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Power-Efficient Beamforming Design for Simultaneous Wireless Information and Power Transfer

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Abstract- This paper reviews a rising simultaneous wireless information and power transfer (SWIPF) technique and some background introduction. Firstly, we will build up out system model that transmitter with multi-antenna and the information and power receivers with K users' each of them with single antennas. Moreover, we will introduce Channel State Information, system capacity as well as total harvesting power from transmitter. Last but not the least, the objective is through MATLAB simulation to evaluate the minimize the transmitter power and then make a conclusion.

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I. Introduction

Recently, wireless power communication has drawn large number of consideration in the area of wireless survey, since limited deice battery life has seen as the explosive important consideration in the frame of the electronic devices. To provide continuous and stable energy for the electronic devices in modern life, wireless energy transfer (WET) technology can be applied. WET can divided into two area, radiative and non- radiative. Capacitive coupling used by electric fields and inductive coupling also used by magnetic fields in near field or non-radiative techniques so that wireless receivers can harvest power from transmitter which charged by stable power source, given in Figure 1

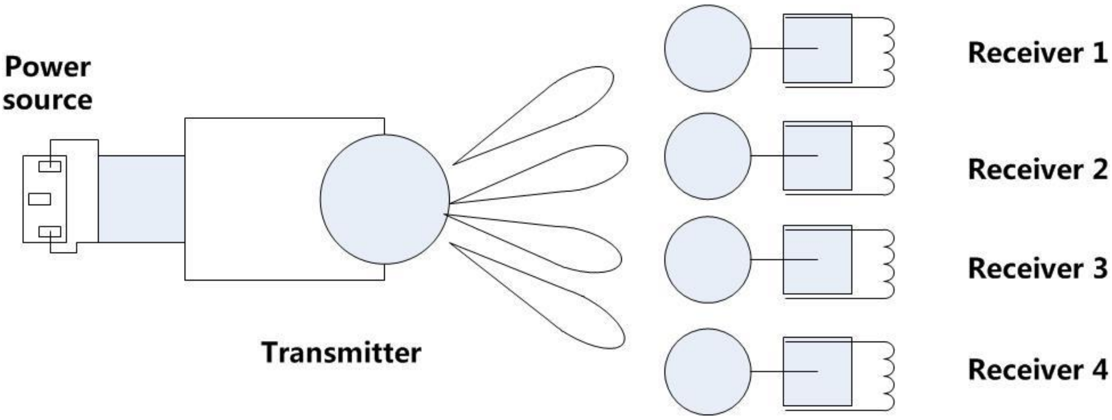

Figure:1 Wireless energy transfer (WET) technology Block Diagram.

Wireless powered communication (WPC) is one of the most important field that enjoys many practical advantages from WET. With energy interrupting in communication devices, WPC is expected to increase higher sustainable performance and users experience. In conventional WPC system, it can commonly support devices which use less power, for example, sensors and RFID tags. Nevertheless, with the developing of antenna technologies and energy harvesting technologies, high power transfer and harvest with efficient is enabled applied by wireless devices [1]. Therefore, in the future wireless powered communication (WPC) technology will be a significant applied in a wide range of industry and commercial area such as RFID devices, Internet of Things (IoT) and large scale wireless sensor networks (WSNs). Moreover, it is worth pointing out that the SWIPT technologies appearance can enhance wireless powered communication system efficiency cause SWIPT can improve gains such as the information transmission delay. And the WPC system efficiency also depend on interference management by power transfer as well as information decoding, spectral efficiency and energy consumption. we will introduce the SWIPT basic structures in the following article.

1.SWIPT BASIC RECEIVER STRUCTURES

In the early studies on SWIPT show that it is possible perform both information and energy simultaneously without losses, telling an elementary trade-off between power transfer and information [2]. Nevertheless, to design a well perform SWIPT system in the real engineering project, received signal must be divide into 2 part, the first part of the purpose is data decoding and second part for the power harvesting. In the next part, we state a summarisation of the SWIPT structures of the receiver including time switching(TS) receiver, power splitting(PS) receiver and separated receiver.

Time Switching Receiver [3]

In this receiver, the transmission block has two time slots, both of them is orthogonal to each other, one for transmitting data and another for transferring power. In particularly, the antenna can switch periodically depend on the time switching sequence from energy harvesting circuit to information decoding or from information decoding(ID) circuit to energy harvesting(EH) circuit, so different trade-off between ID and EH can be successful applied.

Power Splitting Receiver

In power splitting receiver, the components are the same as those of the time switching receiver. However, the PS receiver split the signal into two steams with same or different power level using a certain power splitting ratio ρ to facilitate simultaneous EH and ID [3][9][10]. Where power ratio $0 \leq \rho \leq 1$ used for information decoding and 1- ρ is used for energy harvesting so that achieving rate energy trade-off by changing parameter ρ.

Separated Receiver

In this case, there are two separate receivers using two antennas, one for EH and the other one is for ID [3]. Two individual receivers can easily use off-the-shelf components and trade-off are achieved base on the CSI and get the respond from the two receivers.

