Study of Simultaneous Wireless Information and Power Transfer (SWIPT) in 5G - IoT

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Abstract – The SWIPT technology, recognized as a wireless energy harvesting technique imbued with the prodigious potential to steer the advancement of subsequent generations of wireless systems, namely 5G and its successors. The Internet of Things is anticipated to enhance the life of human quality, including the ability to connect disparate objects, providing information and control functionalities across a myriad of spatial and temporal contexts. IoT devices are confronted with energy limitations stemming from available resource constraints. In recent years, SWIPT-based radio frequency will be regarded as a promising energy harvesting technique. It is very likely that there will be an increase in the number of devices connected to networks and applications in the near future, which will increase the demand for next-generation wireless communications, which will result in an increase in energy consumption. As a consequence, energy harvesting and data transmission are necessary for the energy-efficient communication of new wireless generations such as 5G transmission and beyond. Therefore, green communications based on SWIPT techniques are expected to become an essential component of both 5G and 5G+. SWIPT systems conventionally utilize ambient signals for both information transfer and energy supply. As such, the present dissertation endeavours to scrutinize SWIPT communication with the aim of engendering enhanced comprehension of the system's operation and performance.

This paper reviews two levels of literature on multiuser SWIPT communications for 5G. First, SWIPT enabled the selective OFDM model. Second, SWIPT-enabled mm-wave propagation was reviewed for the system characterized for 5G IoT devices.

Keywords: IoT, SWIPT, 5G, OFDM, mm-wave.

1. Introduction

There is a significant influx of interest with regard to the incorporation of energy-harvesting technologies in communication networks. Numerous investigations have delved into the realm of traditional renewable energy sources, including solar and wind energy, among others. Researchers have also analysed the most effective methods for allocating resources in varying functions and topologies, as evidenced by scholarly literature [9]. In contexts that prioritize ensuring high levels of service quality (QoS), the process of energy harvesting plays a pivotal role. The aforementioned phenomenon can be attributed to the irregular and unforeseeable character of said technology when utilized in tandem with conventional harvesting techniques that demonstrate occasional practicability solely within particular contexts. Wireless power transfer (WPT) embodies an energy-gathering mechanism that successfully bypasses the previously mentioned limitations by allowing nodes to recharge through the utilization of electromagnetic radiation. The deliberate retrieval of sustainable energy in wireless power transfer (WPT) can be realized by either utilizing surrounding signals or employing a specific energy reservoir. In the context of energy transfer, the aforementioned scenario may transpire in instances where the transfer of green energy is facilitated by nodes of greater capacity, such as those possessing greater power. Base stations have the ability to harness conventional forms of renewable energy [9].

The utilization of radio frequency (RF) signals as an energy source has become increasingly popular among consumers seeking long-lasting electronic devices that require minimal recharging. RF signals have been conventionally utilized for conveying information, and therefore, have the potential to be utilized for wireless power transfer (WPT) with efficacy. Moreover, due to the fact that radio frequency (RF) signals possess the ability to transmit both energy and information, considerable research efforts have been directed toward exploring the phenomenon of SWIPT [3]. Thus SWIPT facilitates inter-device communication and ensures a continuous source of energy. By virtue of minor electrical augmentations, the recipient mechanism achieves proficiency in not only deciphering the data propagated by the radio frequency (RF) wave but also acquiring and converting energy from the very same signal. The system exhibits self-sustainability, although its performance remains subject to the constraint imposed by the available receiver power. The augmentation of the energy collected by the receiver is contingent upon the thorough examination of the system and the characterization of the SWIPT system. This, in turn, will facilitate the development of wireless technologies and harvesting mechanisms that can attain genuine self-sufficiency. SWIPT offers several advantages, including enhanced spectral efficiency, reduced time delay, decreased energy consumption, and improved interference management. These benefits are derived from the concurrent transmission of information and power, which is facilitated through the process of superposition. The SWIPT technology is comprised of multiple ultra-low power sensors that are equipped to facilitate a diverse range of sensing applications. This technology possesses the noteworthy potential to become a crucial element in the contemporary epoch of the Internet of Things. The implementation of cellular systems featuring small cells, substantial MIMO antenna configurations, and millimeter wave technologies posits a promising solution to mitigate the impact of the current path-loss phenomenon. This assertion is supported by the literature [3]. Potential high-throughput and energy-efficient outcomes may be attained by incorporating SWIPT as a collaborative solution.

