simulation results, we demonstrate that the proposed algorithm for the asynchronous protocol shows significant performance gains compared to conventional schemes which allocate time and power independently in each cell.

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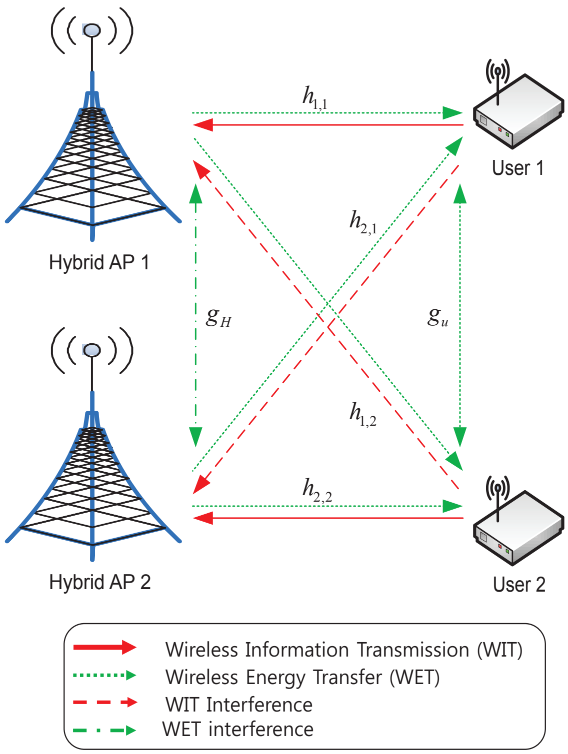

Fig. 1. Schematic diagram for the WPCN in Two-User IFC

II. System Model And Problem Formulation

As shown in Figure 1, we consider a WPCN in a two-user IFC where a H-AP in each cell employs WET in the DL and WIT in the UL in a TDD manner. Each H-AP first broadcasts the WET signals to the users, and then the user transmits the WIT signal to the corresponding H-AP by utilizing the harvested energy. Note that the WIT interference signals from the other cell degrades performance of the information rate at the H-APs. On the contrary, the WET and WIT signals received in the other cell help the user to harvest additional energy.

This is quite different from traditional communication systems, where the interference signal reaching at unintended users usually degrades the performance. In our system, however, the same interference can be exploited to charge the battery further. We assume that the total operation time for one system block is equal to one and set the time durations of the DL and the UL for cell i by τ_i and $1-\tau_i$, respectively ($i = 1, 2$). Also, global channel state information (CSI) and channel reciprocity are assumed for both cells.

To describe a system of the WPCN in the IFC, without the loss of generality, we assume that the WET duration of cell 1 is larger than that of cell 2, i.e., $\tau_1 \geq \tau_2$.[1] Then, the

[1]In general, we should consider both cases of $\tau_1 \geq \tau_2$ and $\tau_1 \leq \tau_2$. However, throughout this paper, we concentrate on the first case $\tau_1 \geq \tau_2$ since a similar derivations can be obtained for the second case $\tau_1 \leq \tau_2$. Then, the final solution is the one that has a greater sum-rate value between two cases. This will be explained in Section III.

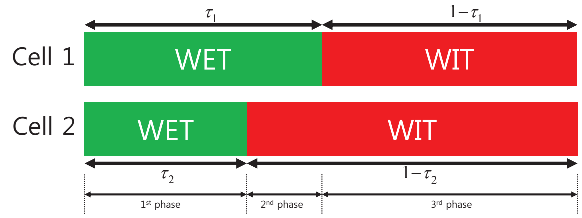

Fig. 2. Illustration of the WET and WIT operation in each cell

system can be divided into three different phases as illustrated in Figure 2. In the first phase $0 \leq t \leq \tau_2$, both the H-APs execute the WET in the DL, and the users collect the energy of those WET signals. Let us define the frequency-flat fading UL channel between H-AP j and user i as $h_{i,j}$ for $i, j = 1, 2$ ($h^*_{i,j}$ for the DL). Denoting $r^{\text{user}}_{i,k}$ as the received signal of user i in the kth phase, the received signal of each user during the first phase is given by

