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Simultaneous Wireless Information and Power Transfer with Cooperative Relaying for Next-Generation Wireless Networks: A Review

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ABSTRACT Wireless Power Transfer (WPT) is an innovative technology employed for enhancing the energy sustainability of wireless devices with a limited life span. The idea of integrating WPT in wireless communication leads to the idea of Simultaneous Wireless Information and Power Transfer (SWIPT) that transfers information and power to wireless devices simultaneously, thereby resulting in a drastic increase in spectral efficiency of the network. SWIPT aided Cooperative Relaying (CoR) has emerged as a new trend for Fifth Generation (5G) and Beyond 5G (B5G) systems owing to the rapidly increasing challenges faced by these networks. Cooperative relaying combined with SWIPT can be helpful in overcoming the rising demands of next generation wireless networks by providing an enhanced date rate, low latency, shorter coverage, wide spread connectivity of massive number of devices along with energy-efficiency. This article provides a comprehensive review of SWIPT technology that enables the use of CoR networks for 5G and B5G mobile networks including the significance, technologies, and protocols which can be applied. This article also examines the deployment of cooperative SWIPT involving a single relay, multiple relays and optimal relay selection, multi antenna systems and optimal beamforming .SWIPT under the influence of Hardware Impairments (HI), imperfect Channel State Information (CSI), non-linear energy harvesting models, Intelligent Reconfigurable Surface (IRS), massive MIMO, massive access for the Internet of Things (IoT) has been discussed in detail. Meanwhile, this study discusses key challenges being faced in the implementation of SWIPT for future wireless networks that need to be addressed efficiently.

INDEX TERMS Cooperative Relaying (CoR), Fifth Generation (5G), Multiple-Input-Multiple-Output (MIMO), Internet of Things (IoT), Simultaneous Wireless Information and Power Transfer (SWIPT), Wireless Power Transfer (WPT).

I. INTRODUCTION

Wireless communication has been progressing enormously for the last two decades and has become an indispensable part of our everyday lives. With the rising inclination towards smart devices aiming to support rigorous and advanced data applications, some significant challenges are anticipated in wireless communications due to environmental impact and high energy utilization constraints [1]. The Fifth Generation (5G) mobile communication networks have been started to be deployed in various countries as the next standard following the Fourth Generation (4G). Primarily, 5G technology provides higher data rates, broader coverage, greater bandwidth, reliable connectivity, a massive decrease in energy consumption, and low latency [2]. However in the course of standardization of 5G networks, it has been witnessed that there is no distinct enabling technology to support all 5G application demands. Thus researchers have already started working on Beyond 5G (B5G) systems by evading from the safety zone of 5G based solutions.

Existing 5G technology integrates with new communication technology to work together in offering communication services, such as IoT and Low Earth Satellite (LES) system. IoT technology is a smart framework involving uniquely recognizable devices capable of communicating wirelessly with each other on a massive scale via the Internet [1]–[3]. Usually, part of these wireless devices is equipped with batteries having a limited life span. With a large number of energy-constrained wireless sensors, especially those entrenched in high-risk environments, replacing batteries cannot be carried out very easily [4]. Also, in order to extend the lifetime of these small sensors by battery replacement, high cost is usually associated. Inspired by this, the primary focus is given on wireless Energy Harvesting (EH) techniques. Natural resources of energy such as solar, thermal and wind energy can be used to perform EH [5]. However, the random and impulsive nature of these resources makes it problematic to be used for applications where utmost significance is given to Quality-of-Service (QoS). Therefore, RF energy harvesting offers significant advantages as it is wireless, has low cost, and is readily accessible in the form of energy transmitted from Base Stations (BS), TV/radio broadcasting signals, and handheld radios. There are two Wireless Power Transfer (WPT) methods for energy harvesting, i.e., from ambient signals or by using a fully controlled and dedicated source of power, e.g., a BS [6].

An exceptional benefit of EH is centered at the concept of Radio Frequency (RF) signals carrying energy and information together, thus enabling the energy-deficient nodes for decoding information and scavenging energy simultaneously [7]. The two fundamental approaches, Wireless Information Transfer (WIT) and WPT, can be used for communication-only and power-only, respectively. On the other hand, Simultaneous Wireless Information and Power Transmission (SWIPT) is a combined scheme that can transfer power and carry information at the same time. It gently grows and provides conciliation between the two basic approaches and uses the RF spectrum adequately to initiate communication and energize the system. This technique facilitates and enables trillions of low-power wirelessly connected devices, e.g., IoT, to communicate and get energy anytime and anywhere [8].

Moreover, several theoretical studies consider the same signal in the literature for both information decoding and rectification [9]. However, this simultaneous transfer is not possible because of practical circuit limitations [10]. Nevertheless, the idea inspired the designing of practically realizable receivers with separate decoding and harvesting energy schemes by employing time switching or power splitting [7]. These designs are mostly implemented in recent literature [11], [12]. In addition, SWIPT technology basically provides an efficient spectral solution for energy harvesting, thereby supplying energy and exchanging information with various ultra-low-power devices supporting heterogeneous applications [13]. SWIPT could be effectively integrated to enhance throughputs and energy sustainability jointly, particularly for B5G cellular systems with small cells, e.g., Millimeter-Wave (mmWave) technologies and massive Multiple-Input Multiple-Output (MIMO) [14].

With the rapidly increasing demand for providing data services around the world, cooperative communications involving relays have been recently encouraged as an effective solution. The reliability of data transmission is greatly enhanced by employing cooperative relaying systems [15], [16]. Also, cooperative communication relaying technology minimizes path-loss and fading effects efficiently, thereby resulting in an increased coverage area and capacity of the system.

This article presents a comprehensive survey on SWIPT based CoR system. The main focus is to provide detailed information and discussion in order to showcase the importance of SWIPT, especially by using the IoT in the B5G wireless networks. Besides, future challenges and opportunities are also provided.

This article is organized as follows: Section II presents the preliminary concepts which include background, motivation, related work and contribution of this study. Section III discusses SWIPT, its techniques, and related architecture including SWIPT with non-linear EH for IoT. A discussion on Cooperative Relaying (CoR) and CoR for the Internet of Things (IoT) is provided in section IV. Section V presents SWIPT Assisted CoR, along with relaying protocols for SWIPT CoR, based on a review of different system configurations like systems with/without direct link, multi-antenna systems, multi-relay systems, MIMO with non linaer EH and imperfect CSI, SWIPT CoR with Hi,SWIPT at 5G and B5G new frequencies. Section VI presents SWIPT assisted CoR particularly for IoT including HI for B5G IoT networks. Challenges and future work are discussed in Section VII. Section VIII concludes the article.

II. RESEARCH BACKGROUND

Cooperative relaying equipped with energy harvesting is substantially not the same as the conventional relaying schemes [17]–[19]. However, relay nodes being energy-limited devices, need wireless energy harvesting to provide better performance and an increased lifetime. More specifically, when the main power supply cannot be accessed, a convenient way for relays is to use self-sustaining RF energy [20]. Fortunately, power-constrained cooperative relaying can be accompanied by RF Energy Harvesting (RF-EH), which motivates an innovative era of academic research, revolutionizing the wireless technology. Thus integration of SWIPT with CoR for next-generation wireless networks e.g Wireless Sensor Networks (WSN), IoT, mmWave, and Device to Device (D2D) communication enables spectral efficiency as well as ensures that reliability in data communication is achieved while keeping the power, complexity, and cost to a minimum.

The network size is expected to increase substantially with the rapidly-evolving B5G wireless communication systems, mainly due to Machine-to-Machine (M2M) communications as well as sensor networks employed in smart cities, and massive IoT applications. Moreover IoT is anticipated to make huge contributions in B5G systems as apart from terrestrial systems, IoT is expected to be deployed in air, underwater (UIoT) etc. Thus massive access and massive connectivity of such large number of energy-hungry devices is a challenging task. As the burden on current power resources is increased traditional sources of power should be accompanied by alternative sources, specifically RF. Among RF EH techniques, SWIPT is considered to be more energy efficient increasing the life span of the existing energy-constrained wireless devices.

A. Motivation

Energy efficiency shall play a critical role in future communication systems and be considered the main design objective for 5G and B5G radio access networks [21]. Limited device life span has always been a critical aspect of modern wireless technologies [22]. Every device is required to replace its battery after every few months or years, depending upon the energy efficiency of the device and battery size.

A considerably high operational cost, as well as difficulty in replacing or recharging device batteries in several scenarios, such as wireless sensors for medical purpose, are placed inside the human body or devices embedded in a building structure, recommends a scheme that enables wireless devices to harvest energy from the adjoining environment. Various studies have discussed renewable energy sources, e.g heat, solar, wind and so on. The optimally designing resource allocation strategies by defining several objective functions and network topologies has been investigated. On the other hand, energy harvesting becomes crucial for most applications due to these resources' intermittent nature. However, RF-enabled wireless energy harvesting provides a considerable increase in throughput, has high robustness, and increased flexibility compared to other energy harvesting schemes. Thus RF energy harvesting shall be a significant building block for many popular industrial and commercial systems in the future. Fig. 1 shows various types of energy sources available for EH.

One of the critical concerns of 5G and B5G technology is to guarantee reliability in communication at low cost, reduced complexity, and power, particularly for applications including the massive IoT as well as large-scale WSNs [22]. Also, the transmission efficiency under SWIPT is improved compared to the conventional time-division multiplexing mechanism, where the transmission of power and information is separate [23], [24]. By employing SWIPT, interference present in the communication channel could potentially destroy information content in the signal and be beneficial for EH [25]. Recently, another SWIPT application is applied in relay-assisted wireless communication, which eradicates the path-loss and fading effects and increases the energy and spectral efficiency of the network. This integration of SWIPT with CoR can be drastically important for large scale wireless sensor network such as IoT [26], [27]. Fig 2 discusses the advantages of SWIPT with CoR.

Several researches has been done on and still going on in SWIPT as well as CoR systems and a number of survey articles provide an analysis of SWIPT [28]–[33] and CoR [34]–[36].Integration of SWIPT in CoR systems have also been discussed in literature [20].SWIPT aided CoR networks and their application in modern technologies, e.g., D2D communications, cognitive radio, WSN, Non-Orthogonal Multiple Access (NOMA) and IoT as well as some future challenges have been suggested in [20].