2.SWIPT Trade-off

As we discussed before, the performance of the information and power transfers can use varying measurement. For instance, power transfer primarily concern distance and efficiency, while information transmission emphasizes efficiency and distance. Therefore, it is very important to make a balance between data transmission and batter charging in the design of SWIPT system.

Transmit power, transfer duration, transmit protocol, transmit beam, channel selection and user scheduling always be key parameters to achieve the optimize performance objectives. For SWIPT, because the performance objectives are comparatively independent, the trade-off is always divided into three varying problem that the designer need to optimize. Firstly, a multi-purpose optimum system has an ability to be applicate two indexes have a best performance as the same time. Secondly, the purpose can be expressed as an ordinary practical function. For instance, this is logical to make more efficient of the weighted sum purposefully. Thirdly, the equation could be devised by limiting one performance index indicator to limited other performance indices. Like a common problem in the existing related literature, the information rate is maximized with minimal harvesting power constraints. The Different between SWIPT and WPC is that WPC are more closely related the two-performance metrics than SWIPT, because the more power which getting form wireless charging is used for data transmission. Hence, trade-off for WPC has an immediate and unitary construct.

3.Resource Allocation for SWIPT System

This part we will discusses about the advantages of SWIPT which is applying resource allocation algorithm. The resource utilization of the optimized physical layer, such as bandwidth, time, energy and space in multiuser systems, has been studied extensively in the literature [4]. Except as the traditional QoS requirements like energy efficiency, dependability, delay, throughput, and fairness. The effective transfer of energy also play a significant part of a recently QoS requirement for SWIPT [5, 6]. SWIPT systems resource allocation algorithm including:

Joint energy and user management:

The RF signal take a part of a dual-purpose carrier for transmitting data and power to the receiver at the same time. However, there is still an obstacle to applicate SWIPT due to extensive dynamic sensitivity range to EH and ID. Consequently, these is an efficient way to promote SWIPT system practically. For example, idle users can be arranged to experience high channel gain for energy transmission, to make the service life of the communication network more longer. Moreover, we can use opportunistic power control to utilize the channel fading for increasing the efficiency of information and energy [5,6,7].

Energy and information scheduling:

For small sensor receivers, it is only possible after the receivers fulfil the energy requirements of the downlink, uplink data transmission can be achieved. The physical limitations of the energy use have inspired the “post-harvest- transmission” design. When system allocate more resource for power harvesting in the downlink result in saving more energy, the uplink has more energy to consume as well. However, this also means that the uplink transmission time is less, which would lead to decrease the transmission data rate. Therefore, changing the plenty of time allocated to power acquisition and data transformation and finally the throughput of the whole diagram can be optimized.

Manage Interference:

As we can know the interference from other channel in telecommunication design are awaked as the main parameter that expose the system in a non-perfect performance and using resource allocation to suppress or avoid it. However, in SWIPT networks, the receiver may be subject to strong interference as it can be used as an important source of energy. Practically, we add artificial interference into the communication system so that the overall system can perform better, especially, the receivers lacking enough energy for maintaining the regular operations. In this situation, energy harvesting becomes the most important rather than information decoding. Additionally, it is easily to create a wireless charging zone which can concentrate and gather multi cell interference in pinpoint location by using interference alignment or interference coordination.

4.Energy Beamforming [17]

The use of multiple antennas can provides antenna power gain, but the most important is multiple antennas enables advanced energy beamforming (EB) technology, concentrating transmit power in smaller spatial areas, significantly improving power transfer efficiency[1]. By discreetly making the emission waveforms of each antenna, the EB can manage the collective behaviour in radiation waveforms so it can coherently be combined on the particular receiver whereas in other respects are mutually destroyed.

In general, there are many antennas mounted on the power emitter can more clearly generate energy beams in the spatial direction. When the transmitter only has one ER, it can directly make a sharp beamforming to make the power harvested most efficient. However, if the transmitter using a multiple ERs, generating a single beam may cause serious inequality between receivers, like near-term problems, in which the user close to the base station getting more power than the user far away from transmitter. In this circumstance, to balance the energy harvesting performance, the transmitter requires producing the different direction multiple energy beams [7]. A valid EB design claims accurate CSIT. Nevertheless, that is hard to applicate practically. This is not only because many primitive energy receivers without capability to do a perfect channel estimation, but also accurate channel estimation spend plenty of time and power so that the power gain be offset procured from energy beamforming. Moreover, receiver mobility would lead to time-varying channels which result in tracking channel difficultly.

The large number of channel estimation techniques already devised to achieve energy beamforming when the channel state information at the transmitter are uncertain by using the balance between energy levels received and the balanced between energy consumption and EB gain over time [8]. Additionally, by using distributed antennas the energy beamforming can get a better performance.

Since the receiver only collects energy from a small portion of the adjacent transmit antenna, the total of channel estimation feedback significantly reduces. Moreover, the implement of distributed antennas always cuts off the distance from the power transmitters to the receivers, so the near-far problem which due to apply a single power transmitter can be effectively deal with.

