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Wireless–Powered NOMA Communications: Opportunities, Challenges, and Future Research Trends

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Abstract

Wireless-powered communication (WPC) is a promising technology to extend the network lifetime for varied important applications like those used hugely in commercial, industrial, transportation, and agriculture sectors. It employs a large number of low-power wireless devices in which the harvested energy from electromagnetic radiations is used for signal processing and transmission instead of the conventional wired-powered sources. Besides, non-orthogonal multiple access (NOMA) has been adopted as a vital approach to fulfill the main objectives of 5G systems and beyond. Significant research activities and advancements have taken place in this direction to support massive connectivity with higher spectral and energy efficiencies over-constrained system resources. In light of the recent developments and key challenges raised by the integrated NOMA-aided WPC networks, this study offers a thorough overview of the existing and suggested state-of-the-art technologies with their features, applications, and practical considerations. Furthermore, some of the key future research trends on this interesting topic are highlighted.

Keywords: Wireless-powered communication; wireless power transfer; radio frequency; wireless networks; NOMA systems.

1. Introduction

The number of connected devices, such as cellphones, personal computers, and household appliances, is anticipated to rise dramatically and globally due to the rapid development of wireless technology. In order to satisfy the primary needs of upcoming wireless networks such as high user-connectivity, ultra-reliability, and inexpensive complexity, numerous communication system designs are examined in the literature [**1].** In particular, one of the most promising radio access techniques for future wireless systems is non-orthogonal multiple access (NOMA). NOMA displays a number of desired potential improvements over the conventional orthogonal multiple access (OMA) such as orthogonal frequency division multiple access (OFDMA), including raised spectrum efficiency, reduced latency with good dependability, and massive user connection **[2].** It can support multiple users simultaneously while using the same resource in terms of frequency, time, and space is the fundamental theory of NOMA. The two primary kinds of NOMA approaches that are now available are power-domain NOMA (PD-NOMA) and code-domain NOMA (CD-NOMA) **[3].** In the former approach and according to the channel conditions, connected users utilize different power levels to facilitate the signal detection based on successive interference cancellation (SIC).

Recent research activities have shown that NOMA can be used in a variety of fifth generation (5G) applications including machine-to-machine (M2M) communications and the Internet of Things (IoT). Additionally, performance of wireless system can be improved when NOMA is combined with other efficient techniques such as beamforming, cooperative communications, multiple-input multiple-output (MIMO), space-time coding, network coding, full-duplex, etc. In particular, MIMO and NOMA schemes are considered as vital parts for modern and future wireless systems due to additional degree of freedom (DoF). Additionally, the integration of MIMO-NOMA schemes can effectively support the massive increase of connected devices and related data traffic over the limited resources **[4]-[6].** Based on the existing evolutions and experiential results, standardization of NOMA has been established for the third generation partnership project (3GPP) and the next-generation American digital television standard (ATSC 3.0) under the names of multi-user superposition transmission (MUST) and layered-division multiplexing **[5].**

The concept of NOMA permits several users to overlap on the same resource which causes interference for such systems. Owing to the increased interference introduced by this new technology, it is necessary to review current resource administration and interference attenuation strategies, particularly for ultra-dense networks. For the same reason, beamforming and the associated issues (such as precoding) in massive-MIMO systems present new difficulties that must be resolved in order to fully utilize these technologies. Existing channel coding, modulation, and estimation-related issues need to be changed from a physical layer standpoint as well [**4], [5].**

Unlike traditional systems, NOMA systems are more appropriate to cognitive, cooperative, and visible light communications paradigms. The difficulties brought on by incorporating this technology must first be overcome in order to enjoy the benefits of these paradigms **[7].** Though NOMA approaches have diverse merits, the high information traffic raises practical security concerns. As a result, security challenges at the physical and application layers must be handled for efficient systems **[8], [9].**

On the other hand, most of the utilized user equipments (UEs) in wireless systems like IoT and sensor networks are battery-powered with constrained energy level and maybe installed on a massive-scale (100s to 1000s) over wide-range regions. To prolong the system's lifetime with effective data gathering, signal processing, and wireless information transfer (WIT), continuous replacement of the consumed UEs' batteries is required. This represents an impractical task with a high maintenance cost, particularly in rural, difficult terrain, and hazardous areas. Thus, energy harvesting (EH) from ambient radio frequency (RF) signals is considered as a promising and sustainable far-field wireless power transfer (WPT) technique for energy-efficient networks of low-powered UEs **[6]-[9].** It employs simple RF to direct current (DC) rectifiers for charging the embedded energy storage units at the UEs. The flexibility of WPT makes the critical target of *charging anytime-anywhere* possible without the need for high investment in the infrastructure **[6], [7].** However, efficient resource allocation must be realized for hybrid WPT and WIT in wireless-powered communication (WPC) systems operating over constrained power and bandwidth resources for 5G and beyond.