$$r^{\text{user}}_{i,1} = \sqrt{P_{D,1}}h^*_{i,1}x_{D,1} + \sqrt{P_{D,2}}h^*_{i,2}x_{D,2} + n^{\text{user}}_i,$$

where $(\cdot)^*$ refers to complex conjugate. $P_{D,j}$ and $x_{D,j}$ with $\mathbb{E}[|x_{D,j}|^2] = 1$ stand for the transmit power and the WET signal in the DL at H-AP j, respectively, and n^{user}_i indicates the complex Gaussian noise at user i with zero mean and variance σ^2.

Then, the amount of the harvested energy $E_{i,1}$ at user i during the first phase can be written by

$$E_{i,1} = \eta\tau_2(P_{D,1}|h_{i,1}|^2 + P_{D,2}|h_{i,2}|^2), \quad (1)$$

where η represents the conversion efficiency of the EH process. For simplicity, we set $\eta = 1$ for the rest of the paper, and ignore the noise power in (1) since it is negligible compared to $P_{D,j}$ in practice [1].

In the second phase $\tau_1 \leq t \leq \tau_2$ where cross-link interference occurs, H-AP 1 still carries out the WET operation in the DL, whereas H-AP 2 receives the WIT signal transmitted from user 2 as well as the WET interference signal radiated from H-AP 1. Thus, defining $r^{\text{H-AP}}_{j,k}$ as the received signal of H-AP j in the kth phase, the received signal of H-AP 2 in the second phases can be expressed as

$$r^{\text{H-AP}}_{2,2} = \sqrt{P_{U,0}}h_{2,2}x_{U,2} + \sqrt{\beta P_{D,1}}g_H x_{D,1} + n^{\text{H-AP}}_2,$$

where $P_{U,0}$ is the UL transmit power of user 2 at the second phase, $x_{U,i}$ denotes the UL WIT signal transmitted from user i satisfying $\mathbb{E}[|x_{U,i}|^2] = 1$, β is the attenuation factor which will be described later, g_H accounts for the channel coefficient between two H-APs, and $n^{\text{H-AP}}_j$ represents the complex Gaussian noise at H-AP j with zero mean and variance σ^2.

Since the WET signal $x_{D,j}$ does not carry any information, we can pre-determine $x_{D,j}$ as an arbitrary random variable and it can be shared between two H-APs as in [2] and [5]. Then, depending on the level of knowledge of $x_{D,j}$ at the other cell, we allow cancelation of cross-link interference at H-AP 2, and we model this by multiplying the attenuation factor $\sqrt{\beta}$ ($0 \leq \beta \leq 1$) on $\sqrt{P_{D,1}} g_H x_{D,1}$.[2] Consequently, denoting $R_{j,k}$ as the achievable information rate at H-AP j in the k-th phase, $R_{2,2}$ is obtained as

$$R_{2,2} = (\tau_1 - \tau_2)\log\left(1 + \frac{P_{U,0}|h_{2,2}|^2}{\sigma^2 + \beta P_{D,1}|g_H|^2}\right).$$

Meanwhile, user 1 can harvest energy not only from the WET signal from H-AP 1, but also from the WIT signal conveyed from user 2. Therefore, the received signal and the amount of the harvested energy at user 1 in the second phase become

$$\begin{aligned} r_{1,2}^{\text{user}} &= \sqrt{P_{D,1}} h_{1,1}^* x_{D,1} + \sqrt{P_{U,0}} g_U x_{U,2} + n_1^{\text{user}}, \\ E_{1,2} &= (\tau_1 - \tau_2)(P_{D,1}|h_{1,1}|^2 + P_{U,0}|g_U|^2), \end{aligned}$$

where g_U indicates the channel coefficient between two users. It is worth noting that the total harvested energy at user 1 is given by $E_{1,1} + E_{1,2}$.