B. Related Work

In [28], Perera *et* al. presented a review on SWIPT, its architecture, and EH using SWIPT for two user Multiple-Input Single-Output (MISO), multi-user MIMO, and broadband communication systems. They extended their work in [29], where SWIPT for next-generation technologies like NOMA, massive MIMO, D2D communication, satellite communications, and IoT was presented. Resource allocation for SWIPT systems along with energy efficient EH including COMP network as well as power allocation for D2D communication was discussed in [30]. Zhang *et* al. [31] provided a basic architectural

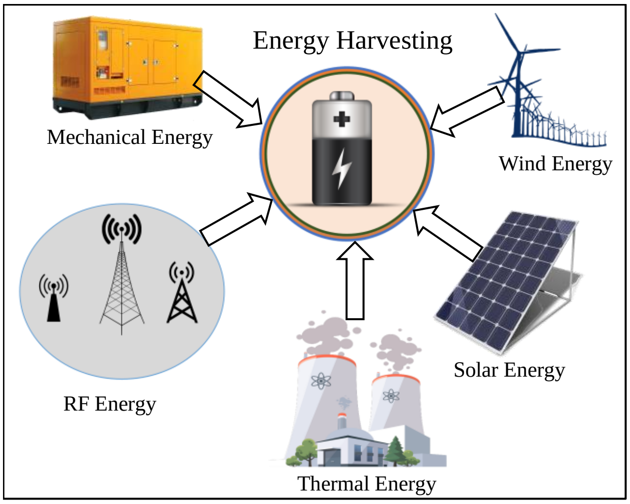

Fig. 1: Energy Harvesting Sources

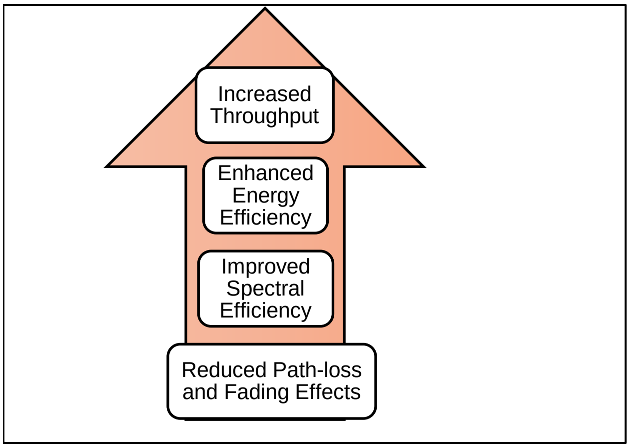

Fig. 2: Advantages of SWIPT via CoR

summary of SWIPT. They also discussed its practicality by notifying several critical aspects ranging from the link-level to system-level design, including multi-antennas, channel coding, modulation, and interference.

The study in [32] discussed MIMO systems with SWIPT enabled relaying using smart antenna schemes. They also reviewed receiver architectures for SWIPT systems. Ku *et* al. [33] studied several effective physical layer security techniques affecting SWIPT performance. Additionally, they suggested the employment of massive MIMO techniques to enhance SWIPT performance via numerical results. All the works from [28]-[33] discussed SWIPT and its various applications in wireless communications. Cooperative relaying systems have also been discussed in literature. The effect of relay selection for a CoR network to enhance the capacity of systems was studied in [34]. They also discussed the optimal relay assignment algorithm that provides an optimal solution for allocating relay nodes in order to enhance capacity. Authors in [35] considered industrial wireless sensor networks and relay selection techniques with a brief review of relay selection parameters. They also discussed the diversity combining techniques for relay networks. In [36], Mansourkiaie *et* al. presented a review of routing protocols in cooperative communication networks. Along with providing the taxonomies of routing protocols, they also highlighted the limitations of each. A comprehensive study of EH SWIPT systems with cooperative relaying has been presented by Hossain *et* al. in [20]. This article focused on various relay selection techniques as well as resource allocation in SWIPT aided CoR systems. The integration of SWIPT and CoR for 5G networks has been explained in addition to a few future challenges.

C. Contribution

This article reviews SWIPT aided CoR systems, for 5G and B5G networks. Table I provides a comparison of existing literature with this work. The contributions of this article include an overview of not only SWIPT, its architecture but a detailed discussion on SWIPT systems considering both linear as well as non-linear energy harvesting models involving imperfect CSI. SWIPT CoR networks in the presence of Hardware Impairments (HI), Intelligent Reconfigurable Surface (IRS), exploring SWIPT CoR at new frequencies, massive MIMO and massive access particularly for the massive IoT have been reviewed, which are key enabling technologies supporting B5G. SWIPT assisted CoR networks, their applications and future challenges have also been presented. Apart from terrestrial IoT network, Underwater IoT (UIoT) has been explored as a future challenge for B5G systems.

III. SIMULTANEOUS WIRELESS INFORMATION & POWER TRANSFER (SWIPT)

One of the modern advances in wireless energy harvesting technology is SWIPT. In SWIPT, either dedicated or ambient RF sources [37], [38] are employed for transmitting energy and information simultaneously, as depicted in Fig. 3. It provides an advantage in terms of Electrical Efficiency (EE) and Spectral Efficiency (SE). The idea of transporting information and energy together was first discussed by Varshney *et* al. [39]. In order to show the fundamental performance trade-off for simultaneous information and power transfer, a capacity-energy function was suggested. By employing realistic fading channels with Additive White Gaussian Noise (AWGN), Sahai *et* al. extended the idea by employing a non-trivial trade-off between energy harvesting and information decoding by considering a Single-Input Single-Output (SISO) system [40]. In theory, energy and information can be extracted from the same waveform in SWIPT. However, due to circuit design limitations, such as the different power sensitivity of antennas at the receiver side, its practical implementation is impossible. An essential aspect of being noted here is that energy harvesting requires

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TABLE I

COMPARISON OF DIFFERENT SURVEY ARTICLES WITH CURRENT STUDY

Study	SWIPT	CoR	Domain	Integrated SWIPT-CoR	Internet of Things (IoT)
Perera *et* al. [28]	Yes	No	MISO, MIMO, Broadband	No	No
Perera *et* al. [29]	Yes	No	NOMA, D2D, WSN, Cognitive Radio	No	Yes
Huang *et* al. [30]	Yes	No	Resources Allocation, Energy Efficiency, CoMP Networks.	No	No
Zhang *et* al. [31]	Yes	No	Link and System Level Design Aspects of Wireless Systems	No	No
Z. Ding *et* al. [32]	Yes	Yes	MIMO SWIPT Systems with smart antennas	No	No
Ku *et* al. [33]	Yes	Yes	EH Techniques, Scheduling, Optimization and Design Issues considering Cognitive Radio Networks and Cellular Networks.	No	Yes
Bhute *et* al. [34]	No	Yes	Basics of Relaying, Relaying Strategies in CoR, MIMO Systems and Optimal Relay Selection.	No	No
Umamaheswari *et* al. [35]	No	Yes	Relay Selection, Diversity Combining Techniques	No	No
Mansourkiaie *et* al. [41]	No	Yes	Routing Protocols and Their Review, and Limitations in Each Protocol.	No	No
Hossain *et* al. [20]	Yes	Yes	EH, SWIPT-CoR, for 5G networks with applications in D2D,VANET,WBAN,WSN, CRN, IoT.	Yes	Yes
Current Study	Yes	Yes	Review of SWIPT assisted CoR for 5G and B5G networks including massive MIMO and massive IoT. IRS for SWIPT aided CoR systems. SWIPT CoR with HI, imperfect CSI, nonlinear EH, as well as SWIPT at new frequencies. Applications of IoT e.g UIoT for B5G systems.	Yes	Massive IoT and UIoT.

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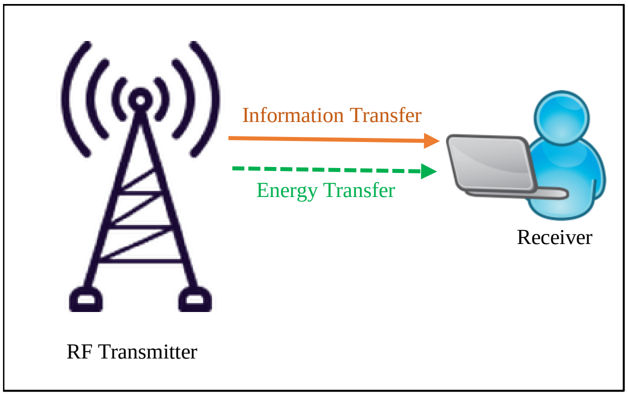

Fig. 3: Basic Architecture of SWIPT

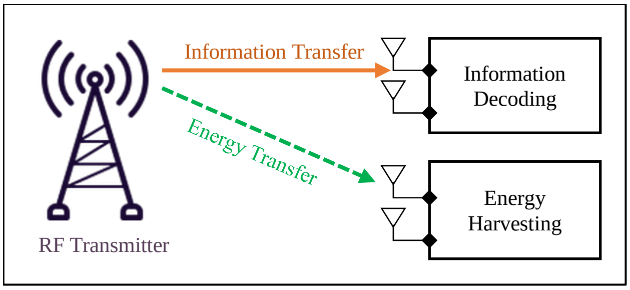

Fig. 4: Separated Receiver for SWIPT

−10dBm power sensitivity, whereas information decoding requires as lower as −60dBm [42]. In order to implement SWIPT, a signal has to be splitted into two parts, one for harvesting energy and other for decoding information.

1) SWIPT techniques

The following are the two primary techniques used for the practical implementation of SWIPT.

1.1. Separated receiver
1.2. Integrated receiver

1.1. Separated receiver

There are separate antennas for both EH and ID for this architecture, working on different fading channels [43]. With the help of this architecture, EH and ID can be done concurrently and independently. For achieving a trade-off between rate of information transmission and energy harvesting, CSI and feedback from the receiver can be utilized to obtain an optimized result, as shown in Fig. 4.

1.2. Integrated receiver

In this type of architecture, there is no separate antenna for ID and EH. This architecture has three types:

1.2.1 Time Switching (TS)

In this type of integrated receiver, same antenna is employed for EH and ID. A switch is employed at the receiver to switch between EH and ID periodically. This TS receiver

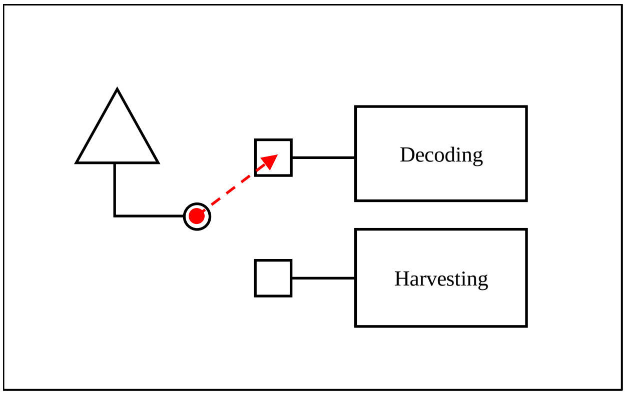

Fig. 5: Time Switching (TS) Receiver for SWIPT

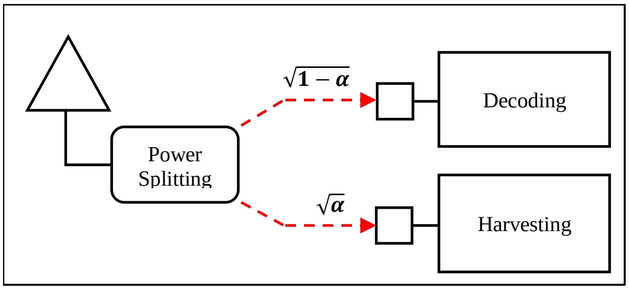

Fig. 6: Power Switching (PS) Receiver for SWIPT

needs precise information and energy scheduling as well as synchronization of time along with the advantage of simplicity in hardware [42]. TS receiver is shown in Fig. 5.