In this paper, we provide a detailed survey of the existing and suggested state-of-the-art technologies of integrated WPC systems and NOMA-based WIT techniques with their important features, applications, and practical considerations. Also, the main future research directions on this interesting topic are highlighted.

The rest of this work is organized as follows. Section 2 presents a review on WPC systems. Section 3 provides relevant background on WPT systems. Integrated wireless information and power transfer networks are investigated in Section 4 while the key challenges are studied in Section 5. Future research trends are given in Section 6. Finally, the paper is concluded in Section 7.

2. Wireless-Powered Communication Systems

For communication systems, wireless charging (i.e. WPT) provides power source through electromagnetic energy to an electrical load without the use of wires. Due to its simplicity and improved user experience, this technology attracts a wide range of applications from low-power toothbrushes to high-power electric vehicles **[9].** Today, wireless charging is quickly moving from ideas to practice [**6], [10], [11].** Many top smartphone producers, including Samsung, Apple, and Huawei, started releasing new models in 2014 that included built-in wireless charging. The application of WPT offers several advantages over conventional wire-based charging such as **[8], [9], [11], [12]:**

- It enhances user-friendliness by eliminating the burden of connections. The same charger may be used for different manufactured devices.
- It enables the creation of considerably smaller gadgets without the need for batteries.
- It gives contact-free devices superior product endurance (such as waterproofing and dustproofing).
- It improves versatility particularly for devices where changing batteries or connections are expensive, risky, or impractical (e.g. body implanted sensors).
- It is energy-efficient since it can supply power as needed in an on-demand manner.

Nevertheless, compared to wired-charging, WPT often has greater implementation costs. The regular charging cord must be replaced with a wireless charger and wireless powered-receiver must be implanted. Also, as wireless chargers frequently generate more heat than traditional ones, additional costs for manufacturing supplies may be incurred **[13].**

Radiative wireless charging (also known as RF-based WPT) and non-radiative wireless charging are the two main ways in which WPT technologies are moving. Radiative wireless charging uses electromagnetic waves, most often RF signals for energy transfer. This technology typically functions in a low power zone because of the safety concerns owing to RF exposure **[5].** For instance, RF radiation is only appropriate for sensor networks with power consumption up to 10mW **[14], [15].**

As an alternative approach, non-radiative wireless charging relies on the magnetic field between two coupled coils. The power transmission distance is significantly constrained since the electromagnetic field attenuates more quickly than the electric field. Non-radiative wireless charging has by far been more prevalent in our everyday items due to safety implementation like toothbrushes and electric car chargers **[16].**

2.1 Non-Orthogonal Multiple Access (NOMA)

To mitigate the impact of co-channel interference, traditional OMA schemes such as time division multiple access (TDMA), code division multiple access (CDMA), space division multiple access (SDMA), and OFDMA divide available resources among users. These approaches, however, are not capable to meet the enormous capacity demands of next-generation networks. As a result, NOMA is included in the Long Term Evolution (LTE) standards for 4.5G and 5G systems in order to meet the crucial requirements of high connectivity and spectrum efficiency [1]. NOMA has been used in mmWave massive MIMO to increase the number of supported users and achieve improved spectrum efficiency **[15], [17].** It has been shown that NOMA is more effective than OMA in terms of power efficiency and spectrum utilization. For instance, a combined three-dimensional trajectory and power optimization is suggested in **[14]** to increase the users' downlink rates for mmWave MIMO that supports unmanned aerial vehicles.