For the third phase $\tau_1 \leq t \leq 1$ where both H-APs carry out the WIT operation, each user transmits its WIT signal based on the harvested energy. Denoting $P_{U,i}$ as the transmit power of user i, the received signal at H-AP j in the third phase is written by

$$r_{j,3}^{\text{H-AP}} = \sqrt{P_{U,1}} h_{1,j} x_{U,1} + \sqrt{P_{U,2}} h_{2,j} x_{U,2} + n_j^{\text{H-AP}}.$$

Since each H-AP cannot perform interference cancelation of the WIT signal, it is treated as an additive noise. Subsequently, the achievable rate $R_{i,3}$ ($i = 1, 2$) in the third phase is expressed as

$$R_{i,3} = (1 - \tau_1)\log\left(1 + \frac{P_{U,i}|h_{i,i}|^2}{\sigma^2 + P_{U,\bar{i}}|h_{\bar{i},i}|^2}\right),$$

where we define $\bar{i} = 1$ for $i = 2$ and $\bar{i} = 2$ for $i = 1$.

In this paper, we investigate a joint time and power allocation problem to maximize the sum-rate given as

$$\begin{aligned} \max_{\{\tau_i\},\{P_{U,i}\}} \quad & R(\{\tau_i\},\{P_{U,i}\}) \triangleq \sum_{i=1}^{2} R_{i,3} + R_{2,2} \qquad (2) \\ s.t. \quad & (1-\tau_1)P_{U,1} \leq E_{1,1} + E_{1,2}, \\ & (\tau_1 - \tau_2)P_{U,0} + (1-\tau_1)P_{U,2} \leq E_{2,1}, \\ & \tau_1 \geq \tau_2. \end{aligned}$$

Note that problem (2) is non-convex, and thus it is not straightforward to find the optimal solution. Therefore, in the following section, we propose an alternating algorithm to solve (2) which yields a locally optimal solution.

III. Joint Time and Power allocation

In this section, we identify a local optimal solution for problem (2) by alternatively optimizing $\{\tau_i\}$ and $\{P_{U,i}\}$. Specifically, we update $\{P_{U,i}\}$ with given $\{\tau_i\}$ using the WMMSE approach [15], and $\{\tau_i\}$ is computed with fixed $\{P_{U,i}\}$ based on the projected gradient method. Then, we repeat this alternating algorithm until converges. In order to make the problem in (2) tractable, we introduce the energy variables as $E_{U,0} = (\tau_1 - \tau_2)P_{U,0}$, $E_{U,1} = (1-\tau_1)P_{U,1}$, and $E_{U,2} = (1-\tau_1)P_{U,2}$.

Then, denoting $\{W_i\}$ and $\{U_i\}$ for $i = 0, 1, 2$ as a positive weight variable and the MMSE receiver, respectively, we can reformulate problem (2) into the equivalent WMMSE problem as

$$\begin{aligned} \min_{\{W_i\},\{U_i\},\{E_{U,i}\}} \quad & (\tau_1 - \tau_2)\left(W_0 e_0 - \log W_0\right) \qquad (3) \\ & + \sum_{i=1}^{2}(1-\tau_1)\left(W_i e_i - \log W_i\right) \\ s.t. \quad & E_{U,0} \leq \tau_2(P_{D,1}|h_{2,1}|^2 + P_{D,2}|h_{2,2}|^2), \qquad (4) \\ & E_{U,1} \leq \tau_1 P_{D,1}|h_{1,1}|^2 + \tau_2 P_{D,2}|h_{1,2}|^2 + E_{U,0}|g_U|^2, \qquad (5) \\ & E_{U,2} \leq \tau_2(P_{D,1}|h_{2,1}|^2 + P_{D,2}|h_{2,2}|^2) - E_{U,0}, \qquad (6) \end{aligned}$$

where $\{e_i\}$ for $i = 0, 1, 2$ represent the mean square error which is expressed as [15]

$$e_i = \begin{cases} \left|\dfrac{\sqrt{E_{U,0}}U_i^* h_{2,2}}{\sqrt{\tau_1 - \tau_2}} - 1\right|^2 + \left|\sqrt{\beta P_{D,1}}U_i^* g_H\right|^2 + \sigma^2|U_i|^2, & i = 0, \\ \left|\dfrac{\sqrt{E_{U,i}}U_i^* h_{i,i}}{\sqrt{1-\tau_1}} - 1\right|^2 + \left|\dfrac{\sqrt{E_{U,\bar{i}}}U_i^* h_{\bar{i},i}}{\sqrt{1-\tau_1}}\right|^2 + \sigma^2|U_i|^2, & else. \end{cases}$$