II. System Model

1. System Model

We focus on a downlink telecommunication frame which the transmitter equipped HAP and the data transmission and power receivers are integrated into K users' terminal with single antennas, shown in Figure.2. It is need to be mentioned that ID and the EH are working in the power splitting manner and the EH component which can gain energy from radio frequency plays an important role of supplying energy for the ID receiver in this system.

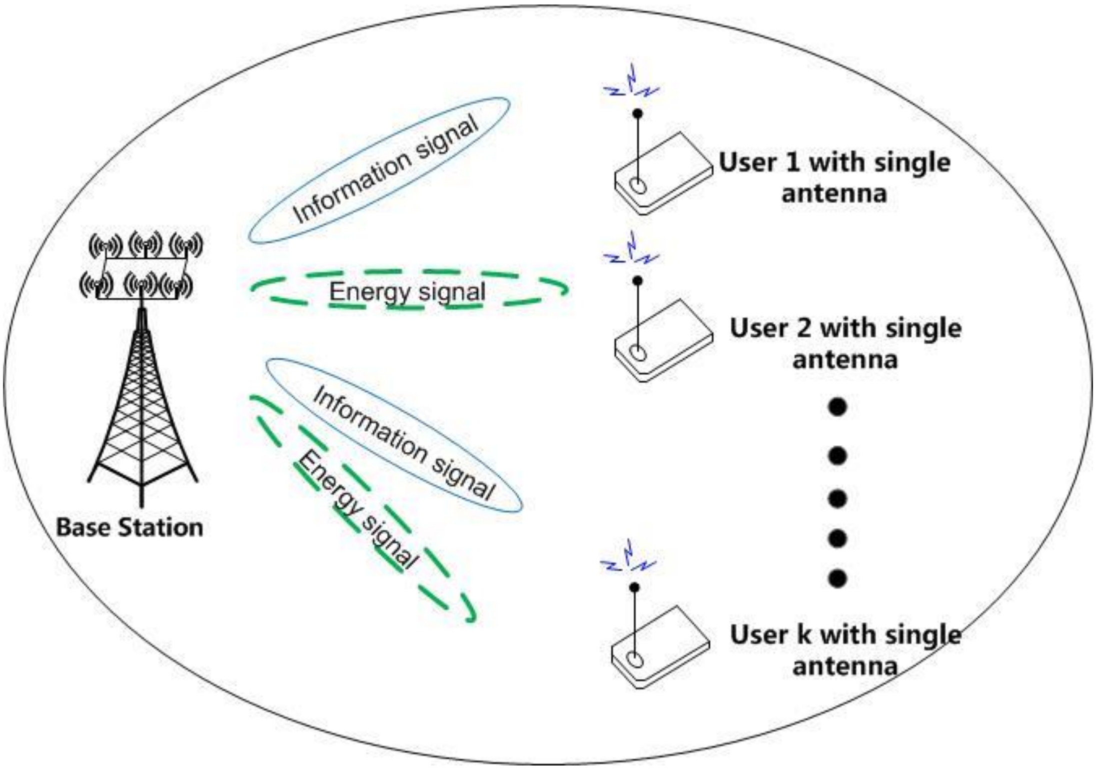

Figure.2 SWIPT communication system model

We assume the total bandwidth is B Hertz and working at a flat slow fading channel. When I consider on a TDD system, in the wireless data transmission and power transformation can be seen occur at many time slots from. Therefore, in one time slot, the downlink ID receivers signal Y_i and the EH receivers signal Y_e can be expressed as, respectively,

$$\mathrm{y_i^{IR} = h_i^H x + n_i^{IR}} \tag{1}$$

$$y_e^{ER} = g_e^H + n_e^{ER} \quad (2)$$

where i in the range of 1 to I and e in the range of 1 to E. $x \in C^{NT \times 1}$, $h_i^H \in C^{NT \times 1}$ and $g_e^H \in C^{NT \times 1}$ represent the transmit vector from the Base Station to the number of K receivers which need to transfer data and the number of M receivers which are obtaining power, the channel vector for base station and the I information transmission and the channel vector for base station and K energy harvesting receivers. Additionally, n_i^{IR} and n_e^{ER} are the additive white Gaussian noises(AWGN) which are Gaussian distribution at the receivers, respectively.

2. Hybrid Information and Energy Harvesting Receiver

During the optimization problem, I assume hybrid receivers [10], [11] which can be divided into two energy streams for ID and HE with a certain power splitting ration $1-\rho$ and ρ, respectively (the energy conversion efficiency is equal to 1).

3. Channel State Information

It is very important to point out that CSIT(Channel state information at the transmitter) play a significant role on both information and energy performance. We can get the optimal system performance when the requirement of the full CSIT achieved. Therefore, in order to available resource allocation at the transmitter, we note that there is perfect channel state information in this system. Therefore, h_i and g_e at each time slots are knowing.