Communications enthusiasts considered hybrid packet optimization technology using NOMA and Intelligent Reflective Surface (IRS) technology with the aim of maximizing the aggregate rate for users. It has been shown that IRS-aided NOMA may improve the performance compared with achieve higher overall system rating than an IRS-aided OMA schemes. In **[16],** the authors explored the issue of energy efficiency (EE), and the results showed that IRS-aided NOMA can achieve greater EE than IRS-aided OMA. In **[17],** an ideal user pairing technique has been proposed to increase the downlink rate of 2-user NOMA. Based on beamforming, NOMA supports multiple users through superposition coding at transmitter and SIC at the receiver [18]. The number of users would not be constrained by the number of beams in this way. In particular, an iterative power optimization approach is given in [10] to improve the sum rate. To increase the sum rate, a beam selection technique has been considered in [19]. The two primary kinds of NOMA approaches can be given as:

PD-NOMA: To reduce inter-channel interference, the supported users in PD-NOMA are assigned distinct power levels based on their channel conditions. By utilizing the natural variance of channel gains, the near-far effect is used to achieve improved spectral efficiency. The receiver can employ SIC approach to separate the signals of distinct users. In this instance, the strongest user will be recognized first, and its contribution to the received overlaid signal will be deleted, followed by the other users being discovered in order of their power levels **[1], [4].**

CD-NOMA: Instead of the usual orthogonal spreading sequences used in CDMA systems, non-orthogonal spreading sequences are used in CD-NOMA for the served customers. The message passing algorithm (MPA) can be utilized for multiuser detection (MUD) at the receiver for the majority of CD-NOMA systems. There are numerous CD-NOMA schemes available today, including low-density spreading CDMA (LDS-CDMA), low-density spreading OFDM (LDS-OFDM), sparse-code MA (SCMA), and multiuser shared access (MUSA) **[1], [3].**

2.2 Multiple-Input Multiple-Output (MIMO)

Wireless and mobile systems are gaining popularity around the world and are having a significant impact on modern life. Therefore, effective spectrum use is necessary to satisfy the growing number of customers' cellular service expectations. Spatial multiplexing MIMO is widely recognized as a crucial technology for faster data rates without using more bandwidth or transmit power. As a result, it is considered as a key enabler for 5G and beyond to achieve gigabit communications **[20].**

Massive MIMO and mmWave technology are seen as promising combination for expanding the spectrum coverage and meeting the demand for growing data traffic. However, using enormous antennas in a mmWave massive MIMO results in extremely high energy consumption and hardware costs since the number of RF chains needed is equivalent to the number of antennas. The RF chains are expensive and power-hungry at mmWave frequency [15]. The beam-space MIMO has emerged as a promising remedy to address this issue. The mmWave space channel may be transformed into its sparse beam-space channel by taking advantage of the lens antenna array (LAA). Based on this, it is possible to choose a part of power-focused beams such that the number of necessary RF chains is drastically decreased. Despite its benefits, the traditional beam-space MIMO can only serve one user per beam at the same radio resource **[15], [16].** Accordingly, the number of supported users is limited by the number of accessible beams **[9], [10].**

3. Wireless Power Transfer Technology

The UEs in various wireless applications, such as IoT, sensor networks, and biomedical implants, are primarily battery-powered with limited energy and can be spread over large geographic areas. This necessitates a regular replacement of the consumed UEs' batteries in order to prolong the network lifetime. In rural and dangerous places, this will be unfeasible with significant maintenance cost. In this context, EH from RF signals is viewed as a viable and long-term method of far-field WPT **[21], [22]** without need for additional infrastructure investment **[23].**

For insightful vision, consider a basic wireless-powered NOMA (WP-NOMA) network of K single-antenna UEs communicating with a common BS over the same time-frequency channel as shown in Fig. 1. Harvest-then-transmit strategy is adopted for each time frame of duration T which is divided between the downlink and uplink into two phases through controlled time-split parameter $0 < \alpha < 1$. In the first phase for energy transmission (ET), a fraction αT is used in the downlink by the BS to broadcast wireless power P_S to the UEs. The remaining portion of time frame $(1-\alpha)T$ is assigned for the second phase to allow uplink data transmission (DT) from UEs with total received power constraint P_t. In this case, the UEs utilizes their harvested energy for concurrent DT in through PD- NOMA with power control parameters $0 < (\beta_k; \forall k) < 1$ where $\sum_{k=1}^{K} \beta_k = 1$.

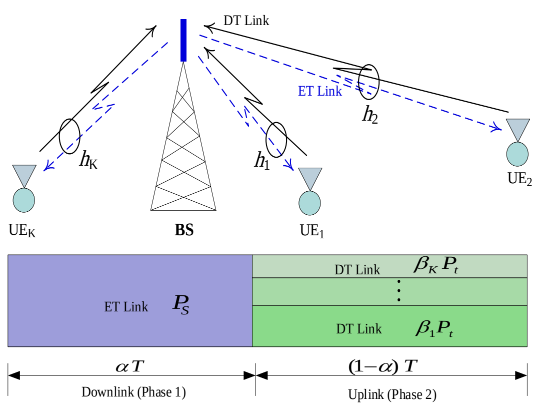

Fig.1 System model for a basic WP-NOMA network.