The deployment of SWIPT towards 5G mobile networks has the efficiency to significantly prolong the operational lifespan of wireless devices exhibiting high transmission rates, obviating the recurring need to search for electrical outlets or consistently carry portable power pack devices in all locations and circumstances. Consequently, wireless devices of diverse types are expected to become more compact and lighter in weight, primarily due to the anticipated reduction in the size of the battery units incorporated within them. SWIPT technology is indispensable to the 5G mobile networks. Owing to the notable attributes of high path loss and propagation of narrow beam width in the mmWave band, there exists a promising future of mmWave communication in the context of 5G-supported SWIPT-enabled mobile devices. In the interim, an investigation into the potential advancement of OFDM-based 5G SWIPT transmission is forthcoming. In essence, the core objective of this article is to furnish a meticulous overview of the ongoing research in SWIPT concerning the 5G mobile networks, particularly the networks encompassing SWIPT technology.

2. SWIPT- Overview

In this section, basic SWIPT transmission architecture, three SWIPT designs and conversion energy, RF signal resource allocation and R-E trade-off.

2.1 Basic SWIPT Transmission

As we disused early, In the current technological landscape, it is apparent that there are three distinct transmission modes including Wireless Information Transfer, Wireless Energy Transfer, and Simultaneous Wireless Information and Power Transfer. The prevailing framework exhibits similarities to the traditional wireless communication system that comprises a singular base station and numerous mobile stations or devices. RF signal sources impart both information and energy to the nearer base station, which will be outfitted with arrays of antennas. The multifunctional stations randomly transition to a mode of communication with the dual purpose of acquiring energy and information. Information data and source energy can be transmitted bidirectional between smart devices through device-to-device (D2D) communication, which represents a fundamental aspect of the Internet of Things (IoT).

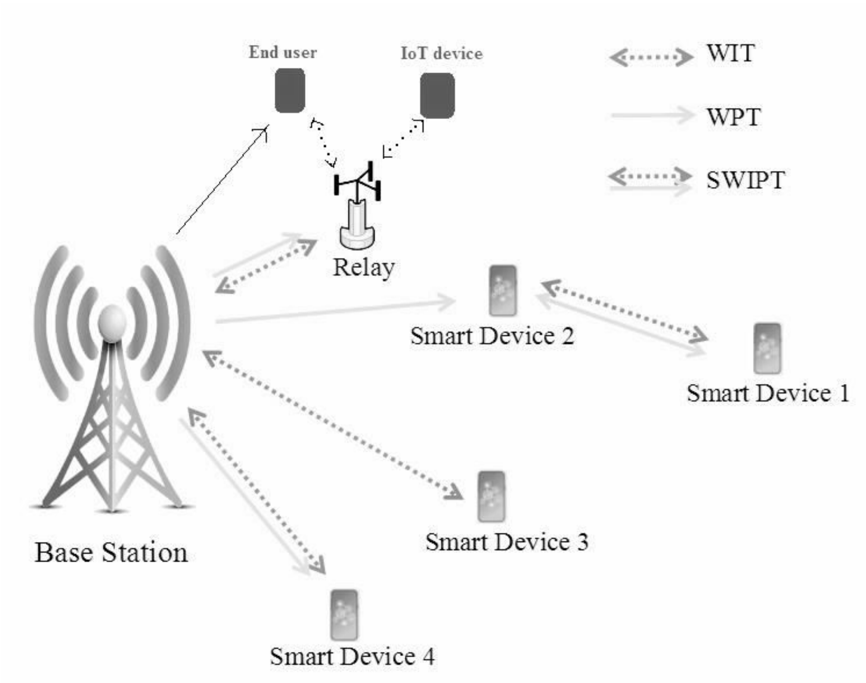


Fig.1. Transmission structure of SWIPT

The conclusion objective of SWIPT innovation is to permit the recipient to draw its working vitality from the transmitted flag itself. In [2], three SWIPT framework plans were displayed in Fig. 1.2 for reference. Fig. 1.2(a) presents a structured and coordinated SWIPT framework design, which comprises a co-collector implementation at the receiving device, aimed at facilitating both energy harvesting and information decoding processes. The proposed SWIPT scheme entails the simultaneous reception of both data and energy from a singular transmitted signal. Fig 1.2(b) details a closed-loop strategy whereby the receiving device acquires power or energy through a transmitted signal while concurrently transmitting data to the transmitting device. In this framework arrangement, both the transmitting and getting gadget take part in downlink/uplink or close-loop flag proliferation. Fig. 1.2 (c) outlines the SWIPT framework which presents a control guide devoted to exchange control for energy gathering by the getting gadget. Whereas the accepting gadget is collecting, it is at the same time interpreting the data from an ordinarily gotten flag [1].