1.2.2 Power Splitting (PS)

In this type of SWIPT architecture, the received signal is split using a power splitter with one part of the signal for EH and other for ID. The PS receiver is shown in Fig. 6. Both EH and ID is done simultaneously by optimization of PS ratio α. However, the hardware becomes more complicated due to the power splitter as a part of the receiver circuit [43].

1.2.3 Antenna Switching (AS)

Antenna switching can be employed for SWIPT with different antennas used for ID and EH. One group of antennas performs EH, while the other group can identify the ID. Sometimes it can be used for optimizing the receiver architecture. It can be thought of as a distinct case for PS architecture, i.e., performing EH and ID concurrently, as shown in Fig. 7.

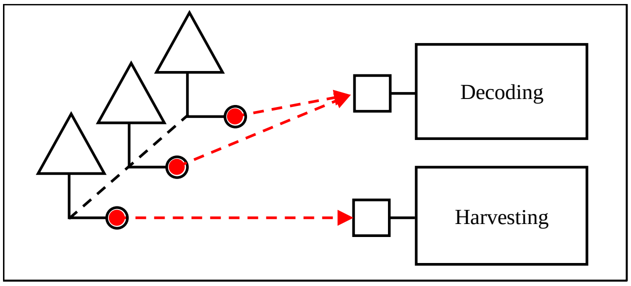

Fig. 7: Antenna Switching (AS) Receiver for SWIPT

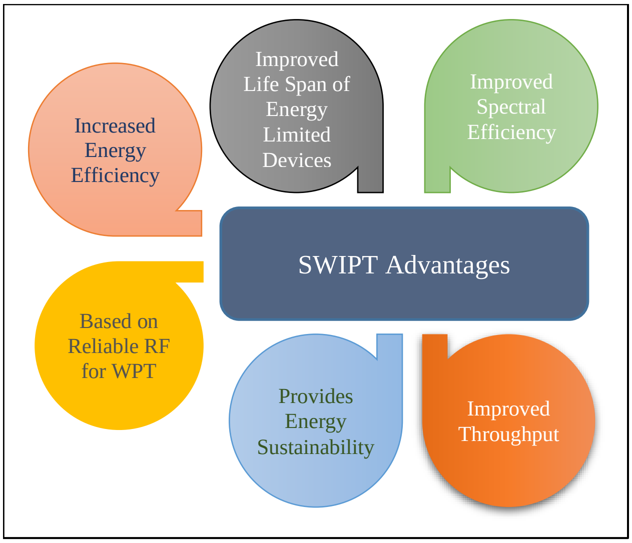

Fig. 8: Advantages of SWIPT

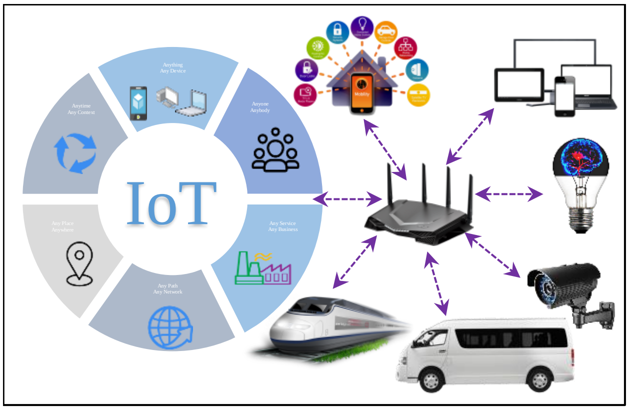

Fig. 9: Internet of Things (IoT)

It has been shown in literature that SWIPT can be employed for EH considering two energy harvesting models; linear as well as non-linear EH model. In linear EH [42], the EH circuit's power conversion efficiency defined as ratio of output power to input signal power is assumed to be constant. Thus the output power (DC) and input power are independent of each other. In a linear EH model, the conversion efficiency is a constant whose values range in the interval from [0, 1] [44]. This conversion efficiency represents the ability of the RF-DC conversion circuit. The authors studied the trade-off between rate-energy regions by developing a MIMO broadcasting channel with three nodes developing a rate-energy (R-E) region and optimal beamformer following linear energy harvesting model [12]. In [45], a MISO broadcast SWIPT system was investigated, with power splitting and transmit beamforming combined. The system was designed to minimize power transmitted with a constraint on minimum value of the received Signal to Noise Ratio (SNR). Results showed that beamforming increases the amount of energy harvested for SWIPT systems. Authors in [46] considered a multicarrier system with an energy-efficient SWIPT, where user scheduling, subcarrier as well as power allocation were discussed. In [11], the authors designed a beamformer with imperfect Channels State Information (CSI), without considering the energy consumed in channel estimation. Optimization of the system was done to achieve QoS and achieve a robust design. However, existing literature studies [11], [12], [43], and [46] are based on linear EH model where power conversion efficiency is independent of input power of the harvesting circuit. Fig. 8 shows the primary advantages of SWIPT.

However, in practical wireless networks, wireless power transfer is non-linear and dependent on practical EH circuit parameters which employ diode as a non-linear component [47]. Authors in [44] designed a non-linear EH based SWIPT model, dependent upon logistic function and real data. They proved a considerable gain in terms of average total energy harvested when compared with the traditional linear model. Boshkovska *et* al. [48] utilized a non-linear EH model and developed a resource allocation scheme for harvested power maximization. Simulation results proved the substantial increase in harvested energy and robustness against imperfect CSI as compared to conventional linear EH scheme and perfect CSI [11].

2) *SWIPT for Internet of Things (IoT)*

An IoT network is equipped with a special type of sensors, transceivers, batteries, and control processors attached to each object to monitor their environment and transmit and capture data from the physical world. An IoT network is shown in Fig. 9. Due to the limited battery life of embedded sensors, a lot of research interest is being developed for utilizing SWIPT in order to increase their longevity and energy efficiency, thus enabling them to become self-sufficient in their operation without compromising QoS.

Wang *et* al. [49] considered a MISO SWIPT system with frequency division duplexing and developed an optimization scheme to maximize net harvested energy in the presence of imperfect CSI. In [50], Chae *et* al. presented a SWIPT system for IoT sensor networks employing K transmitter-receiver pairs for minimizing the total power transmitted with constraints on rate and energy harvesting. By employing interference decoding and hybrid beamforming, they showed that the SWIPT performance for IoT devices could be considerably improved compared to the previous works [49], [51].

The authors in [52] considered MIMO Broadcasting Channel (MIMO-BC) with a TS receiver for an IoT network, where an optimization problem was designed for maximizing EE based on maximum transmitted power and minimum harvested energy at each user terminal.

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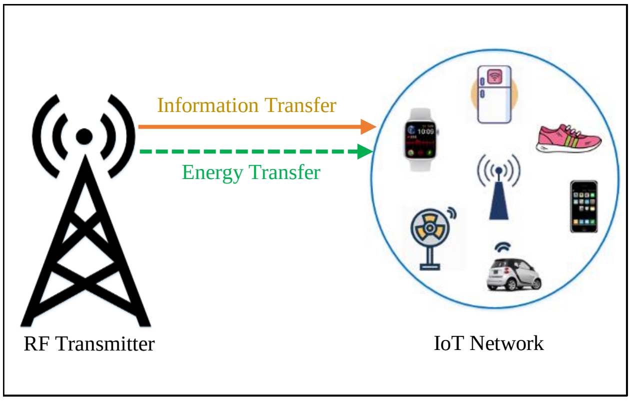

Fig. 10: SWIPT for IoT

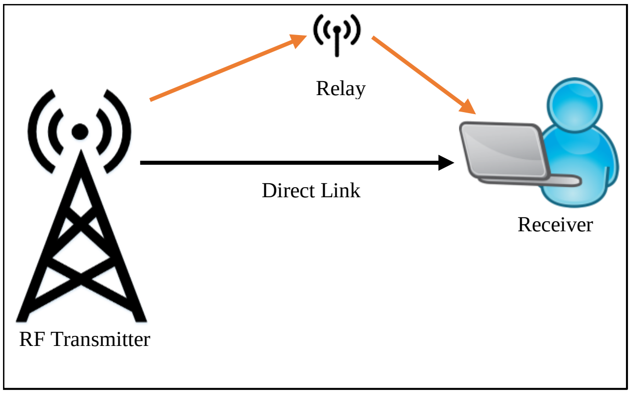

Fig. 11: Cooperative Relaying (CoR)

In [53], Lee *et* al. discussed the allocation of resources and task scheduling for IoT networks. The main idea was to minimize the on-grid energy consumption at the access points based on three constraints: the minimum average harvested energy and data rates and the minimum task performing rates for IoT nodes by designing a centralized algorithm. For reducing the complexity of a centralized algorithm, they also devised a distributed task scheduling algorithm that aimed at assisting each IoT device to satisfy its task performing rate requirement by efficiently utilizing its harvested energy. SWIPT for IoT is shown in Fig. 10.

Outage performance considering a primary and secondary IoT system investigated by [54], by employing Time Switching (TS) based SWIPT for secondary IoT devices that harvest energy while serving as a relay to primary IoT nodes. In [55], a MIMO system with multiple energy and information receivers considering an IoT network was proposed for SWIPT. A resource allocation algorithm was designed based on maximized harvested energy at energy receivers and security at information receivers. Authors in [56] developed an innovative SWIPT algorithm for IoT by sending wireless power via unmodulated Continuous Wave (CW) and transmitting information employing a small modulated wave for decreasing the interference and increasing the power efficiency, instead of conventional PS as well as TS schemes. They developed a novel receiver design for IoT devices, since the receiver circuit for IoT devices is required to have low complexity and low-power consumption, so in order to get maximum utilization of harvested power for various parts of the IoT devices, they suggested the use of envelope detection for information decoding, which avoids power-consuming active components e,g mixers and oscillators. The authors derived expressions for energy harvesting efficiency for power signal and determined frequency response of information signal. The analysis results were validated by both the simulation and development of experimental testbed. Huang *et* al. [57] proposed a scheme by considering a Distributed Antenna System (DAS) with SWIPT and PS, where EE was derived for the IoT network. By changing the transmit power of distributed antennas and PS ratio of IoT devices, EH and ID could be coordinated.