For the entire time frame T of ET and DT links, the users' fading channels $\{h_k\}_{k=1}^{K}$ are assumed to be constant and known at the BS. The channel of UE_k is given as

$$h_k = \sqrt{\mathcal{L}_k} g_k \tag{1}$$

where g_k stands for the Rayleigh fading coefficient with zero-mean unit-variance and assumed to be fixed over T, and $\mathcal{L}_k = d_k^{-\vartheta}$ represents the path loss of UE_k based on the distance d_k from the BS and path loss exponent ϑ of considered wireless environment.

The aggregate EH by UE_k can be found as

$$E_k = \mathcal{G}_S \mathcal{G}_k \eta_k \zeta_k \mathcal{L}_k |g_k|^2 P_s(\alpha T) \tag{2}$$

where $\mathcal{G}_S$ and $\mathcal{G}_k$ are the directional antenna gains of the BS and UE_k, respectively, and $0 < \eta_k < 1$ is the EH efficiency of UE_k with ζ_k conversion factor.

The received signal at the BS during DT phase can be found as

$$r = \sum_{k=1}^{K} h_k v_k + n \tag{3}$$

where v_k is the transmitted signal of UE_k with average power p_k, and n represents the i.i.d complex AWGN of zero-mean and variance σ_n^2.

Based on the capacity of multiuser uplink channel [4], the achievable sum rate can be given for fixed channel realization as

$$R_{sum} = (1-\alpha)T \log_2\left(1 + \gamma \sum_{k=1}^{K} \frac{\beta_k |h_k|^2}{\mathcal{L}_k}\right) \tag{4}$$

where $\gamma = P_t/\sigma_n^2$ is the average SNR at the BS.

For SIC with fixed decoding from UE_1 to UE_K, the rate of $\mathrm{UE}_k; k = 1, \dots, K-1$ is given by

$$R_k = (1-\alpha)T \log_2\left(1 + \frac{\gamma \beta_k |h_k|^2/\mathcal{L}_k}{1 + \gamma \sum_{i=k+1}^{K} \beta_i |h_i|^2/\mathcal{L}_i}\right) \tag{5}$$

The rate of UE_K at the last stage of SIC without interference can be found as

$$R_K = (1-\alpha)T \log_2\left(1 + \gamma \frac{\beta_K |h_K|^2}{\mathcal{L}_K}\right). \tag{6}$$

For $K = 2$ WP-NOMA system, Figs. 2 and 3 demonstrate the capacity (user rate and sum rate in bit/s/Hz) and EH (in Joule) as a function of time-split parameter α, respectively. The considered parameters are: $P_S = 10$; $P_t = 2$; $\mathcal{G}_S = 1$; $\mathcal{G}_k \eta_k \zeta_k = 1; \forall k$; $T = 1$; $\vartheta = 3.8$; $\gamma = 20$ dB; $\beta_1 = 0.8$; $\beta_2 = 0.2$; $d_1 = 20$ m; and $d_2 = 40$ m. As can be seen, the rate capacity is decreased as α increases in contrast to the EH by users. Besides, the tradeoff between the rate and EH can be compromised based on α and desired performance as shown in Table 1.