It is worth noting that the objective function of problem (3) is convex over each of the optimization variable $\{W_i\}, \{U_i\}$, and $\{E_{U,i}\}$. Therefore, we can adopt the block coordinate descent method by sequentially fixing two of the three variables and updating the remaining one. Thus, we can obtain the optimal weight $\{W_i^\star\}$ and the MMSE receiver $\{U_i^\star\}$ by finding the zero gradient condition as

$$W_i^\star = e_i^{-1}, \quad i = 0, 1, 2, \qquad (7)$$

$$U_i^\star = \begin{cases} \dfrac{\sqrt{E_{U,0}}h_{2,2}/\sqrt{\tau_1 - \tau_2}}{\frac{E_{U,0}|h_{2,2}|^2}{\tau_1 - \tau_2} + \beta P_{D,1}|g_H|^2 + \sigma^2}, & i = 0, \\ \dfrac{\sqrt{E_{U,i}}h_{i,i}/\sqrt{1-\tau_1}}{\frac{E_{U,i}|h_{i,i}|^2}{1-\tau_1} + \frac{E_{U,\bar{i}}|h_{\bar{i},i}|^2}{1-\tau_1} + \sigma^2}, & i = 1, 2. \end{cases} \qquad (8)$$

By plugging the optimal weight $\{W_i^\star\}$ and the MMSE receiver $\{U_i^\star\}$ into the objective function of problem (3), the equivalence between problems (2) and (3) can be confirmed. Due to this equivalence, optimizing $\{E_{U,i}\}$ (or equivalently $\{P_{U,i}\}$) of the sum-rate maximization problem (2) can be accomplished through the WMMSE problem (3) with a much more efficient manner.

Next, in order to calculate the $\{E_U^\star\}$ with given $\{W_i\}$ and $\{U_i\}$, we apply the optimal $\{W_i^\star\}$ and $\{U_i^\star\}$ into problem (3).

[2] If the WET signal can be fully shared between two cells, then it can be perfectly canceled $\beta = 0$. Otherwise, we have $0 < \beta \leq 1$.

Then, it follows

$$\min_{\{E_{U,i}\}} q_1(\{E_{U,i}\}) \triangleq (\tau_1-\tau_2)W_0^\star \left|\frac{\sqrt{E_{U,0}}(U_0^\star)^* h_{2,2}}{\sqrt{\tau_1-\tau_2}}-1\right|^2 + \sum_{i=1}^{2}(1-\tau_1)W_i^\star\left(\left|\frac{\sqrt{E_{U,i}}(U_i^\star)^* h_{i,i}}{\sqrt{1-\tau_1}}-1\right|^2 + \left|\frac{\sqrt{E_{U,\bar{i}}}(U_i^\star)^* h_{\bar{i},i}}{\sqrt{1-\tau_1}}\right|^2\right) \quad (9)$$
$$s.t. \quad (4),\ (5), \text{and } (6).$$

Since problem (9) is convex and satisfies the Slater's condition, the strong duality holds for problem (9). Therefore, we exploit the Lagrange duality method to optimally solve (9). The Lagrangian of problem (9) is given by

$$\begin{aligned}&\mathcal{L}(\{E_{U,i}\},\{\mu_i\})\\ &\quad = q_1(\{E_{U,i}\}) + \mu_0\left(E_{U,0}-\tau_2(P_{D,1}|h_{2,1}|^2+P_{D,2}|h_{2,2}|^2)\right)\\ &\quad +\mu_1\left(E_{U,1}-\tau_1 P_{D,1}|h_{1,1}|^2+\tau_2 P_{D,2}|h_{2,2}|^2+E_{U,0}|g_U|^2\right)\\ &\quad +\mu_2\left(E_{U,2}-\tau_2(P_{D,1}|h_{2,1}|^2+P_{D,2}|h_{2,2}|^2)+E_{U,0}\right),\end{aligned}$$

where $\{\mu_i\}$ for $i=0,1,2$ is the non-negative dual variable related to the constraints in problem (9).