3) *SWIPT with nonlinear EH for IoT:*

Since the EH devices in IoT applications are small sensors having lesser hardware size requirement and reduced circuit complexity, thus in such cases, nonlinearity in EH needs to be accounted for since it may be very difficult to practically implement various energy harvesters so as to mitigate nonlinear effects. In [58] ,Kang et al. developed DPS algorithm for SWIPT by considering an ergodic fading channel and nonlinear EH model for IoT applications in the presence of two cases namely CSIR, when CSI is known at the destination only and when CSI is known at source and destination both. The fading conditions were accurately determined at the destination using downlink pilots transmitted from source. Also by employing uplink pilots transmitted from destination, CSI was estimated at the source. The main advantage of proposed scheme was that it can be readily employed after determining the energy consumption requirement for processing as well as information transmission from IoT receiver since harvested energy in IoT sensor should be utilized not only for decoding information but also for processing and transmission of information. Numerical results validate that proposed optimal as well as suboptimal schemes show significant performance improvement as compared to existing algorithms.

Since D2D communication is a promising technology for supporting IoT networks hence authors in [59] developed an algorithm to maximize the EE of all D2D links in a D2D network by the developing the optimized resource and power allocation strategy considering non-linear EH model. Results depicted that cumulative EE is much greater when D2D communication distance is short and there are more number of users and proposed scheme achieved higher EE of all D2D links as compared to the existing algorithms.

In [60] authors discussed, a resource allocation algorithm to enable secure network considering SWIPT for IoT. The algorithm was based on non-linear EH model and an optimization problem was developed for maximizing total energy transferred to the receivers. Numerical results depict that the proposed algorithm guarantees security in communication as well as assists in a significant performance improvement in terms of the energy harvested when compared with existing schemes employing the linear EH model.

IV. COOPERATIVE RELAYING (CoR)

By considering broadcast in the wireless medium, cooperative communication is suggested [61], by which various nodes can cooperatively send signals to a destination together. Recent advancements in technology have proved that cooperative communication aids in substantial performance improvements by increasing capacity, spatial diversity, and enhanced transmission reliability [62], [63]. In a relay-based communication system, the source first transmits its data to the Relay Nodes (RNs). Each RN after utilizing some cooperative relaying protocols forwards the data to the destination. When a signal is received from RNs, the receiver decodes the data [64]. In such a way, the nodes that are out of the source's range but the AP can communicate with them, as shown in Fig. 11.

In a cooperative communication system, the relay node is not only devoted to relaying, but it also transmits its own information. This transferring of information to each other on a voluntary basis [65] is an idea also called as cooperative diversity [66]. Apart from providing network connectivity to remote nodes, relays also can adjust the distance between them to achieve electrical efficiency, thereby reducing the effects of fading in wireless networks [67], [68]. By employing multiple relays, throughput of any network can be increased [69]. By providing spatial diversity, the throughput can be enhanced in a cooperative communication network.

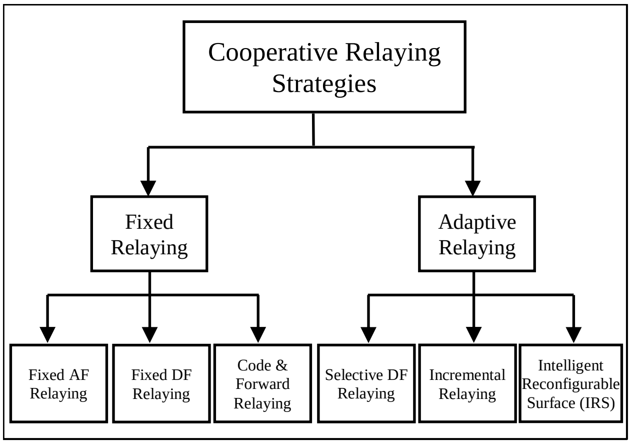

Fig. 12: Cooperative Relaying (CoR) Strategies

1) Cooperative relaying strategies

There are two main strategies for CoR, i.e., fixed and adaptive relaying. For fixed relaying, resources between source and relay are allocated in a deterministic way. In adaptive relaying, relays become active only when they require processing information; otherwise they remain silent [70]. Data processing can be done according to the available protocols at the relay. Different relaying protocols are mentioned in Fig. 12 and discussed in detail below:

1.1. Fixed Amplify & Forward Relaying protocol (FAF):

In this technique, relay amplifies the signal received from the transmitter and forwards it to the receiver, hence it is also named as non-regenerative relaying. AF relaying has advantages in terms of lesser complexity and simplicity, but the main drawback is amplification of noise, thereby effecting the QoS of the network [71].

1.2. Fixed Decode &Forward Relaying protocol (FDF):

In this type of relaying, the relay first decodes and then forwards received signal to the receiver. This relaying eliminates noise as was in AF but introduces computational delay and might allow errors to propagate until the destination [72].

1.3. Code & Forward relaying protocol (CF):

Unlike AF/DF schemes, where relay sends a repeated version of bits from the source, the process is done by dividing the codeword into different segments and being sent through independent fading channels. Segments are equipped with a CRC check. The relay in coded cooperation transmits incremental redundancy, which gives a large redundancy in the codeword at the receiver when combined with that sent by the source. The chances of recovering original information in the presence of errors are increased by this redundancy [73]. However, delay and processing time increases at the cost of reliability and increased accuracy. Moreover, it also reduces interference in any CoR network.

1.4. Selective Decode & Forward (SDF) relaying protocol:

The Selective Decode & Forward (SDF) relaying protocol is an adaptive relaying mechanism that eliminates the noise being amplified as well as error being propagated in DF. Here relay decodes messages from the source, and after performing an error check, it forwards to the destination only if correct decoding took place; otherwise, it remains silent [74].

1.5. Incremental relaying protocol (IR):

The incremental relaying protocol is the highest spectral efficient protocol because a feedback channel is present from the transmitter to relay. An acknowledgment is received at the relay when the message is transmitted correctly, and it does not transmit again during the transmission phase. The second transmission phase is based upon CSI of a channel having direct link between

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transmitter and receiver. However, owing to the high signaling involvement, the complexity might increase [75].

1.6. Intelligent Reconfigurable Surface (IRS):

Intelligent Reconfigurable Surface (IRS) has swayed the research community recently, primarily becoming a potential candidate technology for B5G wireless networks. IRS is composed of a set of reflecting units which are reconfigurable, and their phase shifts can be controlled according to the changes in reflection from the wireless communication environment. As a matter of fact, IRS can suitably reflect RF signals transmitted from transmitters to desired directions, such that the received signal power can be effectively enhanced at the intended destinations while suppressing interference at undesired receivers [76]. Moreover, IRS is actually an antenna array with passive elements such that the spectral as well as EE of a wireless network can be increased in a cost effective way. IRS scheme has proved to be very striking from consumption of energy point of view, mainly because it can amplify and forward incoming RF signals without using any PA, rather by appropriately calculating phase shift of each reflecting part, there by combining each reflected signal constructively. Obviously, since no PA is employed, an IRS shall utilize lesser energy as compared to an AF relay [77].Another advantage of IRS is that it can operate without any power source, complex encoding and decoding algorithms like other technologies e.g MIMO transmit and receive beamforming and relays. The geometrical size of antennas employed at relays is comparable with the wavelength, thus making AF relay a diffuser rather than a reflector. If the geometrical size of RIS is optimized, a large increase in link budget can be obtained as compared to relaying. Also absence of ADCs and PAs makes the IRS unaffected by noise at the receivers thus avoiding addition of noise and providing a full duplex transmission [78].

Recently IRS has been combined with energy harvesting to improve SE and EE of the network. In [79] authors proposed an IRS based MISO system with multiple users by employing SWIPT.For a multi antenna system, joint optimization of transmit beamforming at the transmitter as well as passive reflective beamforming at IRS is suggested for maximizing the received power at EH receivers with SINR and maximum transmit power constraint at the ID receiver as well as the transmitter respectively. Authors in [80], discussed an IRS assisted downlink MISO system with multiple users and presented two low complexity EE maximization algorithms for transmit power allocation of BS and IRS reflector parameters. Simulation results depicted optimal SE performance achievement and proved that IRS based communication provides a greater EE as compared to relay aided one. It was also validated that optimal operating point for EE is dependent upon number of mobile users and IRS components along with individual power consumption of IRS elements. In [81], weighted sum power was maximized in an IRS assisted SWIPT system. Simulation results proved that suggested scheme employing IRS can significantly enhance the R-E performance for SWIPT systems.

Integration of IRS in B5G IoT is a promising area to be explored. IRS has introduced a new idea of beamforming that has been previously implemented at transmitters and receivers only but now has been shifted to a controllable environment. Moreover, IRS structures can be easily integrated in the communication environment, since their very small hardware imprint allows for their easy utilization in the IoT e.g in ceilings of buildings, doors, laptop bags, upto being incorporated in human apparel [82]. In this regard, the joint assimilation of RIS with rapidly emergent technologies, such as massive MIMO, mm waves, free space optical communication, IoT, physical layer security, energy harvesting and beamforming is a favorable and new research trend. Hence, IRS is regarded as an inspiring area to be explored for B5G wireless networks with and without energy harvesting.

1.7. CoR for the Internet of Things (IoT)

Cooperative communication is a providential technique that aims to overcome small as well as large scale fading and aids in increasing the reliability of the wireless network [57]. With the advancement in wireless technologies, the 5G of wireless networks has been focusing on developing new applications in various ways of virtual reality, IoT, D2D communications, smart cities, and smart homes [83]. IoT is a network of a large number of different objects linked together and monitored via the Internet. CoR for IoT is shown in Fig. 13. Although there is a swelling interest in the field of IoT technology, several challenges still need to be investigated. One of the most significant challenges is the limited energy of the sensor nodes comprising the IoT network [84]. In order to overcome this challenge, reliable communication protocols need to be developed that increase network life span and reduce energy consumption. Lots of research has been aimed at the use of the CoR in enhancing reliability and reduction in energy consumption of wireless networks by considering either small scale fading modeled by Rayleigh or Nakagami-m distributions, or large scale fading modeled by Log-Normal distribution [85], [86].