4. System Capacity

we assume Gaussian pseudo random sequence **w** is known for all the transmitters and receivers which means the receiver are given a perfect CSI. For information receiver, the capacity is given by [20],[21]

$$C_i^{IR} = \log_2\left(1 + \frac{\rho\left|h_i^H w\right|^2}{\rho\left[\sum_{j\neq i}^{I}\left|h_i^H w_j\right|^2 + Tr\left(V h_i h_i^H\right)\right] + \sigma_i^2}\right) \quad \text{(bit/s/Hz)}$$

(3)

where the receive SINR=$\frac{\rho\left|h_i^H w\right|^2}{\rho\left[\sum_{j\neq i}^{I}\left|h_i^H w_j\right|^2 + Tr\left(V h_i h_i^H\right)\right] + \sigma_i^2}$ at information receiver i. And signal processing noise power equal to σ_i^2 at the information receiver.

In other words, the capacity(bit/s/Hz) of energy harvesting receiver between the transmitter and receiver is given by

$$C_e^{ER} = \log_2\left(1 + \frac{\rho\left|g_e^H w\right|^2}{\rho\left[\sum_{j\neq e}^{E}\left|h_e^H w_j\right|^2 + Tr\left(V h_e h_e^H\right)\right] + \sigma_e^2}\right) \quad \text{(bit/s/Hz)} \quad \textbf{(4)}$$

where $\frac{\rho\left|g_e^H w\right|^2}{\rho\left[\sum_{j\neq e}^{E}\left|h_e^H w_j\right|^2 + Tr\left(V h_e h_e^H\right)\right] + \sigma_e^2}$ is the received SINR at the energy harvesting receiver e. And signal processing noise power equal to σ_e^2 at the energy harvesting receiver.

5. Total Power

In this system, base station transmits information and provide energy support for information receiver and energy harvesting receiver, respectively [13],[15]. In terms of receiver noise, it can be seen as an energy source. However, cause the power of the noise is limited, it will not consider in the following system. Therefore, the total harvest power is given by

$$P_{EH_j} = (1-\rho)\left[Tr\left(V g_e g_m^H\right) + \sum_{j=1}^{J}\left|w_j g_e^H\right|^2\right] \quad \textbf{(5)}$$

III. Optimization Problem [18], [19]

The purpose of this system is minimizing the total transmit power while providing power allocation. So, we need to solve the following equation

$$\boldsymbol{minimize} = \sum_{j=1}^{j} \left\| \boldsymbol{W}_j \right\|^2 + \boldsymbol{Tr}(\boldsymbol{V})$$

$$\overset{\rightarrow}{\boldsymbol{w}_j}\ , \boldsymbol{v}, \boldsymbol{\rho}_j$$

(6)

s.t C1: $\frac{\rho \left| \mathbf{g}_{\mathrm{e}}^{\mathrm{H}} \boldsymbol{W}_k \right|^2}{\rho [\sum_{\mathrm{j} \neq \mathrm{e}}^{\mathrm{E}} \left| \mathbf{h}_{\mathrm{e}}^{\mathrm{H}} \mathbf{w}_{\mathrm{j}} \right|^2 + \mathbf{Tr}\left(\mathbf{V} \mathbf{h}_{\mathrm{e}} \mathbf{h}_{\mathrm{e}}^{\mathrm{H}} \right)] + \boldsymbol{\sigma}_{\mathrm{e}}^2} \geq \boldsymbol{\Gamma}_{\boldsymbol{req}} \quad , \forall \boldsymbol{j}$

C2: $P_{EH_j} \geq \ P_{min_j}$, $\forall \boldsymbol{j}$

C3: $\mathbf{V} \geq 0$

C4: $0 \leq \rho \leq 1$

Where variable $\boldsymbol{\Gamma}_{\boldsymbol{req}}$ in formula C1 represents the minimum requirement on signal to noise ratio of the receiver for ID. On C2, P_{EH_j} indicates total energy harvesting power must be less than P_{min_j} which means the minimum transmit power the device is required. The constraint C3, C4 specifies the energy beam must be positive and power splitting ratio constrain between zero to one, respectively [12], [14], [16]. As we mention before, in order to available resource allocation at the transmitter, we note that there is perfect channel state information in this system. Therefore, h_i and g_e at each time slots are knowing. The problem what I need to deal with is a non-convex quadratically constrained quadratic program. It is because the beamforming vector W and the power splitting ratio ρ, the problem became a non-convex problem which is hard to solving in the real design process.