Then, by taking derivative with respect to $E_{U,i}$ and equating the result to zero, we have

$$E_{U,0}^\star = \left(\frac{\sqrt{\tau_1-\tau_2}W_0^\star \mathrm{Re}\{U_0^\star h_{22}^*\}}{W_0^\star|U_0^\star h_{2,2}|^2+\mu_c-\mu_1|g_U|^2+\mu_2}\right)^2, \quad (10)$$
$$E_{U,1}^\star = \left(\frac{\sqrt{1-\tau_1}W_1^\star \mathrm{Re}\{U_1^\star h_{11}^*\}}{W_1^\star|U_1^\star h_{1,1}|^2+W_2^\star|U_2^\star h_{1,2}|^2+\mu_1}\right)^2,$$
$$E_{U,2}^\star = \left(\frac{\sqrt{1-\tau_1}W_2^\star \mathrm{Re}\{U_2^\star h_{22}^*\}}{W_1^\star|U_1^\star h_{2,1}|^2+W_2^\star|U_2^\star h_{2,2}|^2+\mu_2}\right)^2.$$

From (10), the dual function $g(\{\mu_i\}) \triangleq \max_{\{E_{U,i}\}}\mathcal{L}(\{E_{U,I}\},\{\mu_i\})$ with given dual variables $\{\mu_i\}$ can be calculated. Then, the dual problem is defined as $\min_{\{\mu_i\}} g(\{\mu_i\})$ and we can efficiently solve this problem by the ellipsoid method [16]. The sub-gradient ν_i of the dual function with respect to μ_i is expressed as

$$\begin{aligned}\nu_0 &= \tau_2(P_{D,1}|h_{2,1}|^2+P_{D,2}|h_{2,2}|^2)-E_{U,0},\\ \nu_1 &= \tau_1 P_{D,1}|h_{1,1}|^2+\tau_2 P_{D,2}|h_{2,2}|^2+E_{U,0}|g_U|^2-E_{U,1},\\ \nu_2 &= \tau_2(P_{D,1}|h_{2,1}|^2+P_{D,2}|h_{2,2}|^2)-E_{U,0}-E_{U,2}.\end{aligned}$$

The optimal solution $\{E_{U,i}^\star\}$ for problem (9) is computed with the optimal $\{\mu_i^\star\}$. Then, obtaining the optimal $\{W_i^\star\},\{U_i^\star\},\{E_{U,i}^\star\}$ is repeated until the sum-rate $R(\{E_{U,i}\})$ converges.

So far, we have determined the energy allocation solution $\{E_{U,i}^\star\}$ for a given $\{\tau_i\}$. Once $\{E_{U,i}^\star\}$ is found, the time allocation solution $\{\tau_i^\star\}$ can be identified by applying the projected gradient method onto the following problem as

$$\max_{\tau_1,\tau_2} q_2(\tau_1,\tau_2) \triangleq (\tau_1-\tau_2)\log\left(1+\frac{\frac{E_{U,0}|h_{2,2}|^2}{\tau_1-\tau_2}}{\sigma^2+\beta P_{D,1}|g_H|^2}\right) +(1-\tau_1)\log\left(1+\frac{E_{U,1}|h_{1,1}|^2}{(1-\tau_1)\sigma^2+E_{U,2}|h_{2,1}|^2}\right) +(1-\tau_1)\log\left(1+\frac{E_{U,2}|h_{2,2}|^2}{(1-\tau_1)\sigma^2+E_{U,1}|h_{1,2}|^2}\right) \quad (11)$$
$$s.t. \quad \tau_1 \geq \tau_2.$$

By checking a Hessian matrix, we can show that the objective function is a jointly concave function of τ_1 and τ_2. Thus, for given $\{E_{U,i}^\star\}$, we can optimally solve problem (11).