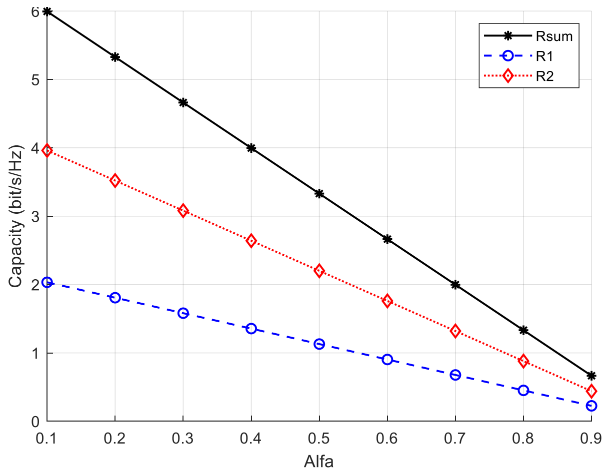

Fig. 2 The rate capacity (bit/s/Hz) as a function of α

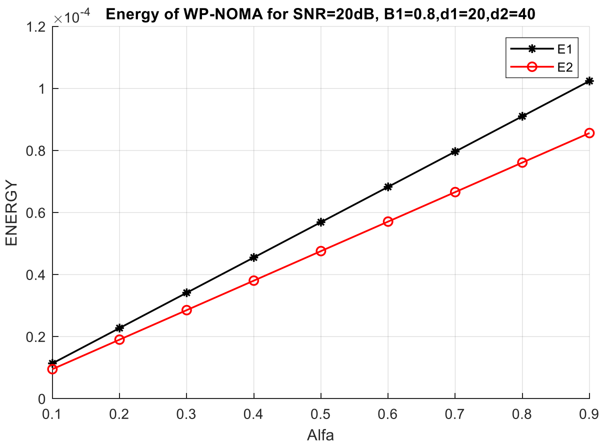

Fig. 3 The energy harvested (Joule) as a function of α

Table 1 Summary of the rate and energy harvested results based on time-split parameter α from Figs. 2 and 3

α	Rate (bit/s/Hz)			Energy (Micro Joule)	
	Sum Rate	R_1	R_2	E_1	E_2
0.2	5.3	1.8	3.5	0.22	0.19
0.5	3.3	1.1	2.2	0.56	0.47
0.8	1.2	0.4	0.8	0.91	0.76

3.1 Energy Harvesting

The incompatibility between energy and data flow may reduce the achieved communication performance if the data bundles also arrive to the buffers at random. For instance, if a battery receives excessive energy but there are no data bundles waiting to be relayed from the data-buffer, the amount of energy garnered may be greater than the capacity of the battery, resulting in energy waste [24]-[27]. In order to achieve a balance amidst the energy flowing and the data bundles flowing in the time-domain, it is essential to simultaneously schedule the energy and data queues [28].

In multi-user systems, user devices with low data loads and adequate energy are permitted to share their extra energy with peers who have high data traffics but scarce energy [21]. To provide energy for communication infrastructure, hybrid sources that rely on both renewable energy and the traditional power grid may be used [29]. But, the electrical grid is needed also to cut maintenance expenses. In this context, the RF transmissions from TV turrets, radio broadcast terminals, cellular base stations, and others are covering the spectrum from 300 MHz to 300 GHz. These RF waves are a rich of energy that may be used to power communication terminals [30]-[32].

3.2 Near-Field WPT Scheme

Elastic wireless charging (WPT) alternatives for electronic devices include resonant inductive coupling and magnetic resonance coupling [33]. Resonant inductive coupling-based wireless charging is based on the magnetic coupling that moves electrical energy between two coils tuned to resonate at the same frequency. Using this method, a number of small electronic devices, including smart watches, electric toothbrushes, and mobile phones, have already been commercialized. The coupling coils, however, can only transmit power wirelessly across short distances of a few millimeters to a few centimeters with efficiency of up to 56.7% at 508 kHz [34]-[37].

3.3 RF-Based WPT

The propagation of the RF waves can facilitate far-field WPT in opposition to near-field methods [38]. The first long-distance WPT experiments were performed in 1960 [42]. DC power may be effectively converted from microwaves using rectennas devices. Extensive research efforts were made into the RF-based WPT [39]-[45]. The RF-based WPT faces three key difficulties. First, long-distance multipath fading may significantly reduce the RF signal power causing energy loss. Second, because RF signals carry alternating-current (AC) energy, it cannot be used directly to drive an electronic load without AC-DC conversion. However, this conversion comes at cost of power loss [46], [47].

The RF-based WPT provides the following benefits over near-field WPT techniques:

- Wide coverage area. Power may be sent to receivers kilometers distant by relying on RF waves.
- Extreme adaptability. The transmit beam may be intelligently changed to charge several devices across a large region, whereas a small beam can be used to provide precise point-to-point energy transmission.
- More submissions. It is possible to use RF signals to channel a lot of energy to energy-hungry devices.
- Little infrastructure investment. RF transmitters have been set up in different places which can be used to send energy to electrical appliances.