IV. Semidefinite Relaxation

As we can know, the main optimization problem is a non-convex optimization problem. In order to solve the non-convexity problem, firstly, we design a new situation as well as make a reassociation for the problem into a convex optimization problem by using SDP relaxation. Now, we are setting $\boldsymbol{W_j} \in H^{NT}$, ∀ j, $\mathrm{W_j} = \mathrm{w_j w_j^H}$, and Rank($\mathrm{W_j}$) ≤ 1, ∀ j, we can write down the optimization problem Equation.

$$\underset{\overset{\rightarrow}{\boldsymbol{w_j}}\,,\boldsymbol{v},\boldsymbol{\rho_j}}{\boldsymbol{minimize}} = \sum_{\boldsymbol{j=1}}^{\boldsymbol{j}} \boldsymbol{w_j^H w_j} + \boldsymbol{Tr}(\boldsymbol{V})$$

(7)

s.t C5: $$\frac{\boldsymbol{\rho}\left|\mathbf{g_e^H}\boldsymbol{w_j^H w_j g_e}\right|^{\mathbf{2}}}{\boldsymbol{\rho}[\sum_{\mathbf{j\neq e}}^{\mathbf{E}} \mathbf{g_e^H}\boldsymbol{w_j^H w_j g_e} + \mathbf{Tr}(\mathbf{V}\boldsymbol{G_k})] + \boldsymbol{\sigma}_\mathbf{e}^\mathbf{2}} \geq \boldsymbol{\Gamma_{req}} \quad , \forall \boldsymbol{j}$$

C6: $$(1-\boldsymbol{\rho})[\boldsymbol{Tr}\left(\boldsymbol{v g_j g_j^H}\right) + \sum_{\mathbf{j=1}}^{\mathbf{E}} \mathbf{g_e^H}\boldsymbol{w_j^H w_j g_e}] \geq P_{min}$$

C7: $\mathbf{V} \geq 0$

C8: $0 \leq \rho \leq 1$

Now, the equation is equal to the following

$$\boldsymbol{minimize} = \sum_{j=1}^{j} \boldsymbol{Tr}(\boldsymbol{W}_j) + \boldsymbol{Tr}(\boldsymbol{V})$$

(8)

s.t C9: $\boldsymbol{Tr}(\boldsymbol{W}_j \boldsymbol{G}_j) \geq \ \boldsymbol{\Gamma}_{\boldsymbol{req}} \ [\sum_{\mathrm{j} \neq \mathrm{e}}^{\mathrm{E}} \mathbf{Tr}\left(\boldsymbol{W}_J \boldsymbol{G}_E\right) + \mathbf{Tr}(\mathbf{V}\boldsymbol{G}_E) + \frac{1}{\rho} \boldsymbol{\sigma}_{\mathrm{e}}^2]$

C10 : $\mathbf{Tr}(\mathbf{V}\boldsymbol{G}_E) + \sum_{\mathrm{j}=1}^{\mathrm{E}} \mathbf{Tr}\left(\boldsymbol{W}_J \boldsymbol{G}_E\right) \geq \frac{\mathrm{P}_{min}}{1-\rho}$

C11: $\mathbf{V} \geq 0$

C12: $0 \leq \rho \leq 1$

C13: Rank($\boldsymbol{W}_J$) ≤ 1

In the equation (8) the $\boldsymbol{W}_\mathrm{j}$ as well as the V stand for a matrix. Additionally, Constraint C11 and $\boldsymbol{W}_J$, V $\in \boldsymbol{H}_{N_T}$ assure that the covariance matrices V and $\boldsymbol{W}_J$ are positive semidefinite Hermitian matrices.

Because we do the transformation, the non-convex problem is transform to equation in C13. In order to circumvent the non-convexity, the semidefinite programming (SDP) relaxation is used to (8) by relaxing constraint C13 which is Rank($\boldsymbol{W}_j$) $\leq$1. When the constraint C13 is removed from the (8) formulation, we can rewrite the equation like that:

$$\boldsymbol{minimize} = \sum_{j=1}^{j} \boldsymbol{Tr}(\boldsymbol{W}_j) + \boldsymbol{Tr}(\boldsymbol{V})$$

(9)

s.t C9: $\boldsymbol{Tr}(\boldsymbol{W}_j\boldsymbol{G}_j) \geq \ \boldsymbol{\Gamma}_{req}\ [\sum_{\mathrm{j}\neq\mathrm{e}}^{\mathrm{E}} \mathbf{Tr}\left(\boldsymbol{W}_J\boldsymbol{G}_E\right) + \mathbf{Tr}(\mathbf{V}\boldsymbol{G}_E) + \frac{1}{\rho}\boldsymbol{\sigma}_{\mathrm{e}}^2]$

C10 : $\mathbf{Tr}(\mathbf{V}\boldsymbol{G}_E) + \sum_{\mathrm{j}=1}^{\mathrm{E}} \mathbf{Tr}\left(\boldsymbol{W}_J\boldsymbol{G}_E\right) \geq \frac{\mathbf{P}_{min}}{1-\rho}$

C11: $\mathbf{V} \geq 0$

C11: $\boldsymbol{W}_j \geq 0$

C13: $0 \leq \rho \leq 1$

~~C13: Rank($\boldsymbol{W}_J$) ≤1~~

Since we remove the equation C13, the equation transfer to convex. According to the optimization theory, the solution $\boldsymbol{W}_j$ for the relaxed problem satisfy a rank-one matrix which we get in the end, and then we can conclude that the original problem in (8) has an optimal solution which is $\boldsymbol{W}_j$. Accordingly, we can use performing an eigenvalue decomposition of $\boldsymbol{W}_j$ get the optimal solution. However, generally, the constraint relaxation would have a possibility not be tight since it is possible that Rank($\boldsymbol{W}_j$) > 1.