The gradient of the objective function $q_2(\tau_1,\tau_2)$ can be calculated as $\nabla\mathbf{g}=[\nabla g_1,\nabla g_2]^T$, which is shown at the top of next page. For simplicity, we denote $\boldsymbol{\tau}=[\tau_1,\tau_2]^T$. Then, by utilizing the gradient in equation (13) as a descent direction, $\boldsymbol{\tau}$ can be updated as

$$\boldsymbol{\tau} = \mathcal{P}_{\mathcal{E}}(\boldsymbol{\tau}+s\nabla\mathbf{g}) \quad (12)$$

where $\mathcal{P}_{\mathcal{E}}(\cdot)$ denotes the operation that projects $(\cdot)$ onto a feasible region $\mathcal{E}=\{\boldsymbol{\tau}|\tau_1\geq\tau_2, 0\leq\boldsymbol{\tau}\leq 1\}$, and s is a small step size.

The above procedure is repeated until the sum-rate $R(\{\tau_i\},\{E_{U,i}\})$ converges. We summarize the proposed algorithm for problem (2) in Algorithm 1. It is worthwhile to mention that although problem (11) is convex, Algorithm 1 only yields a local optimum solution due to the block coordinate descent method for problem (3). To improve the performance, we randomly generate M feasible $\{\tau_i\}$ as the initial points, and the best solution $\left(\{\tau_i^\star\},\{E_{U,i}^\star\}\right)$ is chosen by selecting the one that achieves the highest sum-rate value.

Algorithm 1 Time and power allocation algorithm for the asynchronous protocol

Initialize $\{\tau\}$.
Repeat
  Initialize $\{E_{U,i}\}$.
  Repeat
    Given $\{E_{U,i}\}$, compute $\{W_i^\star\}$ and $\{U_i^\star\}$ in (7) and (8), respectively.
    Obtain $\{E_{U,i}^\star\}$ in (10) using the ellipsoid method.
  Until $R(\{E_{U,i}\})$ converges.
  With fixed $\{E_{U,i}\}$, update $\{\tau_i\}$ utilizing the projected gradient method (12).
Until $R(\{E_{U,i}\},\{\tau_i\})$ converges.

Note that the solution from Algorithm 1 is based on the assumption $\tau_1\geq\tau_2$. To further enhance the sum-rate performance of the WPCN in IFC, we should consider the opposite case $\tau_1\leq\tau_2$ with the same method in Algorithm 1. Then, the final solution $(\{E_{U,i}^\star\},\{\tau_i^\star\})$ is selected by comparing the performance of the two cases.

$$\nabla g_1 = -\log\left(\left(1+\frac{E_{U,1}|h_{1,1}|^2}{(1-\tau_1)\sigma^2+E_{U,2}|h_{2,1}|^2}\right)\left(1+\frac{E_{U,2}|h_{2,2}|^2}{(1-\tau_1)\sigma^2+E_{U,1}|h_{1,2}|^2}\right)\right)$$
$$+(1-\tau_1)\left(\frac{E_{U,1}|h_{1,1}|^2/((1-\tau_1)\sigma^2+E_{U,2}|h_{2,1}|^2)}{(1-\tau_1)\sigma^2+E_{U,2}|h_{2,1}|^2+E_{U,1}|h_{1,1}|^2}+\frac{E_{U,2}|h_{2,2}|^2/((1-\tau_1)\sigma^2+E_{U,1}|h_{1,2}|^2)}{(1-\tau_1)\sigma^2+E_{U,2}|h_{2,2}|^2+E_{U,1}|h_{1,2}|^2}\right)$$
$$-\frac{E_{U,0}|h_{2,2}|^2}{(\tau_1-\tau_2)(\sigma^2+\beta P_{D,1}|g_H|^2)+E_{U,0}|h_{2,2}|^2}+\log\left(1+\frac{\frac{E_{U,0}|h_{2,2}|^2}{\tau_1-\tau_2}}{\sigma^2+\beta P_{D,1}|g_H|^2}\right)$$
$$\nabla g_2 = \frac{E_{U,0}|h_{2,2}|^2}{(\tau_1-\tau_2)(\sigma^2+\beta P_{D,1}|g_H|^2)+E_{U,0}|h_{2,2}|^2}-\log\left(1+\frac{\frac{E_{U,0}|h_{2,2}|^2}{\tau_1-\tau_2}}{\sigma^2+\beta P_{D,1}|g_H|^2}\right) \tag{13}$$

