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A review of Wireless Information and Power Transfer in Multiuser OFDM Systems

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Abstract
We study the resource allocation algorithm design for multiuser orthogonal frequency division multiplexing (OFDM) downlink systems with simultaneous wireless information and power transfer. The algorithm design is formulated as a non-convex optimization problem for maximizing the energy efficiency of data transmission (bit/Joule delivered to the users). In particular, the problem formulation takes into account the minimum required system data rate, heterogeneous minimum required power transfers to the users, and the circuit power consumption. Subsequently, by exploiting the method of timesharing and the properties of nonlinear fractional programming, the considered non-convex optimization problem is solved using an efficient iterative resource allocation algorithm. Recently, simultaneous wireless information and power transfer (SWIPT) becomes appealing by essentially providing a perpetual energy source for the wireless networks. For the TDMA-based information transmission, we employ TS at the receivers; for the OFDMA-based information transmission, we employ PS at the receivers. Under the above two scenarios, we address the problem of maximizing the weighted sum-rate over all users by varying the time/frequency power allocation and either TS or PS ratio, subject to a minimum harvested energy constraint on each user as well as a peak and/or total transmission power constraint.

I. Introduction

SWIPT have assumed that the same signal can convey both energy and information without losses, revealing a fundamental trade-off between information and power transfer. However, this simultaneous transfer is not possible in practice, as the energy harvesting operation performed in the RF domain destroys the information content. To practically achieve SWIPT, the received signal has to be split in two distinct parts, one for energy harvesting and one for information decoding. In the following, the techniques that have been proposed to achieve this signal splitting in different domains (time, power, antenna, space).For the TS scheme, by an appropriate variable transformation the problem is reformulated as a convex problem, for which the optimal power allocation and TS ratio are obtained by the Lagrange duality method.

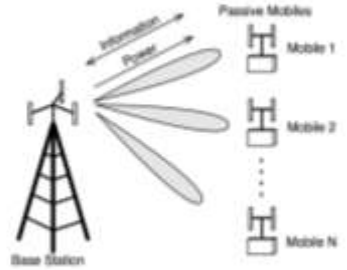


Fig: 1 A multiuser downlink SWIPT system.

Moreover, the SWIPT system offers great convenience to mobile users, since it realizes both useful utilizations of radio signals to transfer energy as well as information. Therefore, SWIPT has drawn an upsurge of research interests [9]–[12]. Varshney first proposed the idea of transmitting information and energy simultaneously in [2] assuming that the receiver is able to decode information and harvest energy simultaneously from the same received signal. However, this assumption may not hold in practice, as circuits for harvesting energy from radio signals are not yet able to decode the carried information directly. Two practical schemes for SWIPT, namely, time switching (TS) and power splitting (PS), are proposed in [1] , [3]. With TS applied at the receiver, the received signal is either processed by an energy receiver for energy harvesting (EH) or processed by an information receiver for information decoding (ID). With PS applied at the receiver, the received signal is split into two signal streams with a fixed power ratio by a power splitter, with one stream to the energy receiver an d the other one to the information receiver. SWIPT for multi antenna systems has been considered in [1], [4]–[6]. In particular, [1] studied the performance limits of a three-node multiple input multiple-output (MIMO) broadcasting system, where one receiver harvests energy and another receiver decodes information from the signals sent by a common transmitter. [4] Extended the work in [1] by considering imperfect channel state information (CSI) at the transmitter for a multiple-input single-output (MISO) system. A MISO SWIPT system without CSI at the transmitter was considered in [5], where a new scheme that employs random beam forming for opportunistic EH was proposed.

II. Orthogonal frequency-division multiplexing (OFDM)

OFDM is a form of multicarrier modulation. An OFDM signal consists of a number of closely spaced modulated carriers. When modulation of any form - voice, data, etc. is applied to a carrier, then sidebands spread out either side. It is necessary for a receiver to be able to receive the whole signal to be able to successfully demodulate the data. As a result when signals are transmitted close to one another they must be spaced so that the receiver can separate them using a filter and there must be a guard band between them. This is not the case with OFDM. Although the sidebands from each carrier overlap, they can still be received without the interference that might be expected because they are orthogonal to each another. This is achieved by having the carrier spacing equal to the reciprocal of the symbol period.

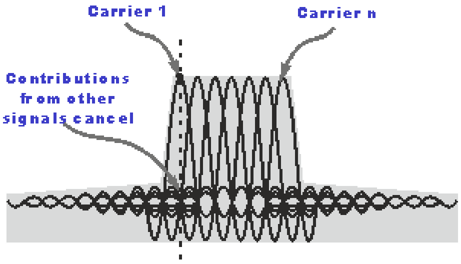


Fig:2 OFDM Spectrum

The downlink received symbol at receiver k ∈ {1, . . . , K} on subcarrier i ∈ {1, . . . , nF } is given

$$Y_{i,k} = \sqrt{P_{i,k} l_k g_k} H_{i,k} X_{i,k} + I_{i,k} + Z^{s}_{i,k} + Z^{a}_{i,}$$

where Xi,k, Pi,k, and Hi,k are the transmitted data symbol, the transmitted power, and the multipath fading coefficient from the transmitter to receiver k on subcarrier i, respectively. lk and gk represent the path loss and shadowing attenuation from the transmitter to receiver k, respectively. Z s i,k and Z a i,k are additive white Gaussian noises (AWGN) originating from signal processing and the antenna on subcarrier i of receiver k, respectively.

III. Techniques for SWIPT

A. **Time Switching** (TS)

If TS is employed, the receiver switches in time between information decoding and energy harvesting. In this case, the signal splitting is performed in the time domain and thus the entire signal received in one time slot is used either for information decoding or power transfer .The TS technique allows for a simple hardware implementation at the receiver but requires accurate time synchronization and information/energy scheduling.