In [87], the authors have suggested a generalized K fading channel model that encompasses multipath fading, path-loss, and shadowing for a multi-hop IoT network. They evaluated the average symbol error probability and OP for single-hop as well as multi-hop links. They also proved that for high SNR, increasing the number of hops results in increasing communication reliability depicted by average symbol error probability and OP. For improving the network reliability in IoT, Yang *et* al. [88] designed a communication protocol to guarantee the network reliability between terminals and BS in Narrowband IoT (NB-IoT).

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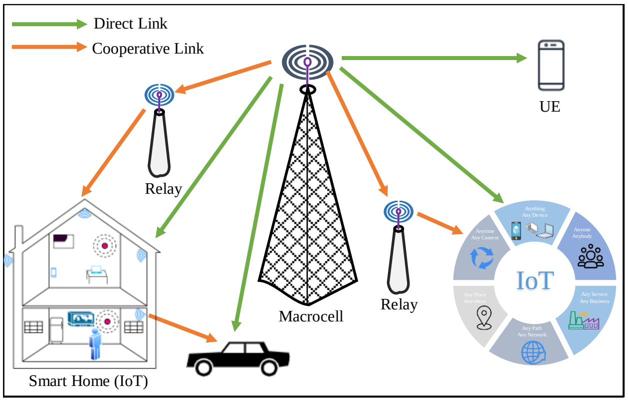

Fig. 13: Cooperative Relaying (CoR) for IoT

They proposed a relay-based cooperative communication framework where D2D communication is suggested to improve network performance, i.e., direct communication between two NB-IoT terminals in a cellular network coverage area with the least involvement of BS.

Authors in [89], proposed a novel relaying framework for energy-efficient uplink transmissions in IoT networks. They formulated a linear optimization problem which was designed to determine optimal positioning of relays along with reducing the total consumed energy while fulfilling a set of constraints, including the budget constraint that decides the maximum number of IoT relays, and the QoS constraint indicated by minimum Signal to Interference Noise Ratio (SINR) of IoT devices. In [90] Bao *et* al. developed an Incremental Selection Hybrid Decode-Amplify Forward (ISHDAF) model for systems with single relay. They developed relay selection algorithm dependent on Hybrid Decode-Amplify-and-Forward (HDAF) scheme considering a multi-relay system along with optimization of power allocation for IoT. They proved that suggested technique can be adopted effectively in cooperative IoT relay systems in order to get high power efficiency and better outage performance [91].

V. SWIPT Assisted CoR

CoR networks equipped with energy harvesting technology, e.g., SWIPT, are getting increased attention by researchers nowadays. This combination of SWIPT and CoR provides lots of advantages for energy limited devices and helps in improving QoS of the network [92].

Relaying protocols for SWIPT based CoR are as follows:

1. Time switching relaying (TSR) protocol:

In TSR protocol, the information block is sent from transmitter to receiver node in time T. The fraction of time for harvesting energy from the source is α, with its value ranging between $0 \le \alpha \le 1$.Here, $(1-\alpha)T$ is utilized for transfer of information, so that $(1-\alpha)T/2$, is used for information transfer from transmitter to relay and remaining portion, given as $(1-\alpha)T/2$, is employed for sending information from relay to receiver [93], [94] as shown in Fig. 14.

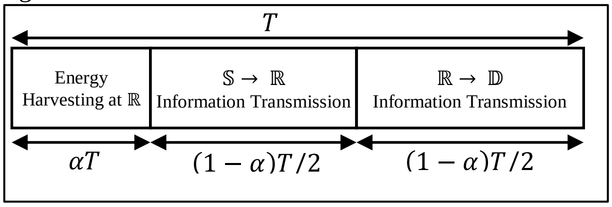

Fig. 14: TSR protocol for SWIPT CoR

2. Power splitting relaying (PSR) protocol:

In PSR protocol, the signal after reception is split in two ratios, ρ being employed for harvesting energy, and remaining $(1-\rho)$ is for information transmission between sources to relay, where $0 \le \rho \le 1$. This can be clearly seen in Fig. 15.

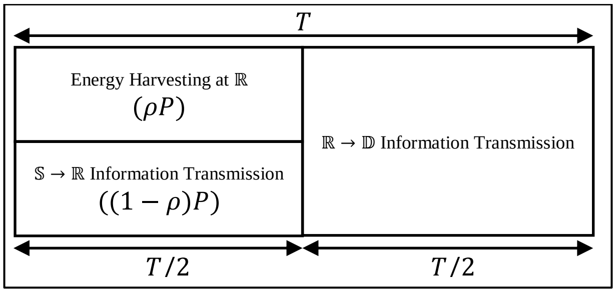

Fig. 15: PSR protocol for SWIPT CoR

3. Hybrid protocol (TSR-PSR) protocol

Atapattu *et* al. in [95] proposed a novel hybrid protocol for EH in SWIPT based CoR networks. It consists of properties of both TSR and PSR protocol. This can be utilized for all types of networks employing relay, with results proving that it outperforms both TS as well as PS protocols [94]. The relay uses αT time for harvesting energy from source, communication between sources to relay takes place in $(1-\alpha)T/2$ time duration. A portion ρ, of signal received is used for EH at relay where $0 \le \rho \le 1$, and the remaining portion $(1-\rho)$ is utilized for transmission of information between S to R. The communication between relay and destination takes place over $(1-\alpha)T/2$ time duration [96]. By putting $\alpha = 0$ or $\rho = 0$, the hybrid protocol turn out to be equal to PS or TS protocol, respectively as shown in Fig. 16.

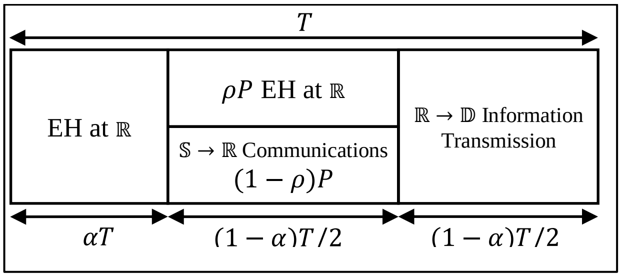

Fig. 16: Hybrid protocol for SWIPT-CoR

A. SWIPT CoR Network without Direct Link

SWIPT CoR has been studied in detail in literature for systems without Direct Link (DL) between source and destination, as depicted in Fig. 17. Nasir *et* al. [90] suggested a three node network having a single source, destination and relay inbetween.AF relaying along with both TSR/PSR protocols were employed for energy harvesting. Outage Probability (OP) as well as ergodic capacity were derived as a measure of throughput in both delay limited as well as delay tolerant transmission modes. They extended their work in [97] using DF relaying instead of AF. Optimal values of throughput with different noise variance values as well as distances between source and relay as well as relay to destination were investigated. Although AF and DF relaying requires additional energy consumption due to power consumed in Power Amplifier (PA) as well as in RF circuitry [98], in analysis of [97] energy required for decoding operation is neglected and complete energy that is harvested at the relay using SWIPT was used for forwarding the data to destination.

Aissa *et* al. [99] discussed the PSR/TSR protocol for harvesting energy with DF relaying at the relay. Here co-channel interference was also utilized to harvest energy. Comparative results showed that PSR is better than TSR at low SNR based on throughput, ergodic capacity, and OP. Considering a three-node network, Wang *et* al. [100] suggested optimal harvested energy and the effect of location of relay on OP in order to explore the idea of deployment of RF EH relays. In [101], the authors studied a two-way AF-based relay network where energy harvesting was done using TSR protocol. Performance analysis of TSR protocol was made based on throughput of network. Since QoS in SWIPT with CoR is directly affected by time and power fraction, authors in [102] worked on finding optimized values of TS parameter (α) and PS ratio (ρ) to maximize the capacity using Lagrange multipliers. SWIPT with cooperative DF systems and non-linear EH model with hybrid relaying protocol was studied in [103]. OP and throughput performance were studied and it was shown that optimal values of ρ and α as well as determining optimal positioning of relay minimizes OP of systems. Furthermore, SWIPT CoR with non-linear EH, the hybrid protocol performs better than TSR as well as PSR protocols in terms OP.

B. SWIPT CoR Networks with Direct Link

A lot of research has been made in SWIPT based CoR networks with DL to increase the diversity gain and performance of communication systems as shown in Fig. 18. In [104] Pan *et* al. considered a dual hop SWIPT system where relay utilizes threshold AF/DF relaying in order to make out whether to assist in S-D direct link transmission or not. OP of system is investigated by employing PSR protocol at the relay. The authors in [105] designed a CoR network where battery enabled relay utilizes SWIPT for charging the battery under delay limited transmission mode. This work is extended to multiple relay scenario where optimal relay is chosen based on minimum outage and minimum distance between source and relay. In [106] Hoolee *et* al. proposed a half-duplex algorithm for a point to point system employing relay being energy constrained and harvesting energy from source using PSR protocol and optimized value of PS ratio (ρ) to obtain minimum OP. Rateless coded SWIPT enabled relay systems were studied in [107].

They devised optimization problems for rate maximization considering three types of receivers, i.e., ideal, PS and TS, respectively. Also, the effect of position of relays on system's performance was discussed. A three-node DF relaying model with PSR protocol for SWIPT was considered in [108], where OP was derived in the presence of Nagakami-M fading channel. They proved that lesser OP is expected in Nagakami instead of the Raleigh fading channel.

In [109], Bai *et al*. investigated PS scheme in nonlinear EH, AF relay network with a direct link. They formulated an optimization scheme for system capacity maximization according to instantaneous CSI based on nonlinear EH model considering a logistic function. Simulation results showed that increased capacity can be attained when PS is optimized with nonlinear EH scheme instead of linear one.

C. Multi-Relays SWIPT CoR Networks

There are a lot of studies in the literature which have focused on involving multiple relays to enhance systems capacity and improve QoS. SWIPT system with multi-relays is depicted in Fig. 19. In [110] a multi-relays CoR system was considered where end to end rate was maximized by optimizing power splitting ratio (ρ) of the relays for both AF/DF relaying protocols. Authors in [111] studied an AF multi-relays network and established HPTS protocol for EH at the relays. Optimal relay is selected based upon end-end SNR. OP and throughput were the performance metrics. Performance analysis of EH multi-relays network in terms of OP with Nagakami-M fading channel is discussed in [112].