In the following, we prove the constraint relaxation is tight of the adopted SDP relaxation in (9) by the way of checking of the dual problem as well as the Karush-Kuhn-Tucker (KKT) conditions of (9). For this purpose, we should have a Lagrangian function of (9) that show below

$$\mathbf{L}\ (\boldsymbol{W_j}, \mathbf{V}, \boldsymbol{\alpha}, \boldsymbol{\beta}, \mathbf{Y})$$

$$= \sum_{\mathrm{j}=1}^{\mathrm{J}} \mathbf{Tr}(\boldsymbol{W_j}) + \ \mathbf{Tr}(\mathbf{V})$$

$$- \sum_{\mathrm{j}=1}^{J} \mathbf{Tr}(\boldsymbol{W_j Y_j}) + \sum_{j=1}^{J} \boldsymbol{\alpha_j}\{-\boldsymbol{Tr}(\boldsymbol{H_j W_j})\boldsymbol{\Gamma_{req}}\ [\sum_{\mathrm{j}\neq\mathrm{e}}^{\mathrm{E}} \mathbf{Tr}(\boldsymbol{H_j W_j}) + \mathbf{Tr}(\mathbf{V}\boldsymbol{H_j}) + \frac{\mathbf{1}}{\boldsymbol{\rho}} \boldsymbol{\delta}_{\mathbf{IR}}^{\mathbf{2}}]\}$$

$$+ \sum_{k=1}^{K} \boldsymbol{\beta_k} \left\{ - \left[\sum_{\mathrm{k}=1}^{K} \mathbf{Tr}(\boldsymbol{W_j G_k}) + \boldsymbol{Tr}(\mathbf{V}\boldsymbol{G_k}) \right] + \frac{\boldsymbol{P_{min}}}{\mathbf{1} - \boldsymbol{\rho}} \right\}$$

$$+ \sum_{\mathrm{j}=1}^{\mathrm{J}} \boldsymbol{\phi_j}\{-[\mathbf{Tr}(\boldsymbol{W_j R_n}) + \mathbf{Tr}(\boldsymbol{R_n}\mathbf{V})] - \boldsymbol{P_n^{max}}\} \qquad (12)$$

Here, $\boldsymbol{\alpha} \geq \mathbf{0}$ is the dual variable regarding the smallest needed SINR of the energy harvesting receiver in the equation C9. Moreover, dual variable is regarding the highest transmission power permission in C10. $\boldsymbol{\Phi}$ is a vector of the maximum transmit power per antenna in C12 where $\emptyset_j \geq 0, \mathrm{j} \in \{1, \ldots., \mathrm{J}\}, \gamma$ with the elements $\gamma_n \geq 0$, is the dual variable vector for the minimum transmit power constraint in C12. Matrix $\mathbf{Y} \geq \mathbf{0}$ is dual variable towards the semi-definiteness constraint on matrix $\boldsymbol{W_j}$. Therefore, the dual problem regarding to SDP relaxed problem can be seen as

$$\underset{\phi \geq 0}{\text{maximize}} \ \underset{W_j, V \in H^{NTL}, \boldsymbol{h}_j}{\text{minimize}} \ L(\boldsymbol{W_j}, \mathbf{V}, \boldsymbol{\alpha}, \boldsymbol{\beta}, \mathbf{Y}) \qquad (14)$$

Next, we expose the tightness of the SDP relaxation adopted in (9) by below theorem.

Theorem 1: Supposing that the channel vectors like IR, H, and the ER, $g_k, k \in \{1, \ldots \ldots, K\}$. So in statistically, we can model a independent random variables, then we can have a way to solve of (9) which is rank-one Rank($\boldsymbol{W_j}$)=1, with probability one.

Proof: Please refer to Appendix.

Therefore, when the channels achieve the condition proving in Theorem 1, the SD relaxation can be seen as tight. Moreover, at each iteration we can get the optimal solution of this problem as well as get the dual variables.

V. Result

In the following, we use MATLAB to perform simulation to evaluate the performance of the resource optimal allocation algorithm.

From Figure 1, the average power splitting ratio rises with the required SNR and Γreq. While the SNR requirement becomes more stringent, the power splitting receiver is forced to harvest additional received signal power for data decoding at the power splitting receiver to improve the receive SNR. In other words, adopting a fixed power splitting ratio, is strictly suboptimal for reducing the total transmit power in general. On the other hand, it is expected that the number of transmit antennas does not have a large impact on the value of power splitting ratio. This is because for a fixed receive SNR requirement at the power splitting receiver, the transmitter has to maintain the same level of receive signal strength at the power splitting receiver regardless of the numbers of transmit antennas.