4. Integrated Wireless Information and Power Transfer Networks

The RF signals have the ability to transmit energy across long distances, bringing us one step closer to our ultimate objective of on-the-go charging [22]. However, RF-based WPT may harm WIT when utilized in the same spectrum. Thus, for simultaneous wireless information and power transfer (SWIPT), which develops into integrated wireless data and power network (IDPN), it is imperative to coordinate and balance WPT and WIT. For multiuser WPC networks, the integration of WPT and WIT methods has been examined while taking into account various time-splitting and/or power-splitting (control) strategies [6], [34]. The authors in [22] provide a thorough evaluation to this significant research issue. The viability of outfitting the BS with MIMO antennas for effective WPT has been studied in [34] and [44]. For a specific performance target, it displays an expanded WPT range.

4.1 WPT and WIT Technologies

The optimal spectrum for steering energy beams is in the region of 10 MHz to 100 GHz, which almost encompasses all the bands of wireless services. RF-based WPT requires great flexibility in terms of beam tendency to serve various charging requirements. For example, WiFi runs between 2.4 and 6 GHz [49], LTE cellular system operates between 800 and 3.7 GHz [48], and TV/Radio broadcasting operate in the region between 40 and 220 MHz [50]. Additionally, the mmWave band, between 10 and 100 GHz, offers an important option for indoor and outdoor applications [51]. The following set WPT and WIT apart when utilized in the same RF band:

- Different functional units are present Pass-band RF waves cannot be straight used for EH or DT. Since all signal processing must be done in base-band, the pass-band signals must be transformed for DT. In contrast, since only DC can be stored or used in electronic devices, the AC energy taken by pass-band signals must be transformed to DC for EH.
- At the receivers, they demand various absolute RF powers [52], [53]. For instance, Pletcher *et al.* [54], [55] have created a receiver with sensitivity of 72 dBm for wireless sensors. A binary-frequency-shift-keying receiver of 76 dBm sensitivity has been developed for 6 Mb/s transmission rate and 90 dBm for 500 Kb/s has been developed in [56] for high rate. As a result, there is a sensitivity of more than 50 dB between the EH and the information receiver.
- They go varying distances. The path-loss, shadowing, and multipath fading channels reduce the RF signals. Power may be sent over shorter distances than information because effective WPT demands a larger absolute power at the receivers than WIT.
- They approach noise and interference differently. Every WIT system has interference and noise, which substantially reduces the achieved WIT performance.
- For WIT system design, minimizing the performance deterioration brought on by both interference and noise becomes a significant task. In contrast, since they are RF signals and both convey valuable energy, interference and noise are desired in WPT systems.

- They apply different energy efficiency theories. The energy efficiency of WIT may be stated in bit/s/Hz using Shannon-Hartley theorem in AWGN channel as follows [22]

$$\eta_{\text{WIT}} = \frac{1}{P_t} \log_2 \left(1 + \frac{P_r}{P_I + P_N}\right) \quad (7)$$

where P_N is the power of the noise at the receiver, P_t is the transmit power of the RF signal, P_r is the power received after the signal has been attenuated by the hostile wireless channel. Contrarily, the energy efficiency of WPT in bps/Hz/Watt or bps/Hz/Joule is the ratio of energy gathered by the receiver to energy produced by the transmitter, which is denoted by [22]

$$\eta_{\text{WPT}} = \frac{1}{P_t} \rho(P_r + P_I + P_N) \quad (8)$$

where ρ is the rate at which incoming AC energy is converted to DC energy.

Operating in the same spectrum band, WPT and WIT may hinder one another's performance. For instance, WPT mandates that the UEs to receive high power RF signals. However, this will affects the WIT receivers leading to performance degradation. Thus, designing of RF circuits, resource scheduling and allocation algorithms, and medium access-control (MAC) protocols are essential. A unified networking concept for heterogeneous data and energy transceivers is also necessary. Innovative IDPNs are needed to address all of these complex problems [57].

