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Overview of the Current Development of Simultaneous Wireless Information and Power Transfer System

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Abstract

Simultaneous Wireless Information and Power Transfer (SWIPT) technology provides a good solution for energy-constrained networks. Compared with traditional wireless communication networks, energy efficiency (EE) has been significantly improved. Combined with the content of fifth-generation (5G) green communication, further improving the EE of the SWIPT network has become the focus of academic attention. In recent years, SWIPT systems combining new technologies such as multiple input multiple output (MIMO) and non-orthogonal multiple access (NOMA) have emerged one after another. This paper continues to summarize and analyze the integration of SWIPT and 5G emerging technologies from the perspective of resource allocation and effective information transmission, aiming to provide thinking for the development of wireless energy-carrying communication technologies.

Keywords

SWIPT, MIMO, NOMA, energy efficiency.

1. Introduction

Driven by the exponential growth of mobile Internet services, research on fifth-generation (5G) cellular networks has received unprecedented attention from academia and industry [1]. However, due to the increasing demand for high data rates, spectral efficiency (SE) has become a major performance metric for wireless system design and optimization, but it also results in rising network power consumption, which has serious economic and ecological implications [2]. Therefore, energy saving has been considered as a key issue in wireless network research. To meet these requirements, 5G cellular networks are required to provide higher resource utilization efficiencies, including SE and energy efficiency (EE) [3].

Energy harvesting (EH) is considered as an effective solution to prolong the life of power-constrained devices and improve the energy efficiency of wireless communication systems [4]. In addition to natural renewable energy sources such as wind, solar, and biomass, wireless power transfer (WPT) has also become a strong promoter of EH. Using WPT, the transmitter can transmit energy to the receiver through radio frequency (RF) signals [5]. Therefore, techniques based on RF energy harvesting provide feasibility for simultaneous wireless information and power transfer (SWIPT) in communication systems. Zhang and Ho studied practical beamforming for MIMO-SWIPT systems and discussed two receiver methods, namely time-switching (TS) and power-splitting (PS), which laid the structural foundation for the transmission of later SWIPT receivers [6].

However, based on the literature in recent years, there are endless discussions and researches on SWIPT, but there is a lack of summaries for its shortcomings. This paper just synthesizes the literature on SWIPT research in recent years, discusses the development status of SWIPT technology and the deficiencies in the current research work, and hopes to play a guiding role in the follow-up SWIPT research.

This paper is organized as follows: The second section introduces the basic model of the SWIPT system, including the energy loss model and the energy efficiency model. The third section introduces the current research status of SWIPT technology and several key technologies of 5G. In section 4, we discuss the advantages of the current SWIPT technology development and the current shortcomings of this research. The fifth section is gives the conclusion.

2. Energy Efficiency Modeling of SWIPT Systems

2.1. Energy Loss Problem

In the actual SWIPT system, energy loss is an important index that affects EE [7]. [8][9][10][11] studied the performance of SWIPT system under different loss models, including circuit loss in irrational state, signal processing loss, loss in information decoding, etc.[12] . In most of the current research, the energy loss of the system is basically defined as the sum of fixed circuit loss, signal processing loss, and linear loss with respect to the information rate, such in [4], [5], [10] and [13], etc. In the simulation of the SWIPT system, it is necessary to make reasonable energy loss modeling in combination with the specific research background.

2.2. Energy Efficiency Model

When conducting energy efficiency studies of SWIPT systems, EE is usually defined as follows:

$$\eta = \frac{R}{E_{loss}} \tag{1}$$

That is the amount of information transmitted per unit of energy consumed. The information rate can be obtained by Shannon's formula [6].

3. SWIPT EE Optimization for Integrating 5G Technologies

3.1. SWIPT Energy Efficiency Combined with MIMO

MIMO is a technology that can significantly increase the information capacity of wireless communication systems [14], [15]. Judging from the literature in recent years, there are many studies on MIMO at present, and there are also many studies on SWIPT combined with MIMO structure.

In [5], the author studies the energy efficiency optimization problem of SWIPT system combined with MIMO broadcast channel, and the author establishes a single base station multi-user wireless model, both the base station and the users are equipped with multiple antennas. Through the analysis of this model, the optimization problem of transmitting resource allocation and receiver power allocation factor is proposed when the energy efficiency of the system is maximized. And a dual method is proposed, and the optimal solution when EE is optimal is successfully found with low complexity.

Reference [5] is a remarkable example of a SWIPT system combined with MIMO. From the results, the information capacity of the SWIPT system has indeed been improved, which together with the literature in recent years, reflects that MIMO is beneficial to the SWIPT system. However, the shortcomings of this type of work are still obvious. Most of the work adopts the gradient global search method, which results in a high complexity of derivation .

3.2. SWIPT Energy Efficiency Combined with NOMA

NOMA is also a wireless communication technology that has become popular with the development of 5G [16]. 5G, has conducted in-depth research on non-orthogonal multiple access. Its basic idea is to get rid of the restriction of orthogonality, so for N users, the resources allocated to each user can be greater than $\frac{1}{N}$, realizing resource sharing among multiple users.