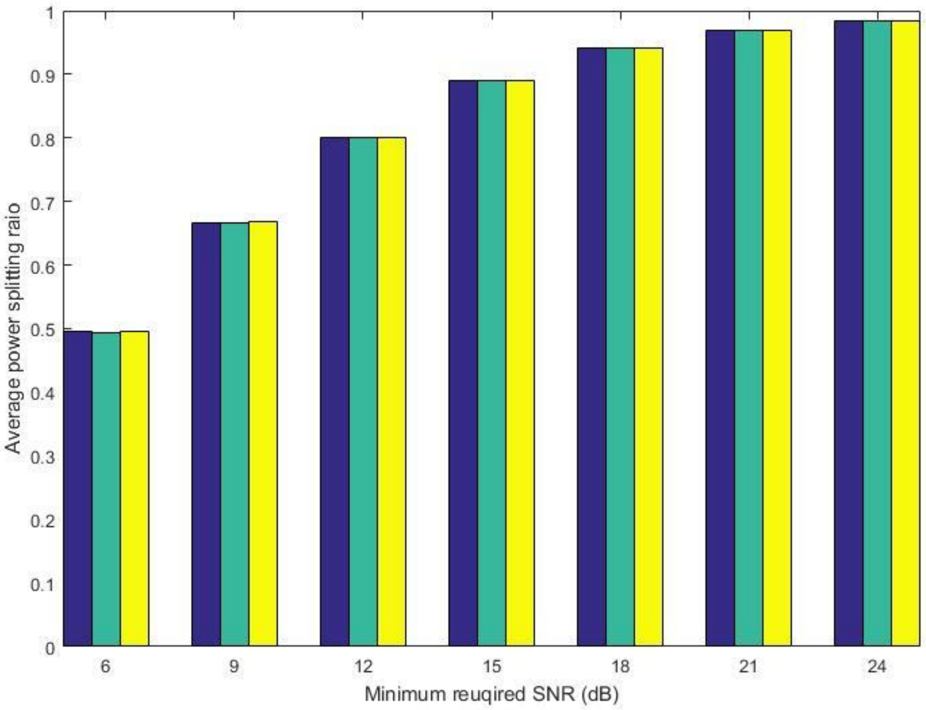
Average power splitting raio
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
6
9
12
15
18
21
24
Minimum reuqired SNR (dB)

Figure 1

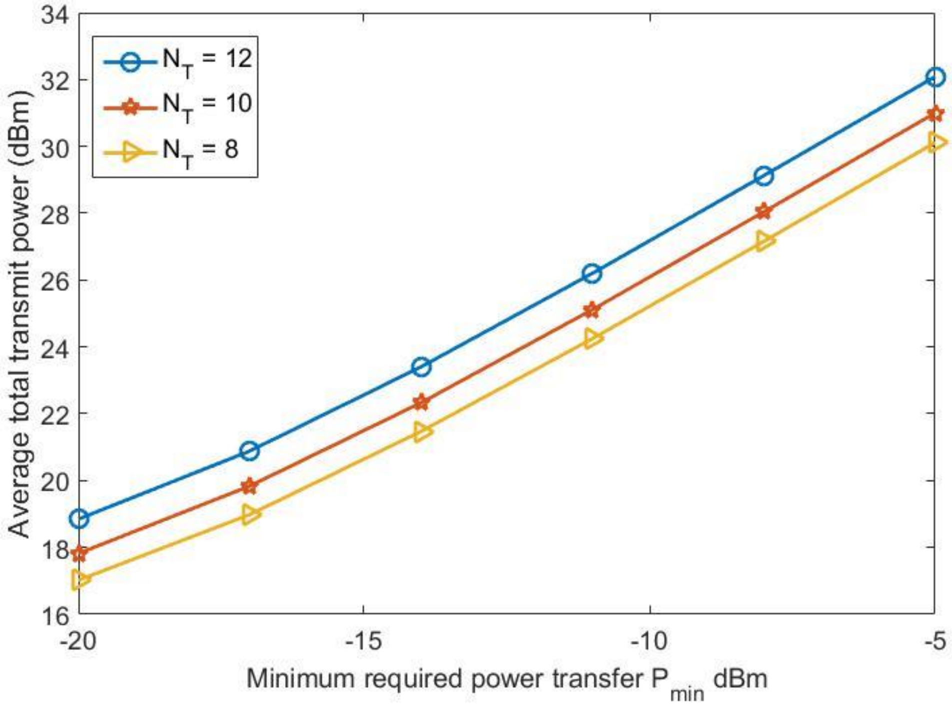

Figure 2 shows the minimum required power transfer to the receivers, P_{min}, for different resource allocation schemes. We assume that both IR and ERs require the same minimum amount of power transfer, i.e., P_{min}= P_{minj}, ∀j ∈ {1, . . . , J}. The minimum required SNR of the power splitting receiver is set to Γreq = 6 dB. In generally, the total transmit power rises with the minimum required power transfer. In reality, while the minimum required power transfer increases, the feasible solution set shrinks which reduces the flexibility of the optimal beamforming. Moreover, the average total transmits power declines with raising the number of transmit antennas. The multiple transmits antennas which can offer additional degrees of freedom make power resource allocation more efficiency . In additionally, the planed optimal scheme provides a substantial resource saving better than the baseline scheme due to the adopted optimization.