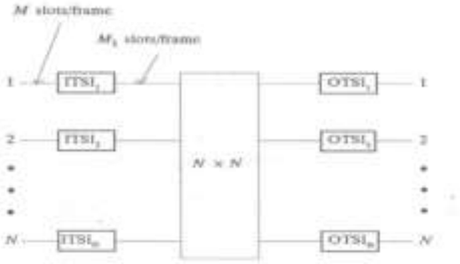
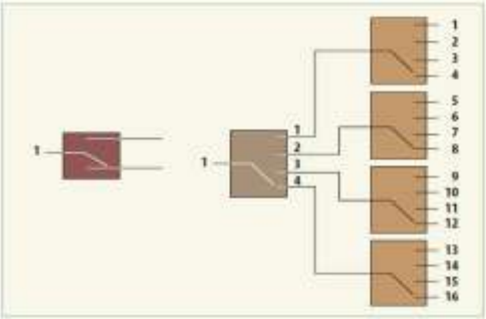


Fig:4 Time Switching

B. **Power Splitting** (PS)

The PS technique achieves SWIPT by splitting the received signal in two streams ofdifferent power levels using a PS component; one signal stream is sent to the rectenna circuit for energy harvesting and the other is converted to baseband for information decoding. The PS technique entails a higher receiver complexity compared to TS and requires the optimization of the PS factor α; however, it achieves instantaneous SWIPT, as the signal received in one time slot is used for both information decoding and power transfer. Therefore, it is more suitable for applications with critical information/energy or delay constraints and closer to the information theoretical optimum.

Fig:5 Power Splitting



C. **Antenna Switching (**AS)

Typically, antenna arrays are used to generate DC power for reliable device operation. Inspired by this approach, the AS technique dynamically switches each antenna element between decoding/rectifying to achieve SWIPT in the antenna domain. In theAS scheme, the receiving antennas are divided into two groups where one group is used for information decoding and the other group for energy harvesting [6]. The AS technique requires the solution of an optimization problem in each communication frame in order to decide the optimal assignment of the antenna elements for information decoding and energy harvesting. For a MIMO decode-and-forward (DF) relay channel, where the relay node uses the harvested energy in order to retransmit the received signal, the optimization problem was formulated as a knapsack problem and solved using dynamic programming in.

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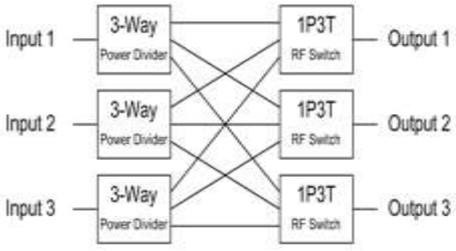

Fig: Antenna Switching

IV. LITERATURE REVIEW

"MIMO broadcasting for simultaneous wireless information and power transfer", [11] in this paper Energy-constrained wireless networks, such as sensor networks, are typically powered by batteries that have limited operation time. Although replacing or recharging the batteries can prolong the lifetime of the network to a certain extent, it usually incurs high costs and is inconvenient, hazardous (say, in toxic environments), or even impossible (e.g., for sensors embedded in building structures or inside human bodies). A more convenient, safer, as well as "greener" alternative is thus to harvest energy from the environment, which virtually provides perpetual energy supplies to wireless devices. In addition to other commonly used energy sources such as solar and wind, ambient radio-frequency (RF) signals can be a viable new source for energy scavenging. It is worth noting that RF-based energy harvesting is typically suitable for low-power applications (e.g., sensor networks), but also can be applied for scenarios with more substantial power consumptions if dedicated wireless power transmission is implemented.

"Transporting information and energy simultaneously", [12] in this paper The fundamental tradeoff between the rates at which energy and reliable information can be transmitted over a single noisy line is studied. Engineering inspiration for this problem is provided by powerline communication, RFID systems, and covert packet timing systems as well as communication systems that scavenge received energy. A capacity-energy function is defined and a coding theorem is given. The capacity-energy function is a non-increasing concave ∩ function. Capacity-energy functions for several channels are computed.

"Wireless information and power transfer: architecture design and rate-energy tradeoff", [13] in this paper Simultaneous information and power transfer over the wireless channels potentially offers great convenience to mobile users. Yet practical receiver designs impose technical constraints on its hardware realization, as practical circuits for harvesting energy from radio signals are not yet able to decode the carried information directly. To make theoretical progress, we propose a general receiver operation, namely, dynamic power splitting (DPS), which splits the received signal with adjustable power for energy harvesting and for information decoding. Moreover, we propose two types of practical receiver architectures, namely, separated versus integrated information and energy receivers. The integrated receiver integrates the front-end components of the separated receiver, thus achieving a smaller form factor. The rate-energy tradeoff for these two architectures are characterized by a so-called rate-energy (R-E) region. Numerical results show that the R-E region of the integrated.

V. Conclusion

In this paper, the resource allocation algorithm design for simultaneous wireless information and power transfer in OFDMA systems was studied. We focused on power splitting receivers which are able to split the received signals into two power streams for concurrent information decoding and energy harvesting. The algorithm design was formulated as a non-convex optimization problem which took into account a minimum system data rate requirement, minimum individual data rate requirements of the receivers, a minimum required power transfer, and the total system power dissipation. We first focused on receivers with continuous sets of power splitting ratios and proposed a resource allocation algorithm. The derived solution served as a building block for the design of a suboptimal resource allocation algorithm for receivers with discrete sets of power splitting ratios. Simulation results showed the excellent performance of the two proposed suboptimal algorithms and also unveiled the trade-off between energy efficiency, system capacity, and wireless power transfer.

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