4.2 Towards Integrated WPT and WIT

As shown by the outer shell of Fig. 4, several enabling techniques from the wireless communications and electrical engineering systems may be used to effectively coordinate WPT and WIT in the same spectrum. The following provides further clarifications:

- NOMA has higher bandwidth efficiency than OMA. Although the overlaid RF signals for various UEs could make receivers quite complex, merging RF signals in a constructive (non-orthogonal) way might help concentrate the energy and improve the efficiency of WPT. However, accurate estimation of the communication channel is needed.
- The receive antennas and the RF-DC converters must have an exact Impedance Matching Network to reduce the energy leakage.
- Interference management in the case of many transmitter and receiver pairs is important. The performance limitations of data transmission under the restriction of output signals carrying enough energy to be gathered by the receiver may be investigated due to critical impact.
- In [50], the authors have suggested joint source and channel coding approach for managing integrated WPT and WIT. Because the original messages are converted into codewords of different energy levels, joint source and channel encoders may be able to govern the energy transfer process effectively.
- To enable IDPN, information data may also be modulated onto DC signals using pulse amplitude, width, and position modulation techniques. These are used in optical communications to minimize the hardware complexity [49]. As a result, the pass-band to base-band converter can be replaced by the RF-DC energy converter at the cost of lower rates.
- IDPN is possible by multi-functional MIMO owing to their multiplexing and diversity merits [41]. These systems can easily coordinate WPT and WIT in different spatial domains, and the diversity gain is capable of lowering the error rate while concurrently increasing the energy transferred to the receivers.
- Signal splitters (time switcher and power splitter) are vital components in receiver designs for integrated WPT and WIT. They can divide the RF signals into two parts for energy and information transfer.
- For WPT and the integrated WPT and WIT, beam forming is important to avoid energy loss. Analog and digital beam forming are the two main methods for creating a directed beam.

The effective design of integrated WPT and WIT requires knowledge of a variety of contextual information types, including the unique activities of the appliances, position data, battery extents, energy consumptions, and channel coefficients. The summary of the general optimal design rules to be followed for harmonizing WPT and WIT in the similar spectral band may be found in the inner shell of Fig. 4.

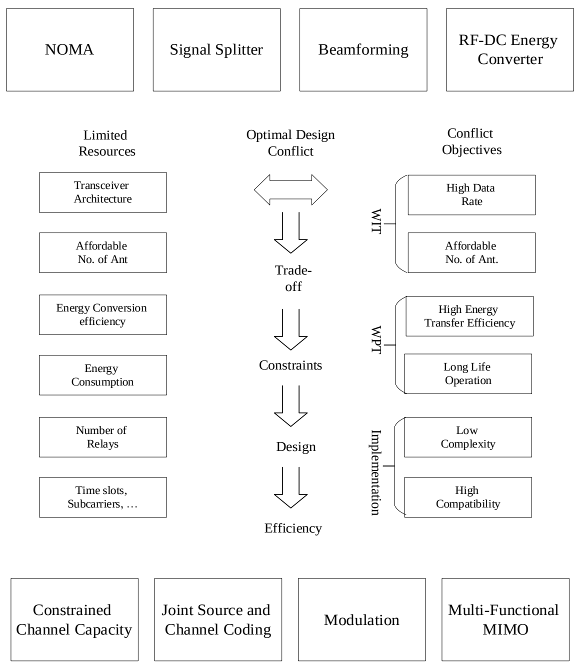

Fig. 4 The most effective design ideas for combined WPT and WIT at the same RF spectrum

The basic tension between finite resources and unbounded quality of service (QoS) criteria must be resolved in the design of combined WPT and WIT. For instance, the hardware design of IDPN restricts their functionality. Finite number of antennas will impact the diversity and multiplexing gains. Imperfect transceiver electronics may cause energy leakage and inefficient conversion. While limited resources are available, IDPN requires unbounded QoS targets. In particular, WIT is required to achieve high data rates with low delay, but WPT strives to achieve high energy transfer.

4.3 SWIPT Technology

The potential for combining WPT with communication networks raises the need for technologies that can send information and power to the end devices concurrently. The idea of SWIPT was initially presented from a theoretical standpoint can be of essential significance for energy and information transfer inside a variety of new wireless applications. It is possible that RF waves may combine their power and information transmission functions to serve as SWIPT approach. This can reduce power consumption, improve spectrum efficiency, regulate interference, and reduce transmission delay. A thoughtful design that takes into consideration both information and power can result in wireless communication that is notable for its energy efficiency and might pave the way for cutting-edge services and applications for 5G and the next generation of sustainable societies [33].

5. Key Challenges

5.1 NOMA Challenges

The implementation complexity of NOMA schemes in terms of UEs pairing, SIC decoding of possible delay and error propagation, and CSI acquisition are among the main difficulties. This is especially true in dense networks where the system's complexity rises sharply with the number of UEs [1], [4].