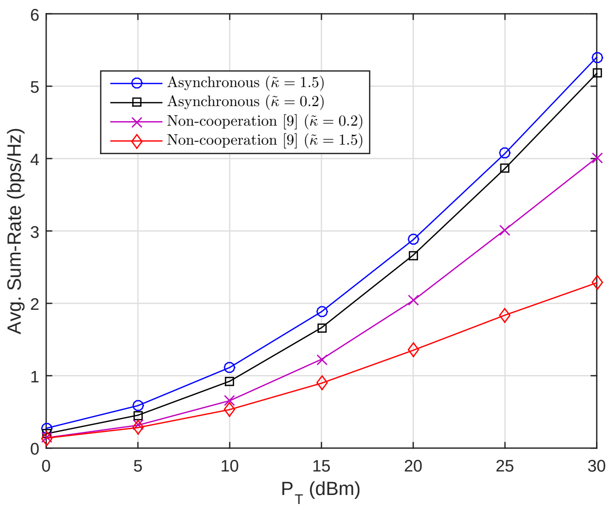

Fig. 3. Average sum-rate performance versus P_T when $\beta = 0$

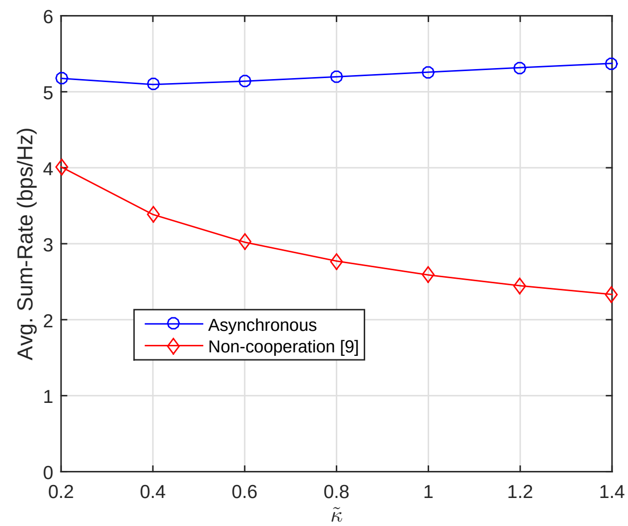

Fig. 4. Average sum-rate performance versus $\tilde{\kappa}$ when $P_T = 30$ dBm and $\beta = 0$

IV. Simulation Results

In this section, we evaluate the sum-rate performance of proposed asynchronous protocol for the WPCN in two-user IFC. Throughout this section, the UL and the DL channel power gains are generated as $|h_{i,j}|^2 = d_{i,j}^{-\alpha}\kappa_{i,j}|\tilde{h_{i,j}}|^2$, where $d_{i,j}$ m and $\tilde{h_{i,j}}$ are the distance and the small-scale Rayleigh fading coefficient between H-AP i and user j, respectively. In addition, α represents the pathloss exponent, and $\kappa_{i,j}$ indicates the power of the interference channel. We set $d_{i,j} = 10$m $\kappa_{i,i} = 1$ for $i = 1, 2$, and $\kappa_{i,j} = \tilde{\kappa}$ for $i \neq j$ as in [17]. Similarly, the power gain of the cross-link $|g_H|^2$ and $|g_U|^2$ are generated as $|g_H|^2 = d_H^{-\alpha}\tilde{\kappa}|\tilde{g_H}|^2$ and $|g_U|^2 = d_U^{-\alpha}\tilde{\kappa}|\tilde{g_U}|^2$ where $\tilde{g_H}$ and $\tilde{g_U}$ are the small-scale Rayleigh fading channels. Also, we fix the noise power as $\sigma^2 = -50$ dBm, the transmit power $P_{D,i}$ at H-AP i as $P_{D,1} = P_{D,2} = P_T$, and the number of initial points for Algorithm 1 to $M = 20$.[3]

