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# Resource allocation for hybrid TS and PS SWIPT in massive MIMO system☆

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ABSTRACT

In this paper, we consider the hybrid time switching (TS) and power splitting (PS) simultaneous wireless information and power transfer (SWIPT) protocol design in massive MIMO system. In this system, the base station (BS) simultaneously serves a set of half-duplex (HD) sensor nodes which are uniformly distributed in its coverage. The whole protocol can be divided into two phases based on the idea of TS. The first phase is designed for sensor nodes energy harvesting as well as downlink training. During this phase, the BS transmits energy signals to the sensor nodes. Based on the idea of PS, the sensor nodes utilize the received energy signals for energy harvesting and downlink channel estimation. In the second phase, the BS schedules the sensors intelligently based on the beam-domain distributions of channels to mitigate interference between sensors and enhance transmission spectral efficiency. Then, the BS forms the receive beamformers for the reception of signals transmitted by sensors. By optimizing transmit powers at the BS and the TS ratio, the system achievable sum rate performance is maximized. Simulation results show the superiority of the proposed protocol on spectral efficiency compared with conventional massive MIMO SWIPT protocol.



## 1. Introduction

The ever-growing challenges due to significant traffic growth driven by mobile Internet and the Internet of things have made system capacity enhancement the most important feature of the fifth generation (5G) mobile communication systems [1]. As a promising technique for 5G, massive multiple-input multiple-output (MIMO) [1,2] has the ability to greatly improve the spectral efficiency (SE) of wireless communications system, and thus has gained widely concern in the academia and industry [3–5].

Massive MIMO uses large-scale antenna arrays to serve several tens of users simultaneously [1]. As the number of antennas increases, the additive noise as well as the uncorrelated interference can even be effectively eliminated by using the simple linear precoder and detector [1,2]. Compared with the conventional MIMO, the spatial resolution of massive MIMO system is improved significantly, so that various types of interference can be substantially reduced [4–13].

### 1.1. Motivation and related work

In addition to the SE, the design of energy efficient wireless networks has also been extensively studied [14,15]. For example, energy constraint limits transmit power and associated signal processing of a wireless device, especially for a battery powered device [16]. As a practical solution to prolong the lifetime and improve the energy efficiency (EE) of battery powered wireless networks, energy harvesting (EH) technique has received extensive attention in recent years [17–19]. EH technology can effectively solve the charging problem in battery powered wireless networks, wherein the wireless nodes are inaccessible or a large number of wireless nodes are widely distributed.

A variety of renewable energy sources can be used for powering wireless communication nodes, e.g., solar, wind, vibration, ambient heat and so on [16]. However, one major problem in harvesting energy from these sources listed above is its inherent randomness. The availability of energy varies with conditions, such as location, time, temperature, which makes the allocation of energy resources in such systems challenging. Radio frequency (RF) signals emitted by surrounding transmitters can be considered as a feasible method of achieving efficient EH [20–22]. Compared with conventional energy sources, RF signals can carry information

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and energy at the same time, which brings new opportunities and challenges in the design of wireless protocols.

Wireless nodes collect the energy of surrounding RF signals to power the data transmission is called simultaneous wireless information and power transfer (SWIPT) [23–26]. Owing to its remote charging features, SWIPT can be used in a variety of battery powered wireless applications, e.g., Internet of things, wearable networks, wireless sensor networks and future cellular networks. In addition, the latest advances of SWIPT in antenna and RF energy harvesting circuit design have greatly increased the feasibility of EH in practical wireless applications, such as multi-user MIMO [27], cloud radio access networks (C-RAN) [28] and relaying systems [29].

The SWIPT receiver was first designed to collect the power of the received signal while decoding the information it contained [30–32]. However, the assumption in [30,31], that is the SWIPT receiver can decode and harvest energy from the received signal simultaneously was proved impractical [32]. Due to the non-ideal EH circuit design, part of the RF signal energy will be lost when decoded [33]. Hence, practical EH circuits cannot be used directly for information decoding (ID). In the following design of SWIPT receivers, antennas with different functionality are adopted for decoder and energy harvester, respectively. For example, in [34], receiver with power sensitivity from −20 to −10 dBm was designed for EH while −60 dBm for ID.

There are two types of practical receiver architecture, namely, the time switching (TS) and the power splitting (PS), according to the signal partition method for EH and ID [23]. The TS receiver alternates between EH and ID according to the TS ratio [34], as a result, the incoming RF signal was first sent to the energy harvester and then to the signal receiver. For the PS receiver, the incoming signal is split into two parts according to the PS ratio [24], one portion is sent to the energy harvester while the remaining portion is sent to the signal receiver.

In [35,36], the TS and PS protocols for one-way single-antenna amplify-and-forward (AF) SWIPT relay networks were studied. In [37], the SWIPT protocol was designed for a wireless-powered MIMO one-way relay network, where the relay can simultaneously harvest energy from the destination signal and decode the signal sent by the source. Since two-way relaying (TWR) system can further improve the SE, SWIPT protocol for TWR systems were studied in many literatures. The authors in [38] studied the SWIPT protocol in a two-way AF relaying system, where the relay node equipped with an energy harvester is adopted to help two source nodes exchange information. In [39], the sum-throughput maximization problem for a TWR network with wireless powered nodes was studied. The authors in [40] considered the SWIPT protocol design in multiple relay AF TWR network, where two source nodes harvest energy from multiple relays.