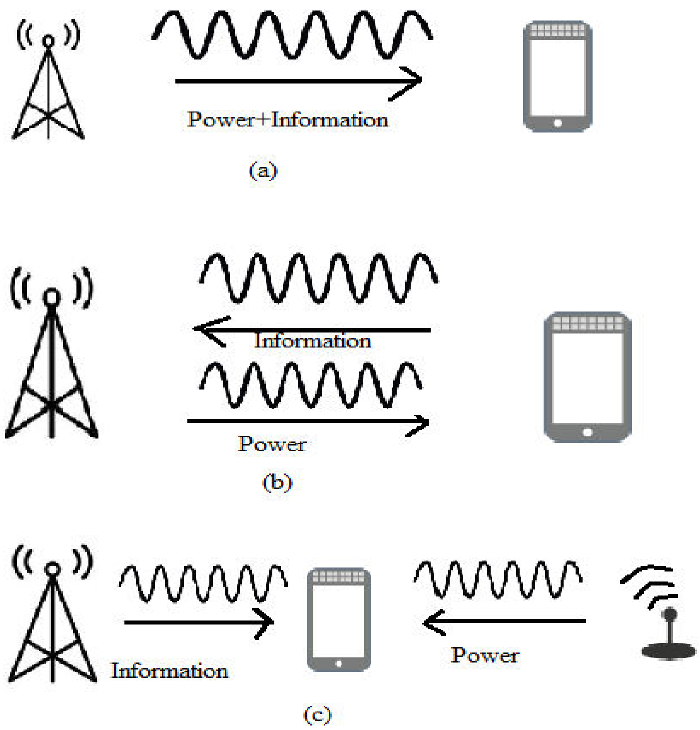


Fig.2. SWIPT System Configurations. [8]
Fig. 2(a) shows an integrated SWIPT system.
Fig. 2(b) shows closed-loop SWIPT system.
Fig. 2(c) shows decoupled SWIPT system.

2.2 Conversion energy

SWIPT transmission by and large involves get-to-point communication with different clients, an expansion of SWIPT transmission in multiuser communication is normally considered. As outlined in Fig. 3, multiuser communication incorporates the transmission from a get-to-point (AP) to K UEs. In [5], to get it multiuser transmission, centers on collector assignment for either energy gathering or information translating. As such, the AP was taking part in downlink communication with an assigned UE which at the same time performed control exchange to the remaining UEs within the multiuser environment. Work in [4] centered on a multiuser SWIPT transmission plot which gave both information translating and energy collecting at each recipient.