Figure 3 compares the average sum-rate under two different interference channel conditions, i.e., $\tilde{\kappa} = 1.5$ and $\tilde{\kappa} = 0.2$ with $d_U = 10$ m, $d_H = 15$ m, and $\beta = 0$. In this figure, we also plot the performance of the non-cooperation scheme where each H-AP assigns the UL transmit power and $\{\tau_i\}$ based on the single cell WPCN solution in [9]. For all P_T regime, it is observed that our proposed algorithm for the asynchronous protocol significantly outperforms the conventional non-cooperation scheme. Especially, under the strong interference channel ($\tilde{\kappa} = 1.5$), the proposed algorithm for the asynchronous protocol provides a 55% gain over the conventional non-cooperation scheme when $P_T = 25$ dBm. Also, for a weak interference channel condition ($\tilde{\kappa} = 0.2$), although a performance gain between the asynchronous case and the conventional non-cooperation scheme is reduced for all P_T regime, a 23% performance gain is still observed at $P_T = 25$ dBm.

Next, for $P_T = 30$ dBm and $\beta = 0$, Figure 4 illustrates the average sum-rate performance with different $\tilde{\kappa}$, which represents the level of the interference strength. Due to a trade-off between the amount of the harvested energy $\{E_{i,k}\}$

[3] We have confirmed through simulations that $M = 20$ is sufficient for achieving good performance.

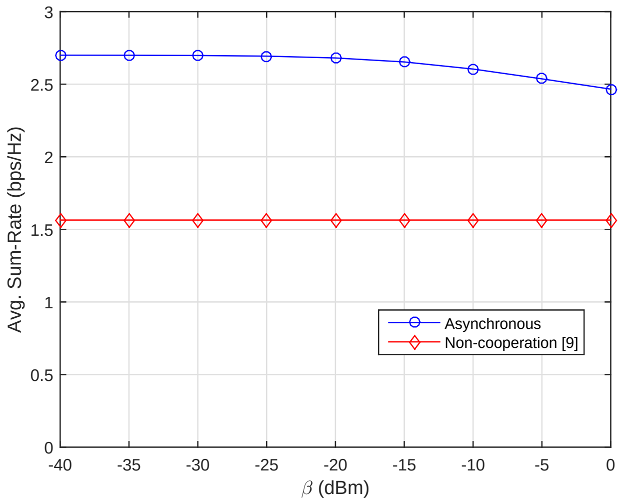

Fig. 5. Average sum-rate performance versus β when $P_T = 20$ dBm and $\tilde{\kappa} = 0.8$

and the WIT interference, we can observe that the sum-rate performance of the asynchronous protocol decreases for low $\tilde{\kappa}$. In contrast, the performance of the conventional non-cooperation scheme constantly declines as the interference strength grows.

In Figure 5, the average sum-rate performance with different β is demonstrated. Since the conventional non-cooperation scheme does not share WET signal between two H-APs and thus does not execute interference cancelation, the sum-rate performance remains constant. We can see that the proposed algorithm for the asynchronous protocol outperforms the conventional non-cooperation scheme for all β region. Also, this figure shows that $\beta = -20$ dBm is sufficient to provide the performance with almost no cross-link WET interference for the asynchronous protocol.

V. Conclusion

In this paper, we have investigated a joint time and power allocation method of WPCN in two-user IFC, where cross-link interference occurs. We have provided a new algorithm where the power allocation method is performed based on the WMMSE approach for given time duration, and the time duration is allocated by the projected gradient method for given power. Simulation results have confirmed that the proposed algorithm for the asynchronous protocol, which utilize the harvest energy from cross-link interference, outperforms the conventional schemes.

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