5.2 MIMO Challenges

To fulfill the high spectrum efficiency needs of 5G and beyond, MIMO is one of the primary strategies that employed with NOMA. For single input instances, it is simple to calculate the channel conditions of each user, which determine the power allocation in PD-NOMA. However, the channel gains of MIMO are in a matrix form, making the power allocation highly difficult [1].

5.3 SWIPT Challenges

There can be a considerable retard in terms of bodily response and memory processes when exposed to RF radiation [31]. Furthermore, prolonged exposure to RF radiations might result in significant tissue heating [32]. The scientific community must thus, with the aid of government organizations, obtain a deeper knowledge of the possible health and safety effects related to the use of SWIPT in generic settings. One of the main issues with RF-based EH is transmission distance [34]. The receive antenna s have a significant impact on the RF-EH rate. As a result, creating high gain antenna that can handle a variety of frequencies is another crucial study area.

Due to the development of communication technology, RF-EH modules must be compact to be embedded into low-power devices. Nevertheless, it is difficult to scale back the RF-EH module without sacrificing the high EH efficiency. Compared to the receiver used in RF-EH, an information receiver has a higher sensitivity and thus some communication scenarios cannot be handled by the SWIPT system. The power limitations of RF powered devices make it challenging to implement algorithms with high processing requirements. Therefore, a rethink of modulation methods, channel coding, routing protocols, and receiver running principles is needed.

5.4 WP-NOMA Challenges

Future wireless networks are predicted to need a large amount of energy. Hence numerous ideas have been put up to build self-sustainable communication systems. The integration of WP-NOMA makes it possible for wireless devices to proactively refill their energy, and it evolves into a promising solution to power wireless networks that are energy-constrained. Due to the high computational demands of intelligent processing, the next generation devices will be more power-hungry. However, WPT has a narrow transmission range [1]. The highest energy efficiency in the distant field is often not more than 50%. As a result, further research is required in the far-field region to boost energy transmission efficiency and directivity in different communication technologies.

Additionally, destructive interference may be viewed as a useful energy source in the context of WP-NOMA. In this instance, a thorough investigation is necessary to determine how to decrease interference while also smoothing energy transmission, which may be in conflict. Due to their time-varying nature, WP-NOMA systems should also take the impact of mobility into account when allocating resources. This requires dynamic and adaptive resource allocation. Due to safety concerns over the use of high-frequency broadcasts, more thorough examinations into the influence on health are also required. In particular, thorough research is wanted to evaluate the integrity of terahertz radiation. The necessity for energy harvesting and power transmission components to be tiny sufficient to be incorporated in low-power devices makes circuit design another practical problem [34].

6. Future Directions

6.1 Security Issues

The primary driving forces behind wireless network research and development are security, dependability, and throughput. In typical wireless systems, these issues are ensured by distinct procedures, which is possibly inefficient because of the interconnected situation [58]. By increasing the sources transmit power, the reliability and throughput of the major link can be increased. However, this will raises the capacity of the wiretap channel and increases the chance that the eavesdropper will be successful in intercepting the source message. To maintain safe, dependable, and high-rate communications, it is required to look at the combined optimization of security, dependability, and throughput.

6.2 Underwater Wireless-Powered Sensor Networks

Sensor network holds the potential to revolutionize many fields of science, home automation, business, and even government. Underwater wireless sensor networks (UWSN) is developing into a technology that makes underwater applications and expeditions possible. While terrestrial and UWSN have many similarities, they also differ significantly in many ways. Therefore, these variations need for specific new underwater protocols and methodologies. The power consumption is higher for underwater than terrestrial networks [59].

The networking protocols for UWSNs are distinct from wired and wireless networks due to the major variances in acoustic channels, electromagnetic waves, and optical waves. UWSN has a variety of dynamic properties, including issues with high power consumption, taller propagation delays, mobility brought on by floating nodes, and synchronization issues. Several features that set them apart from terrestrial sensor networks are given below:

- It uses acoustic signals for communications since the radio waves are ineffective underwater.
- The strength of signals fluctuates in UWSN due to the use of acoustic communication.
- The sensor nodes in UWSN are most prone to failure due to fouling and erosion.
- The performance of UWSN is restricted by limited battery power source.

Conclusion

In this paper, a thorough survey on WIT, WPT, integrated WP-NOMA, and related developing technologies for 5G and beyond systems have been provided. Besides, the important features, practical applications, and promising designs of these schemes are extensively clarified and discussed. Then, the key future directions on this interesting topic are highlighted to facilitate the research activities in both academic and industrial societies

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