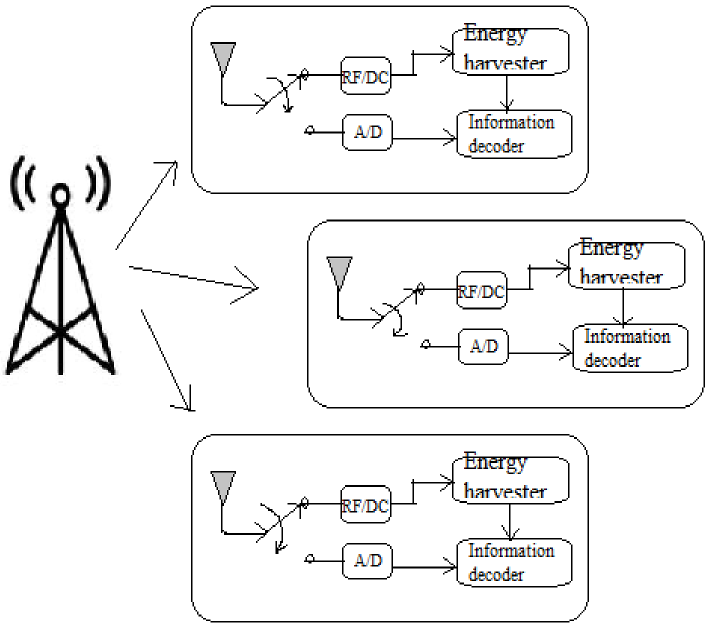


Fig.3. Single access point communicating

2.3 Resource Allocation of RF signal

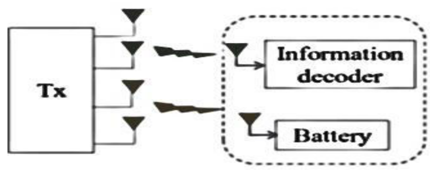
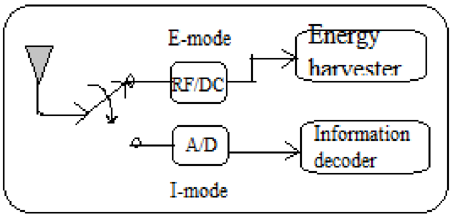
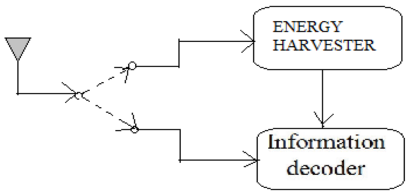
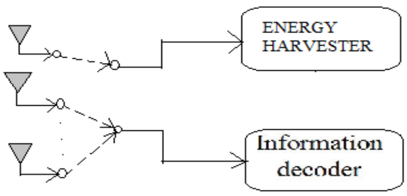
This subsection deliberates on five customary structures employed for allocating resources. A significant number of researchers prioritize the exploration of disparate allocation strategies within the context of antenna design, while a subset of antenna designers evince particular interest in the development of novel antenna structures.

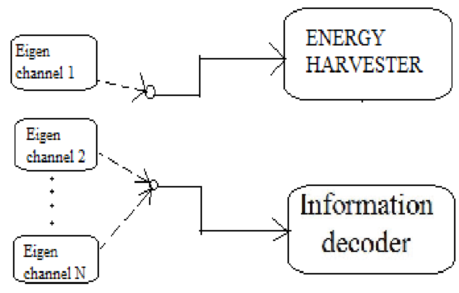
- ❖ Antenna separated:
  At the transmission stage, multiple antennas are installed in order to implement transmission infrastructure. The paper designated as [6] presents a dual-band antenna configuration devised to facilitate the transmission of mmWavesignal utilizing two distinct frequencies. According to scholarly sources, high frequency is conventionally employed in the transfer of power, whereas low frequency has been primarily associated with the transfer of information [9]. Consistently, the identical dual band antenna may be installed on the terminal end of the equipment.
- ❖ Time Switching: A co-receiver arrangement with a TS procedure in which, for a given time period the RF flag is completely utilized for energy harvesting or information decoding [3].
- ❖ Power-Switching (PS): The present study employs a comparable approach; however, the RF signal that is obtained is bifurcated into two separate streams with

distinct power levels. The power levels may be delineated through the implementation of a power splitting factor α, which is utilized to determine the manner in which the signal will be distributed.

- ❖ Antenna-switching: The employment of antenna(s) involves the flexible deployment of one or multiple collections of antennas in a dynamic manner for the purpose of energy harvesting, while the remaining antennas are allocated for communication.
- ❖ Spatial Switching (SS): The phenomenon of spatial domain switching is observed in a configuration where the channel is decomposed into parallel channels, each capable of transmitting either decoding information or energy for harvesting.

Table I presents a summary of various RF resource allocation structures.

Transmitter	Antenna separated	
Receiver	Time Switching	
	Power Switching	
	Antenna Switching	

	Spatial Switching	

2.4 R-E trade-off

Within the context of SWIPT systems, a critical and routine predicament concerns the allocation strategies employed for the RF signal resource, with particular attention paid to the trade-off between radio frequency (RF) energy and communication rate (R-E) [7].In order to uphold superior communication quality, it is imperative to determine the appropriate allocation of RF signal resources for information decoding, whilst concurrently ascertaining the ideal allocation for energy harvesting, with the ultimate goal of prolonging the lifespan of the respective devices. Irrespective of whether there is a need to allocate additional antennas for the purpose of transmitting information, prolonged the harvested information duration or enhance the power of the signal that flows toward the decoder, all of these processes result in a minimal residue of radio frequency (RF) signal available for battery charging. It is essential to establish an appropriate allocation scheme for optimizing the trade-off in the context of the 5G SWIPT system.