Here a direct link is present in the multi-relays scheme. The results show that increase in the number of relays, decreases the OP. An analysis of TSR/PSR protocol with AF/DF relays was presented by Perera *et* al. [113]. Throughput and OP was derived by considering delay limited transmission mode. Multi-relays having direct link between source and destination was discussed. Results show that for lower values of transmission rates, TSR protocol outperforms PSR considering OP, Bit error rate (BER), and throughput. Relay selection (RS) for battery-less and battery-equipped relays were discussed in [114] using PSR for SWIPT and AF relaying protocol at the relays. By studying OP analysis, it was observed that full order diversity K is attained in both non-EH and EH relays. Considerable performance

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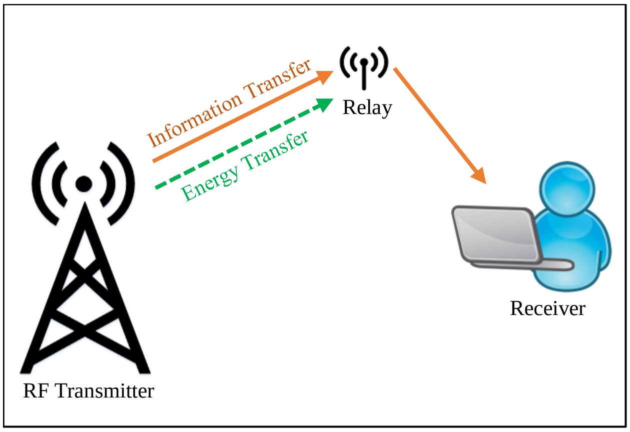

Fig. 17: SWIPT CoR System without Direct Link

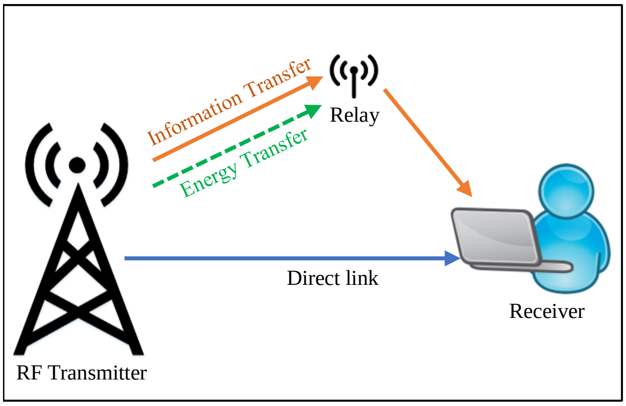

Fig. 18: SWIPT CoR System with Direct Link

improvement is attained if EH relays are used in addition to conventional relays. Here relay selection was based upon highest end to end SNR.

Li *et* al. in [115] derived performance analysis by considering relay assisted cooperative network with multiple relays. From results it was concluded that if multi-relays are utilized for outage improvement CoR can be very helpful. In this article an ON-OFF Markov model was established to discuss stochastic nature of energy harvested.

The idea of selecting optimal relay based upon rateless codes was presented in [116]. Optimization is based upon maximum achievable rate of the network. For the relays harvest-use-store PS strategy was employed. In [117], relay is selected based upon statistical and perfect CSI. Here a dynamic power allocation based relay selection is considered. The results proved that proposed scheme gives a better performance as compared to traditional min-max algorithm. Trade-off exists between acquisition of statistical CSI involving resources vs non practical (ideal) CSI. Relay selection with SWIPT aided CoR was made based upon CSI at the relays. Results showed that a trade-off exists between energy efficiency of real nodes vs number of relays present. In [118], Kridis *et* al. discussed relay selection for Wireless Powered Communication Network (WPCN) based on power level of battery at the relay. Relay selection in the

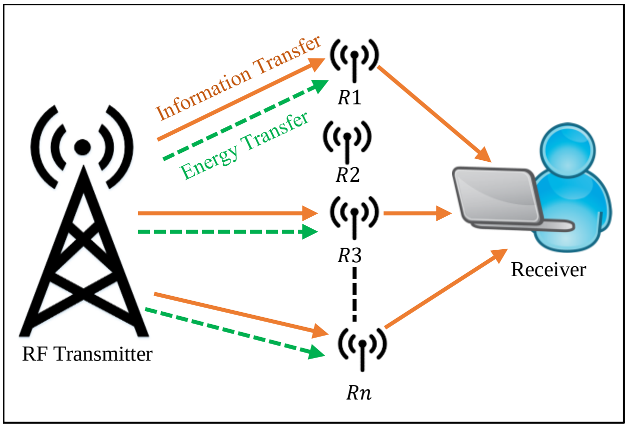

Fig. 19: Multi-relays SWIPT CoR System

presence of multiple relays was dependent upon battery's status. Authors in [119] suggested relay selection considering full duplex two way communication network. PSR was used for EH and Single Relay Selection (SRS) as well as Global Relay Selection (GRS) scheme is proposed.

D. Multi-Antenna SWIPT CoR Networks

Multi-antenna systems have gained significant importance in 5G and beyond networks due to the fact that with a larger number of antennas employed at the transmitter or receiver (MIMO, MISO, SIMO, mMIMO) higher SE and EE can be achieved. It also results in improved diversity along with capacity increase by reducing multipath fading and channel interference by focusing the radiation only in expected direction and then modifying radiation with reference to the signal environments or varying traffic circumstances, a technique named as beamforming[120]. Authors in [121] considered SWIPT based multi-antenna system with DF relaying protocol and TSR at the relays. Performance metrics are throughput and outage for delay limited as well as delay tolerant transmission modes. A multi-relays multi-antenna SWIPT CoR system is shown in Fig. 20. Results show that an increasing the number of antennas along with beamforming enables more energy to be harvested in case of SWIPT. To explore the advantage of multi-antennas at relays Maximum Ratio Transmit (MRT) and Maximum Ratio Combining (MRC) strategies are exploited. An optimal time/power allocation scheme to maximize EE was presented in [122] for full duplex system with relay. The EE of dual vs single antenna is compared and results prove that full duplex mode outperforms half duplex mode. In [123], a joint antenna switching and PS scheme was proposed for rate maximization with optimized values of PS ratio as well as set was determined. A comparison between direct, conventional relaying and proposed scheme showed that highest rate is achieved while using proposed strategy.

A joint resource allocation scheme for multi-antenna relay using DF and PSR protocol at the relay was proposed in [124]. An antenna clustering scheme was suggested for

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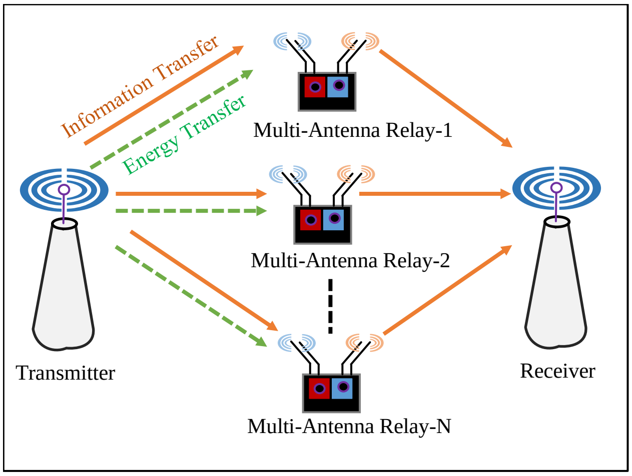

Fig. 20: Multi-antenna SWIPT CoR

antennas in order to perform decoding of information and harvesting energy exclusively. A greedy clustering algorithm to minimize complexity of optimal clustering of antennas was also developed. Results depicted that by increase in the number of antennas at the relay, the spatial diversity and amount of harvested energy can be increased. Authors in [125] suggested a two way multi-antenna CoR system with single antenna at source and destination .Here BER for six relaying schemes as a function of relay antennas, PS ratio and EH time was proposed.

Results showed that optimal values of power splitting ratio and time switching factor which minimized BER depends upon number of relay antennas. Authors in [126] considered a multi-relays multi-antenna system with MRC at the destination to choose best combination of signals from relays and antennas for a given SNR. OP and throughput for both TSR/PSR and AF relaying is discussed. Results show that increase in number of relays and number of relay antennas significantly improves performance of system in terms of throughput. Zahidi *et* al. in [127] proposed a multi-relays multi-antenna system having single antenna at source and multiple antennas at destination. Simulation results showed that MRT strategy at the relay performs better as compared to antenna selection in terms of throughput.

In [128] Liu *et al.* designed a MIMO AF multiple-hop wireless sensor network with both PS and TS schemes applie d at the receiver. The design included multiple relays and multiple antennas to determine a combined beam-forming solution for source and relay precoders for maximizing achievable rate for WSN, based on transmit power and harvested energy constraint and ignoring hardware impairments in the transceiver circuitry. In order to find joint design of beamforming matrices a diagonalization-based optimization scheme was suggested.

E. MIMO with nonlinear EH and imperfect CSI:

In [129] authors investigated a dual hop MIMO system having multi antenna source, destination as well as single antenna relay with PSR for EH and DF for processing information, by assuming negligible energy consumption for DF operation. The energy harvester at relay was considered to be utilizing a non-linear EH model having a saturation threshold. The transmission delays and the complexity of wireless environment was accounted for by assuming imperfect CSI both at source and destination. Thus authors employed a TAS scheme at the source by considering outdated CSI fed back from the EH relay and MRC at the destination in order to handle duplicate copies of signals with channel estimation errors. By considering best relay selection beamforming criterion giving best performance in terms of OP considering relay, source and destination, analytical expression of OP was calculated and validated through simulations. In [130], authors developed a SWIPT based protocol by considering non-linear energy harvesting model in massive MIMO systems. Here a more realistic power consumption scheme was suggested. Particularly, after harvesting the energy, a part of energy harvested is employed for basic processing, e.g. consumption of energy for channel estimation, energy consumed by the hardware circuitry and feedback from the channel. The remaining energy is used for subsequent information transmission. Authors proposed a beam-domain SWIPT protocol for massive MIMO system and the SE of the system was maximized by finding optimized values of TS ratio and BS transmit power. The results showed that by employing Basis Expansion Model (BEM) great reduction in size of channel that requires estimation can be achieved together with number of CSIs needing feedback, thereby reducing feedback overhead for downlink estimation of channel.

F. SWIPT COR with hardware impairments (HI):

In order to physically implement RF transmitters we need to consider a number of impairments that deteriorate the quality of signal received, apart from the effects of fading and thermal noise at the receivers [131]. RF transmitters use Power Amplifiers (PAs) to guarantee that signals are communicated at the desired power levels. Due to this fact, PAs are operated with large input power resulting in undesired and nonlinear distortions. Although pre-distortion or calibration algorithms, can be utilized to partially mitigate of these problems and their impact, but still these Hardware Impairments (HIs) cannot be fully removed. Added impairments owing to low quality hardware e.g. I/Q imbalance, phase noise, sampling rate offset and carrier frequency as well as impedance mismatch together with other rapidly changing nonlinearities further degrade the performance of systems [132].