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One of the difficult problems of NOMA is receiver design. Due to the multi-user interference caused by non-orthogonal design, the receiver needs to deal with this kind of interference with great complexity. The most typical design scheme is: successive interference cancellation (SIC). The SIC receiver demodulates each user's signal one by one in a certain order (usually sorted by channel quality). After the first user's signal is demodulated, its signal is reconstructed and subtracted from the received signal, so there is no interference to other users. In this way, the signals of all users are demodulated successively. This method has high complexity and is also very difficult to implement in hardware. Therefore, the design of NOMA receivers is also a very important direction for a period of time. In the current research on SWIPT and NOMA, the research object is mostly the energy efficiency optimization problem of the system, to find the optimal resource allocation method and receiver PS ratio. Inter-user interference is actively introduced at the transmitter, and serial interference cancellation is used at the receiver to eliminate this interference.

In [16], a single base station multi-user downlink NOMA system is discussed. The user receiver adopts a power split design. The author does not optimize the energy efficiency of the system, but optimizes the information rate and the energy collected by the user at the same time, and obtains the optimal design scheme of transmission resource allocation and power division factor. In [17], the authors also discuss such a communication model. However, the energy efficiency optimization problem of the system is studied, and the design of resource allocation and power division factor in the case of optimal energy efficiency is obtained. These two studies are two characteristics of the SWIPT system combined with NOMA technology in recent years, to optimize the energy efficiency and information rate of the system, and to find the resource allocation scheme and the size of the power splitting factor under the optimal energy efficiency. In recent years, many new solutions have been proposed in the literature around these two topics, but the common disadvantage is the problem of high computational complexity.

3.3. SWIPT energy efficiency combining NOMA and MIMO

The intention of combining MIMO and NOMA with SWIPT is obvious, which is to improve the performance of the SWIPT system, such as energy efficiency, achievable rate, etc., by utilizing the positive effects of MIMO and NOMA on the wireless communication system. A conventional three-in-one system is as follows:

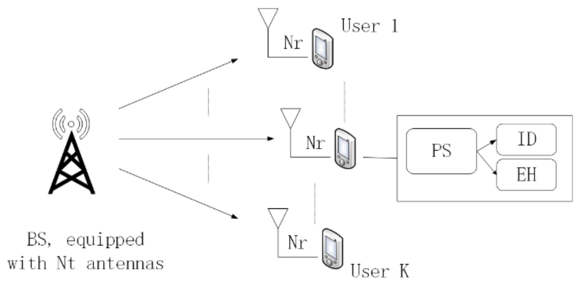

Figure 1: conventional system model

As shown in the figure above, both the transmitter and the receiver are equipped with multiple antennas. User interference is introduced at the transmitter, and the receiver decodes the received mixed signal through SIC to obtain the required signal. In general, the signal received by each user can be expressed as:

$$y_k = h_k \sum_{j=1}^{k} \omega_j \cdot x_j + n_k \tag{2}$$

Through power division, the received signal is divided into two parts, and for the part of the signal decoded by the information, we can get the user's information rate as:

$$R_k = \log_2\left(1+\frac{\rho_k\cdot|h_k\cdot\omega_k|^2}{\delta_k^2+\rho_k\sigma_k^2+\rho_k\sum_{i=k+1}^{k}|h_k\cdot\omega_i|^2}\right) \tag{3}$$

For the power harvesting part of the signal, we can get that the harvested energy is:

$$E_k = \eta\cdot(1-\rho_k)\cdot\left(\sum_{j=1}^{k}\left|h_k\cdot\omega_j\right|^2+\sigma_R^2\right) \tag{4}$$

Then, the overall energy efficiency is:

$$\eta = \frac{R}{P_c-E_k} \tag{5}$$

So now, the problem has become to optimize this energy efficiency and find the encoding matrix and power division factor when η is the largest. For the solution of optimization problems, the current research is various, but basically rely on the following methods: Dinkerbach method[18], semi-definite relaxing (SDR)[19], gradient search, and various other methods of converting non-convex functions to convex functions.

4. Discussion

However, the difficulties of the current research are also obvious. There are many researches on various SWIPT scene models, but some of them are still at a simple level, such as the power loss model of the SWIPT system. For example, [9], [20], [21] and [22] did not give a good model for circuit loss. And even in many works, for the convenience of analysis, the nonlinear loss of the circuit is regarded as linear. Another problem is the innovation of mathematical methods. In the current literature, as long as it is about the performance and efficiency optimization of SWIPT, the processing methods are similar. In the final analysis, the innovation of mathematics has been stagnant. The optimization theory has been developed for so many years, and there are many new theories and new methods every year. However, in the optimization of SWIPT performance, many old methods are still used, and there is indeed a lack of innovation

5. Conclusion

Judging from the current literature, the research on SWIPT has been very rich, and various SWIPT system models have been discussed and verified, which has brought important theoretical support for the development of the communication industry. And combining SWIPT with current advanced communication technologies such as MIMO, NOMA, etc., greatly improves the performance of the SWIPT system. This also has a positive impact on the current development of 5G.

However, as discussed above, there are still some shortcomings in the research of SWIPT. This also requires us to keep close to the actual situation in our research, use the actual communication model to study and discuss the SWIPT system, and at the same time actively follow up the latest developments in mathematics, so as to combine SWIPT research with the latest mathematics theories.

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