3. Development of SWIPT towards 5G

The implementation of 5G mobile networks and utilization of mmWave in such networks provides individuals with an exceptional transmission rate, as noted in reference [8]. Notwithstanding, several issues persist; chief among them is the potentially deleterious consequence whereby the utilization of an ultra-high transmission rate has the potential to cause a significant increase in power consumption amongst wireless devices that are linked within the network. The topic of contemporary academic inquiry pertains to the SWIPT-enabled fifth-generation cellular networks, which exhibit a propitious course of action for tackling the antecedent recognized difficulty. The principal objective of SWIPT technology is to ascertain a suitable allotment scheme for radio frequency (RF) that enhances the balance between dependability and energy efficiency. This objective also takes into account other significant network constraints. The emergence of SWIPT has gained significant traction, as renewable sources of energy, such as solar and wind power, prove to be inadequate under various circumstances. This is owing to the fact that radio frequency signals possess the capacity to convey both data and energy. [21],[23], [24]. The realization of ubiquitous communications of wireless devices in a self-sustainable manner has become a vital requirement for the advancement of 5G technology.

Considering this, Simultaneous Wireless Information and Power Transfer has emerged as an indispensable solution that caters to the energy requirements for wireless charging of energy in constrained devices, and facilitates the transmission as well as the reception of information.
The utilization of this technology in the charging of sensor nodes situated in remote and difficult-to-reach areas is particularly advantageous due to its cost-effective nature. In [25], a novel conspires for SWIPT has been proposed, wherein energy is transported via an unmodulated, high-power signal whereas the transmission of information is achieved through a relatively weak modulated signal. The experimental findings confirm that a power yield greater than 0.5 mW can be collected from a distance of four meters, thus proving viable for the recharging of numerous 5G-IoT devices. The SWIPT technology, akin to power-line communication, presents an opportunity for considerable advantages, including increased longevity of system operation, heightened spectral efficiency, improved interference mitigation, and reduced transmission latencies. [16], [22]. With regard to the core pillars of the 5G network, it is projected that SWIPT technology will play a pivotal role in facilitating forthcoming industry standards. Conversely, SWIPT introduces a structural transformation for wireless communication networks, resulting in novel architectural challenges. Notably, the evaluation of system performance mandates an equilibrium between the rate of information transmission and energy extracted at the end terminals [18]. A fundamental compromise arises concomitantly with regard to the rate of transmission of information and the magnitude of energy harvested. This was designated by the region of rate and energy which was formed by all possibilities of energy harvested levels and rate of transmitted information [10].

3.1 mmwave communication

The authors of reference [1] conducted channel measurements at both 3.5 GHz and 28 GHz frequencies to evaluate the practicability of SWIPT with millimetre-wave (mmWave) technology. This study reveals that the employment of the 28 GHz frequency is optimal for line-of-sight transmissions with limited scope, whereas the utilization of the 3.5 GHz frequency, which experiences reduced large-scale fading compared to the 28 GHz frequency, is more appropriate for long-range transmissions. As per the findings, the authors have put forth a proposition regarding the present study, introducing a dual-band SWIPT network that incorporates a zone with a high concentration of access points (hot-spot) as well as a zone with expansive geographical coverage. Within this zone of heightened activity, the utilization of a 25 gigahertz frequency enables the instantiation of the concurrent transmission of wireless information and power via a line-of-sight mechanism. In the context of broader coverage, the communication of information is facilitated through the utilization of a 3.5 gigahertz frequency. Ultimately, a mathematical approach to optimizing the allocation of power and channels is introduced, driven by the goal of maximizing the minimum quantity of energy harvested by individuals, with TS structure serving as a foundational principle.

3.2 SWIPT - OFDM signal excitation

It proposes two solutions to improve the efficiency of the conversion process in order to ensure system sustainability [9].

The introduction of a new design of OFDM transmitter with selective architecture tailored for the transmission of SWIPT is the first component of the solution. This newly proposed architecture of the transmitter includes an insertion module of excitation, which adds a signal torturing to a segment of the signal broadcast. The module of excitation allows the harvested component of the signal transmitted to be conditioned, resulting in a higher PAPR for that portion of the signals. The conditioned signal is gathered and given via the receiver's dynamic switching capability.