Recently, there has been a lot of research on performance analysis and other related issues in several cooperative relaying systems which consider the involvement of HIs. In

[133], authors discussed the OP analysis of dual hop MIMO systems having AF relaying and involving HIs. By considering fixed as well as variable gain relaying beamforming algorithms, OP expressions were analyzed at SNR. Results showed the effects of HIs and number of antennas employed at relay on performance of system. Authors in [134], discussed the outage performance of a PS based two way AF SWIPT cooperative network with Time Division Broadcast (TDBC) and Nakagami-m fading channel, including HIs at the transceivers. An expression in closed form for system's OP based on HIs was derived. Results showed that optimal PS ratio increases when there is an increase in shape parameter of relay links and there is a decrease in OP as soon as the relay is located closer to that terminal which a lesser shape parameter of its relay link.

Apart from HIs, imperfect CSI (ICSI) is also a critical factor affecting the performance of various 5G and beyond wireless systems. NOMA based AF relay system in the presence of residual hardware impairments (RHIs), Channel Estimation Errors (CEE) and imperfect Successive Interference Cancellation (ipSIC) were discussed in [135]. By considering OP and EE as performance metrics, it is observed that RHIs, ipSIC and CEE all have an adverse effect on performance of the system. Additionally, it was depicted that CEEs have more effect on OP than RHIs. In [136], Li et.al discussed the effects of HIs and ICSI (imperfect channel state information) by considering a cooperative multi-relay system with NOMA and EH.OP was derived using PSR protocol. Simulation results showed that HIs have a considerable effect on OP performance and ICSI has a negative impact resulting in an increase in OP, the effects of which can be greatly reduced by an increase in number of relays. In [137], authors suggested a SWIPT based NOMA network where EH is done using TSR protocol by taking into account ICSI and residual hardware impairments (RHIs).OP as well as throughput in (delay limited transmission mode) were the performance metrics . It is depicted that performance of system is greatly limited by ICSI and RHIs resulting in an error floor for OP and diversity order gets zero. Additionally, it is seen that the throughput can be maximized by carefully determining the TS parameter.

G. Exploring SWIPT at 5G and B5G new frequencies:

5G and B5G is expected to offer end users with Gbps data rate as well as minimum latency, so that various new applications can be supported anytime anywhere. Nevertheless, the requirement of high data rate typically results in a greater consumption of energy, which reduces the QoS experience of users, specifically battery equipped powered devices. Thus some IoT sensors and wearable devices suffer from energy insufficiency as recharging is often very difficult in certain situations. Therefore, it has become a notable concern in optimization and design of B5G wireless communication as how to manage the conflict between conservation of energy and rate enhancement, where in SWIPT can play its vital role.

Although a lot of research has been made on integration of SWIPT with various multiple access technologies e.g. orthogonal frequency-division multiple access (OFDMA), time-division multiple access (TDMA) and NOMA. However most works in literature studied SWIPT only in the low frequency (LF) band. For satisfying the extremely high data rate requirements of 5G and B5G, high frequency (HF) band, i.e., mmWave, becomes unavoidable choice for enhancing available spectrum since LF band has a limited bandwidth. Furthermore, the channel propagation characteristics of some new frequencies that are considered in 5G and shall be exploited in B5G are entirely different from traditional LF channel models specifically lower than 3 GHz [138]. Thus it is imperative to determine correct channel propagation characteristics in order for SWIPT to work at new frequencies in both low and high frequency bands. In [139], authors examined SWIPT at 5G new frequency bands comprising measurement of channel parameters by considering large scale fading in both LF (3.5GHz) and HF (28GHz) spectrum, network design and optimization by taking into account both indoor and outdoor setups. A comparison of propagation characteristics of these two frequency bands was discussed and a more precise channel model was developed. For enhancement of EH efficiency of the proposed SWIPT network, a dual band network model was suggested with an optimized power allocation scheme and channel assignment for every user

VI. SWIPT CoR FOR INTERNET OF THINGS (IoT)

IoT is an evolving technique providing smart exchange of information for various intelligent devices in future networks including 5G and B5G [140]. With the advancements in IoT, energy as well as spectral efficiency are the two vital concerns owing to a widespread increase in the number of IoT devices. The aim of IoT is to establish a connection between physical and virtual environment to realize a self-sustaining system [141]. In order to attain this integration in future, many research works have been done to accomplish the application of IoT technology in smart cities, smart energy, smart homes, smart commutation and many more. The evolution of IoT originated from WSN and established into various heterogeneous networks capable of communicating with each other by utilizing Internet [142].While WSN networks are operating in their private networks, IoT accumulates numerous sensor networks in an IoT network which can access the Internet [143].

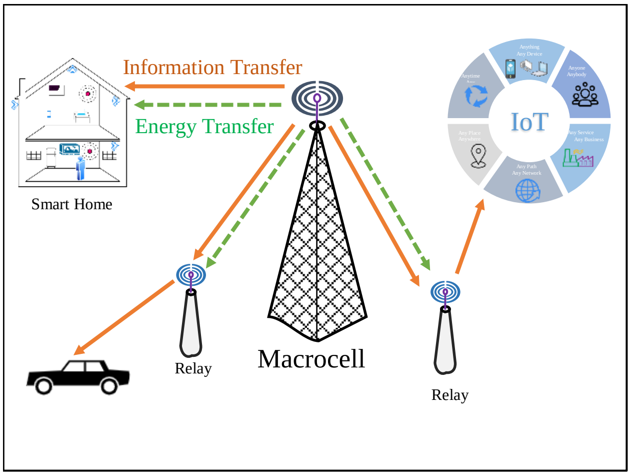

Fig. 21: SWIPT CoR for IoT

The rapidly developing IoT region is aiming to accelerate the consumption of energy required by small devices drastically. Since many sensors are being employed with power consumption of order of 1 W or less, the huge amount of such devices approx. 25 billion is aiming to utilize greater power as compared to cellular networks throughout the world [144]. Consequently, it is imperative to deal with this evolving challenge of EE in all of these small devices by employing an emerging RF harvesting technique called SWIPT. Apart from prolonging their lifetime, cooperative relaying has been employed for IoT systems with SWIPT, primarily to improve their coverage and capacity along with self-sustainability. Thus SWIPT CoR for next generation wireless networks particularly for IoT is an emerging area of research. Guo *et* al. in [144] discussed optimal scheduling of information and power transfer by the transmitter and introduced the concept of crowd harvesting, i.e., harvesting from other sources apart from transmitters. They discussed SWIPT and non-SWIPT based relaying where non-SWIPT case can make use of crowd harvesting from wireless access points, TV and BS downlinks. For Line Of Sight (LOS) TV bands are helpful sources of EH while for non-LOS Wi-Fi can play its part. SWIPT CoR for IoT is shown in Fig. 21.

Authors in [145] discussed resource management scheme in a DF cooperative IoT network. They proposed an optimization scheme to maximize overall sum rate considering proper relay assignment, power splitting ratio selection and power allocation. Results showed that CoR with diversity increases the data rates for individual IoT devices while enhancing the sum rate of overall network. Lu *et* al. devised an optimization problem for transmission rate maximization in a multi-relays Orthogonal Frequency Division Multiplexing (OFDM) based IoT network [146]. Simulation results based on effect of number of relays, conversion efficiency and power splitting ratio on transmission rate proved that the rate of transmission is increased considerably by the suggested scheme.

In [147], relay selection criterion based upon residual energy at the relays for IoT system was suggested. Using stochastic geometry approach large and small scale fading effects were encountered. OP based on simple relay selection was derived based on approximate relay location. An Ultra-Reliable Low Latency Communication (ULLC) network was considered in [148] where reliability of IoT based CoR network was improved by optimized parameters for TS and PS along with finite block length codes.

In [149], an EH CoR system comprising of source, destination as well as multiple relays with DF protocol was considered by employing PSR protocol to harvest energy. A comparison between equal Power-Splitting-Based Relay Selection (EPS-RS) vs Optimal Power-Splitting-Based Relay Selection (OPS-RS) was made. They also proposed optimal relay selection for EH relays having batteries to store energy harvested. Results showed that battery enabled optimal power splitting relay selection outperformed the conventional equal power splitting based relay selection without batteries.

Authors in [150], examined a DF SWIPT with multi-hop relays considering IoT sensor network. A node with single antenna was considered with two optimization problems. The first problem optimized PS ratio by considering minimization of source transmit power and then as a second case the PS ratio was optimized with the objective of maximum achievable rate. Along with obtaining closed form solutions a few extension in their work have also been suggested.

A. SWIPT CoR with HI for B5G IoT:

One of the most challenging task for 5G and beyond 5G (B5G) is the connectivity of enormously large number of intelligent devices i.e IoT. The extensive applications of IoT and massive IoT in various fields, such as industrial applications, medicine, agriculture and many more have stimulated an extensive increase in number of IoT devices. Thus B5G wireless communication networks shall be facing large number of issues, such as energy consumption requirements and efficient spectrum utilization specifically for massive IoT. Recent studies involving IoT focused on ideal hardware circuitry and perfect CSI. However, non-linearity in the hardware as well as imperfections in channel estimates must be accounted for in order to develop a close approximation of realistic environments. In [151], authors determined the performance of cooperative SWIPT IoT systems based on NOMA, in the presence of RHI and CEE. By employing PRS protocol, OP for Near User (NU) and Far User (FU) as well as diversity orders in high SNR region were studied. Results showed that CEE has an adverse effect on system's performance causing an increase in OP, but by increasing number of relays, effect of HI and CEE can be reduced.

Authors in [152] discussed a cooperative NOMA system for IoT with a master node serving multiple client nodes in the presence of HIs. The relay node can operate in both half as well as full duplex mode. The performance metrics are

OP and ergodic capacity, and results showed that there is a degradation in performance owing to HIs. The combined effect of in phase and quadrature phase imbalance (IQI) and ipSIC on NOMA based cooperative IoT network is discussed in [153]. Performance metrics are OP for near and far IoT, throughput and EE in the presence of HIs. It is depicted from simulation results that compared ipSIC has a greater effect on OP for the near IoT device as compared to IQI of the proposed system. Results show that OP of IoT devices can be decreased by designing a specific scheme for power allocation.

Authors in [154] investigated the performance of SWIPT with cooperative relaying and NOMA in the presence of CEE and HIs for IoT system. Multiple relays were employed and optimal relay was selected based on partial relay selection (PRS) protocol to forward the received signal to near and far users in proposed IoT network. Simulation results depicted that hardware impairment parameter (k) has a negative impact on system performance whereas the channel estimation parameter (δ) was found beneficial for OP. Security aspects exploiting the existence of eavesdroppers for B5G networks were discussed in [155]. A framework was developed to estimate the security and reliability of SWIPT based multi-relay network employing DF relays. Analysis was based on nonlinear energy harvesters, CEE and IQI. Analytical expressions for OP and intercept probability (IP) were obtained and simulation results depicted that IQI mismatch decreases OP performance and provides IP performance improvement. Also by increasing the number of relays better OP can be achieved.