Although there are studies on the SWIPT protocol design for massive MIMO system, to the best of our knowledge, a few works have been done on the design of SWIPT protocol in cellular system with massive MIMO base station (BS). In [41], SWIPT protocol for three-dimensional (3D) massive MIMO system is designed, where the matched filter (MF) precoder is adopted at the BS. In [42], the SWIPT protocol is designed for multi-pair TWR system with massive MIMO, where the linear precoders, i.e., zero-forcing (ZF) and maximal ratio combining (MRC), are adopted at the relay. A low-complexity SWIPT scheme with retrodirective maximum ratio transmission (MRT) beamforming is studied in [43], where all energy receivers (ERs) send a common beacon signal simultaneously to the energy transmitter (ET) in the uplink and the ET simply conjugates and amplifies its received sum-signal and transmits to all ERs in the downlink for SWIPT. For SWIPT system with massive MIMO, instantaneous full dimensional CSI is needed to perform linear precoding. To obtain full dimensional CSI, the uplink training overhead scales linearly with the number of user equipments (UE) in TDD system, the downlink training overhead scales linearly with the number of antennas in FDD system and the corresponding CSI feedback yield an unacceptably high overhead, and therefore poses a significant bottleneck on the achievable SE.

### 1.2. Contributions

In this paper, we design the beam-domain hybrid TS and PS SWIPT protocol for massive MIMO (MM) system, where the BS serves a set of uplink fixed half-duplex (HD) sensor nodes which are uniformly distributed in its coverage area. The whole transmission process can be divided into two phases based on the idea of TS.

The first phase is designed for sensor nodes EH as well as downlink training. During this phase, the BS transmits energy signals to the sensor nodes. Based on the idea of PS, the sensor nodes utilize one portion of the received energy signals for EH and the remaining portion for downlink Sensor-BS channel estimation. After obtaining the downlink Sensor-BS CSI, sensor nodes feedback it to the BS. Moreover, the basis expansion model (BEM) [44] is introduced to greatly reduce the channel dimensions need to be estimated and the amount of CSI feedback.

In the second phase, the BS schedules the sensors intelligently based on the beam-domain distributions of the associated channels to mitigate the interference between sensors as well as enhancing transmission SE. Moreover, the BS forms the receive beamformers for the reception of signals transmitted by sensors. By optimizing the TS ratio and transmit powers at the BS, the system achievable sum rate performance is maximized. Simulation results show the superiority of the proposed hybrid TS and PS SWIPT protocol on SE compared with the conventional massive MIMO SWIPT protocol.

The rest of the paper is organized as follows. The system and channel model are introduced in Section 2. Section 3 considers the practical sensor grouping problem. Section 4 illustrates the proposed beam-domain hybrid TS and PS massive MIMO SWIPT transmission scheme. Section 5 derives the system achievable sum rate and optimizes the transmit powers and TS ratio in two phases. Section 6 presents the simulation results. Our conclusions are presented in Section 7.

*Notations*: In this paper, $\mathbb{E}(\cdot)$ denotes the expectation. $\mathbf{A}^{\{B_1,B_2\}}$ is the submatrix of $\mathbf{A}$ containing rows of set $B_1$ and columns of set $B_2$. $\mathbf{A}^{\{B,:\}}$ and $\mathbf{A}^{\{:,B\}}$ is the submatrix of $\mathbf{A}$ containing rows and columns of set $B$, respectively. $\delta(\cdot)$ denotes the dirac delta function. $(\cdot)^T$, $(\cdot)^*$, $(\cdot)^H$, $|\cdot|$, $\|\cdot\|$ and $tr(\cdot)$ denote transpose, conjugate, conjugate transpose, determinant, Frobenius norm, and trace of a matrix, respectively. $\lfloor\cdot\rfloor$ and $\lceil\cdot\rceil$ denote the floor and ceil operation, respectively. $\mathbf{I}_V$ denotes $V \times V$ identity matrix.

## 2. System and channel model

We consider a massive MIMO SWIPT system, where the BS serves a set of $K_u$ fixed uplink sensor nodes $\mathbf{K}_U = \{1, 2, \ldots, K_u\}$. We assume that all the sensor nodes are uniformly distributed in the coverage area of the BS. The BS is equipped with a massive antenna array with $N$ antennas. We assume that all sensor nodes operate in HD mode and are equipped with a single antenna. Each sensor node employs a rectenna to collect energy and uses the harvested energy for the subsequent data transmission.

In this paper, we consider frame-based SWIPT protocol design for massive MIMO system (see Fig. 1). The length of one frame is fixed to $T$ seconds, and we assume that $T$ is less than the coherence interval of the fading channel. Let $\mathbf{h}_{k_u} \in \mathbb{C}^{N\times 1}$ and $\mathbf{h}_{k_d} \in \mathbb{C}^{N\times 1}$ denote the channel vector of the uplink Sensor-BS channel between transmit antenna array of BS and sensor node $k_u$ and corresponding downlink channel vector.