The second element of the approach entails a new design of rectifying circuit that is also optimized for efficient conversion. The rectifying circuit ancestors were modeled and simulated. The single-diode rectifier type outperformed the bridge rectifier. As a result, for efficiency and trade-off analysis, the single-diode rectifier solution was utilized. To analyze the performance, a proposition and evaluation of an analytical formulation detailing the relationship between the rate and energy trade-offs of a receiver in the context of SWIPT transmission are presented. The study also produced the analytical expression for the self-sustainability of the system. In conclusion, Signal conditioning increased the self-sustainability of the selective OFDM system through the adoption of a new architecture of transmitter along with the model of rectifying circuits. [9].

4. Analysis of distinctive 5G empowered SWIPT systems

Reference	Scenario/ Transmission Methodology	Resource allocation Structure	Key perspectives	Contribution
[1]	5G new frequency network	TS	Optimization of energy efficiency for minimum energy harvest of the end-users.	A proposition for a SWIPT network with dual band is presented. The optimization of power allocation in conjunction with channel assignment is a central element of this proposal.
[3]	OFDM	TS	system self-sustainability	Proposes selective ODFM system with new transmitter and single rectifier model
[10]	NOMA system	PS	Secure and reliable	Probabilistic long distance path loss using

			communication , outage probability	beam forming for SWIPT
[11]	Industrial IoT network NOMA	PS	Resource allocation in LoS	One UAV as a base station with an array antenna and multiple pairs of D2D with single antenna
[12]	IRS assisted MIMO network	PS	Average secrecy rate maximization	Proposed low complexity algorithm, Rician fading with CSI uncertainty
[13]	SU-SISO network downlink	PS	Optimal power splitting in SWIPT	Rayleigh fading
[14]	MU- MIMO downlink network	Non liner PS	Average Harvested energy maximization	Transmit BF and AN under co-operative jamming
[15]	MU-MIMO relay network with NOMA SWIPT	PS	Achievable Secrecy rate	Two way AF relay transmit BF with NOMA downlink
[16]	MU-MISO IoT network downlink	PS	Average secrecy rate energy harvest model	Transmit BF and AF under Rayleigh fading with imperfect CSI
[17]	mmwave Co-operative NOMA downlink	PS	Energy efficiency coverage probability in SWIPT	Rayleigh fading with half duplex DF two hop relaying
[18]	NOMA system in SWIPT	TS	Optimize the energy proficiency	Implementation of a dual-layer iterative resource allocation algorithm for optimal resource allocation in the field of resource management.
[19]	Relay network	PS	The optimization objective involves the maximization of throughput and stored energy.	Simultaneously optimizing caching capacity and quality of service (QoS) in a joint manner.
[20]	Unnamed Arial Vehicle network relay	PS	Optimize the minimum limit and mean level of confidentiality rate.	Simultaneously optimizing the transmit power of the source or UAV relay, ratio of power splitting and the location of the UAV device

5. Conclusion and Future Enhancement

This study has investigated the incorporation of explicate the application of SWIPT technology within the emerging realm of fifth-generation (5G) mobile networks, with a specific focus on its implications for facilitating the rapidly expanding Internet of Things (IoT) ecosystem. The following discourse elucidates a paradigmatic pattern for the transmission of SWIPT, which consists of preeminent informatics and dominance allocation frameworks, as well as the pivotal predicament of maximizing Receiver Efficiency (R-E) while considering the concomitant trade-offs in the realm of SWIPT. The following manuscript presents an extensive review of recent advances in the field of SWIPT within the wider framework of 5th Generation (5G) mobile networks, as supported by pertinent scholarly publications. Empirical data has demonstrated that the power of mmWave signals that can be power generated by terminal devices through harvesting techniques exhibits a range of 1 microwatt to 5 microwatts when subjected to a source power span of 1 watts to 4 watts. The insufficient power output poses a challenge to sustaining the functionality of wireless devices, More specifically, those utilizing the technological advancements of the Internet of Things (IoT) are under consideration. In light of the substantial energy consumption attributed to wireless devices, the investigation of SWIPT through prior research has been primarily directed towards low-power equipment, particularly compact relays, and sensory instruments. The realization of SWIPT in millimeter-wave (mmWave) networks is subjected to necessitate the backing of hardware advancement for commercialization purposes. But the new selective OFDM for SWIPT transmission maximized the total energy harvest with that extension to the multiuser transmission was simulated and system performance was improved.

In forthcoming advancements, Multi-user ODFM - SWIPT implementation will be suggested for high-end Internet of Things (IoT) devices based on fifth-generation (5G) technology. An analytical statement that articulates the exchange of data transmission rate for energy consumption and the ideal transmission scheme will be obtained.

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