Authors in [156] suggested SWIPT based EH by employing TSR, PSR and NOMA in the presence of interference for IoT cooperative relay systems. Novelty of their work was that they developed a model in which data was transmitted not only by source node but IoT relay node data was also forwarded by employing NOMA protocol to the destination. OP and throughput were the performance metrics. Authors suggested a very realistic scheme that could be simply employed for various IoT applications e.g underground tunnels, coal mines, under water applications as well as hazardous and toxic surroundings where IoT devices are utilized as detectors.

VII. FUTURE CHALLENGES

There are a few future challenges in SWIPT based relay networks which have to be explored in order to get better performance. The brief review of major challenges is outlined below:

1) Interference Management:
One of the significant challenges in SWIPT scheme is exploiting the interference, which involves proper interference management as it is supposed to be a harmful factor affecting the QoS of the information signal. However strong interference could be useful in increasing the energy harvested for an EH receiver. A challenging task is to utilize interference from various sources e.g in a large scale IoT network to its maximum for EH by keeping QoS constraints on ID [157].

2) Resource Allocation:
Resource allocation is a critical factor to enhance performance of SWIPT systems. Optimized resource scheduling mechanisms need to be developed based on maximum harvested energy and QoS constraint along with minimum transmission power of the source. Although a lot of research is ongoing on this area [158], [159] still new algorithms need to be developed specifically for massive IoT networks.

3) CSI Estimation:
When considering a wireless communication network taking into account effects of fading is of prime importance. If availability of CSI is made at the transmitter, the transmitter can adjust it's transmit power according to channel state such that there is no wastage of energy for transmission when deep channel fading is there. A more challenging task is CSI acquisition using training sequences and their management for large scale IoT network with billions of devices connected together and exchanging formation.

4) Relay Selection Optimization:
When considering a multi relay CoR network with SWIPT for EH, a major task is to optimally select relay for both EH and ID. As it is seen in literature [13], that the relay which is suitable for ID may not be optimal for harvesting energy. Although existing researches explore the idea of optimal relay selection in SWIPT systems, yet more algorithms needs to be developed so as to satisfy EH and ID constraints at the same time with proper relay selection specially when considering an IoT framework.

5) Security Issues:
In SWIPT with CoR, although the relay is a cooperative node, it may be a malicious node or an eavesdropper. Thus an untrusted relay may escalate probability of interception considerably. Use of massive MIMO techniques to improve information transmission security and to increase power transfer efficiency simultaneously have been discussed in [150]. Although lots of research work is done in this field, still more attention has to be given to develop adaptive and dynamic security algorithms for energy harvesting cooperative SWIPT networks.

6) Massive MIMO and massive access for B5G networks:
Multi antenna technology has certainly been a vital part of 5G networks, but it is equally important for researchers all over to globe to devise new multiple antenna schemes so as

to obtain the enormously large data rate, traffic loads and reliability in the B5G networks. For B5G, massive MIMO involving an array of at least 64 antennas has gained significant attention. In [160], authors reviewed multiple antenna technologies that play a massive role in B5G networks namely cell-free massive MIMO, beamspace massive MIMO, and IRS. Cell-free massive MIMO comprises of many APs with one or more antennas connected to a central unit through optical fiber links [161]. Cell-free massive MIMO widens the coverage area and has a high spectral efficiency. The extensive uses of IoT in various fields, such as agriculture, telemedicine as well as traffic have stimulated a drastic increase in number of IoT devices. In [162], authors discussed massive connectivity for 5G and B5G wireless networks. The massive IoT applications can acquire access to numerous wireless networks primarily through low-cost technologies e.g ZigBee, WiFi and Bluetooth. In order to have a broader coverage for IoT, presently, cellular IoT and Long Range Radio (LoRa) are two major access techniques. As compared to LoRa technology, cellular IoT is more helpful and cost-effective for service providers because it reutilizes prevailing cellular infrastructure. They have provided a detailed review on massive access in B5G cellular IoT involving less power, enormous connectivity as well as wider coverage. Massive access is still an emerging area of research in the context of SWIPT and CoR.

7) SWIPT CoR for mmWave:

Owing to enormous available bandwidth potential, the mmWave has a huge potential to fulfill the demand of the next generation wireless networks [163]. The mmWave communications suffer from major technical challenges like severe path loss, directivity issues, sensitivity to blockage and smaller beamwidth because of short wavelengths [164]. The mmWave and its integration with SWIPT CoR is relatively a new research area which has gained swelling interest by researchers in detail. In [165], authors discussed the characteristics of 5G mmWave systems and provided a general framework of SWIPT assisted mmWave network. . In [166], a rectenna at 24 GHz was successfully designed and the possibility of WPT towards mmWave technology was demonstrated. Also, a harvest-use strategy was suggested in [166], where harvesting energy from BS via mmWave signals and then consuming the harvested energy to transmit data was proposed. In [167], authors discussed a scheme by which a joint optimization of the transmit power, beamforming, and power splitting ratio for a lens-array antenna structure leading to maximization of energy efficiency of SWIPT systems was suggested . Kamga and Aissa [168] examined the performance of WPT in mmWave massive MIMO, working in both rainy as well as clear conditions. It was demonstrated that rain attenuation has a significant effect on EH efficiency in HF band and can also make WPT difficult in severe cases. The performance of relay assisted mmWave massive MIMO system was suggested in [169]. In a similar system, authors in [170] examined the EH capability of mmWave by considering the stochastic geometry approach. Optimized power allocation algorithms still have to be developed so that enhancement in performance of mmWave based SWIPT systems can be made with particular focus on a network of largely connected IoT devices. Future challenges in terms of SWIPT based mmWave communications include exploiting the diversity and spatial multiplexing gain for massive MIMO systems, power splitting and transceiver design, development of hybrid precoding model and exploring the design of RF hardware prototypes. In summary, extensive research needs to be carried out to explore the benefits of mmWave SWIPT systems involving CoR in future.

8) SWIPT for Underwater Internet of Things (UIoT):

An expansion of the IoT in the submarine surroundings, is called the underwater IoT, which has started to become a progressively more leading technology to develop the smart ocean environment [171]. Underwater IoT (UIoT) is a smart network having autonomously learning intelligent computing abilities. The sensing, monitoring, and identification of underwater objects can be done in UIoT by employing wired or wireless communication technologies. Hence, the model and design of the land-based IoT cannot be adopted directly by the UIoT. For instance, ocean currents constitute a non-negligible issue for the deployment of the UIoT [172]. Underwater node movement in the UIoT caused by ocean currents often affects network coverage and data transmission quality. In addition, the battery power of UIoT sensor nodes is severely limited, and node batteries cannot be conveniently recharged owing to the limitation of seawater corrosion and seawater pressure. A challenging task is to design a framework for recharging the batteries of underwater equipment [173]. Hence, underwater research and development could have a significant impact on many aspects of human’s life by establishing and rolling out the UIoT. Therefore the design ,analysis and implementation of SWIPT protocols for energy efficient sensor nodes employed underwater is an open challenge for 5G and B5G networks.

VIII. CONCLUSION

This article reviewed the important concepts of SWIPT and its applications in wireless networks. SWIPT is an emerging technology that enables the transmission of energy along with the information at the same time providing spectral and energy efficient resolution considering 5G and beyond wireless networks. This article particularly focused on SWIPT, its architecture and its application in IoT networks. Moreover, it also provided a review on CoR and its use in IoT technology. The combination of SWIPT with CoR for IoT networks is also presented in detail. Although a large

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number of opportunities as well challenges are coming forward in SWIPT based CoR, some of them have been stated above. However, greater attention and investigations are required to completely explore the two conspicuous technologies for additional development of future generations of wireless networks.

APPENDIX

TABLE II
A LIST OF ACRONYMS USED IN THIS MANUSCRIPT.

Acronyms	Definition
4G	Fourth Generation
5G	Fifth Generation
AF	Amplify and Forward
AS	Antenna Switching
AWGN	Additive White Gaussian Noise
B5G	Beyond Fifth Generation
BEM	Basis Expansion Model
BER	Bit Error Rate
BS	Base Station
CF	Code & Forward relaying protocol
CoR	Cooperative Relaying
CSI	Channel State Information
CW	Continuous Wave
D2D	Device to Device
DA	Distributed Antenna
DAS	Distributed Antenna System
DC	Direct Current
DF	Decode and Forward
DL	Direct Link
EE	Electrical Efficiency
EH	Wireless Energy Harvesting
EPS-RS	Equal Power-Splitting-Based Relay Selection
FAF	Fixed Amplify & Forward Relaying Protocol
FDF	Fixed Decode &Forward Relaying Protocol
GRS	Global Relay Selection
HDAF	Hybrid decode-amplify-and-forward
HI	Hardware Impairments
IoT	Internet of Things
IR	Incremental relaying protocol
IRS	Intelligent Reconfigurable Surface
LES	Low Earth Satellite
LOS	Line Of Sight
M2M	Machine-to-Machine
MIMO	Multiple-Input-Multiple-Output
MIMO-BC	Multiple-Input Multiple-Output Broadcast Channel
mmWave	Millimeter-Wave
MRC	Maximum Ratio Combining
MRT	Maximum Ratio Transmit
NB-IoT	Narrowband IoT
NOMA	Non-Orthogonal Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
OP	Outage Probability
OPS-RS	Optimal Power-Splitting-Based Relay Selection
PA	Power Amplifier
PS	Power Splitting
PSR	Power Splitting Relaying
QoS	Quality-of-Service
R-E	Rate-Energy
RF	Radio Frequency
RF-EH	Radio Frequency Energy Harvesting
RNs	Relay Nodes
RS	Relay Selection
SDF	Selective Decode & Forward Relaying Protocol
SE	Spectral Efficiency
SINR	Signal to Interference and Noise Ratio
SISO	Single-Input-Single-Output
SIMO	Single-Input-Multiple-Output
SNR	Signal to Noise Ratio
SRS	Single Relay Selection
SWIPT	Simultaneous Wireless Information and Power Transfer
TDBC	Time Division Broadcast
TS	Time Switching
TSR	Time Switching Relaying
TSR-PSR	Hybrid Protocol
UIoT	Underwater Internet of Things
ULLC	Ultra-Reliable Low Latency Communication
WIT	Wireless Information Transfer
WPCN	Wireless Powered Communication Network
WPT	Wireless Power Transfer
WSN	Wireless Sensor Networks
α	Time Switching Parameter
ρ	Power Splitting Ratio

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