VI. Conclusion

This paper introduces a rising simultaneous wireless information and power transfer (SWIPF) technique and some background introduction. Firstly, we are giving out system model that transmitter with multi-antenna and the information and power receivers with K users' each of them with single antennas. Secondly, we introduce Channel State Information, system capacity as well as total harvesting power from transmitter. Moreover, we transform the non-convex problem into a convex optimization problem by using SDP relaxation and through MATLAB simulation to evaluate the minimize the transmitter power. Finally, we found that as the minimum required power transfer becomes more stringent, the feasible solution set shrinks which reduces the flexibility of the optimal beamforming.

VII. Appendix

Since we use the SDP relaxation of the problem in equation (8), the KKT conditions are necessary [45] for the optimal way to solve the relaxed problem. Therefore, we concentrate in KKT conditions that easy to deal with our proof:

$$\boldsymbol{Y}^* \geq 0,\ \alpha^*, \beta^* \geq 0 \qquad (15)$$

$$\boldsymbol{Y}^*\boldsymbol{W}^* \geq 0, \qquad (16)$$

$$\boldsymbol{Y}^* = \boldsymbol{I}_{\boldsymbol{N}_T} - (\alpha^* + \beta^*)\boldsymbol{H} \qquad (17)$$

where $\boldsymbol{I}_{\boldsymbol{N}_T}$ and α^*, β^* are the optimal Lagrange multipliers for (14). In Equation (16), when the columns of $\boldsymbol{W}^*$ lay in the null space of $\boldsymbol{Y}^*$, which means the equation is the complementary slackness condition. From above theory, we can say that if the equation satisfies $\boldsymbol{Rank}(\boldsymbol{Y}^*) = \boldsymbol{N_T - 1}$, $\boldsymbol{W}^* \neq 0$ should be a rank-one matrix.

So the dual problem in (14) can be expressed as

$$\underset{\boldsymbol{W}_j,\boldsymbol{V}\in \boldsymbol{H}^{NTL},\boldsymbol{h}_j}{\text{minimize}} \; L(\mathbf{W},\mathbf{V}^*,\boldsymbol{\alpha}^*,\boldsymbol{\beta}^*,\mathbf{Y}^*) \qquad (18)$$

Suppose $\boldsymbol{A}^*$ is not positive definite, i.e., $\boldsymbol{A}^* \leq 0$, as well as $\mathbf{W} = \mathrm{t}\mathbf{w}\boldsymbol{w}^{\boldsymbol{H}}$, in the equation $\mathbf{w}$ is the eigenvector which is respect a non-positive eigenvalue of $\boldsymbol{A}^*$. Next, we replace $\mathbf{W} = \mathrm{t}\mathbf{w}\boldsymbol{w}^{\boldsymbol{H}}$ into (18) which leads to

$$\mathrm{Tr}(\mathrm{t}\boldsymbol{A}^*\mathbf{w}\boldsymbol{w}^{\boldsymbol{H}}) - \mathrm{tTr}(\mathbf{w}\boldsymbol{w}^{\boldsymbol{H}}(\boldsymbol{Y}^* + (\alpha^* + \beta^*)\boldsymbol{H}) + \Delta \qquad (19)$$

Δ denotes a collection of the variables that are independent of **W**. we setting t → ∞, the term $-\mathrm{tTr}(\mathbf{w}\boldsymbol{w}^{\boldsymbol{H}}(\boldsymbol{Y}^* + (\alpha^* + \beta^*)\boldsymbol{H}) \rightarrow -\infty$ so the dual optimal value change to unbounded from above.

By utilizing (17) and an essential disparity for the rank of matrices, we can write that

$$\mathrm{Rank}(\boldsymbol{Y}^*) + \mathrm{Rank}\big((\alpha^* + \beta^*)\boldsymbol{H}\big)$$
$$\geq Rank(\boldsymbol{Y}^* + (\alpha^* + \beta^*)\boldsymbol{H})$$
$$= Rank(\boldsymbol{A}) = \boldsymbol{N_T} \rightarrow \mathrm{Rank}(\boldsymbol{Y}^*) \geq \boldsymbol{N_T} - \mathbf{1} \qquad (20)$$

Thus, Rank ($\boldsymbol{Y}^*$) is either $\boldsymbol{N_T} - \mathbf{1}$ or $\boldsymbol{N_T} - \mathbf{1}$. Furthermore, $\boldsymbol{W}^* \neq 0$ is has a requirement to achieve the smallest SINR of the power splitting receiver in C1 for Γreq > 0. Hence, $\boldsymbol{Rank}(\boldsymbol{Y}^*) = \boldsymbol{N_T} - \mathbf{1}$ and Rank ($\boldsymbol{W}^*$) = 1 hold with probability one. Therefore, we can make a conclusion that we can using the way of performing eigenvalue decomposition of $\boldsymbol{W}^*$ to get the optimal beamformer $\boldsymbol{w}^*$ as well as choosing the main eigenvector to be the beamformer.

VIII. References

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