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A Brief Overview of SWIPT in Wireless Communication Networks

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Abstract
Simultaneous Wireless Information and Power Transfer (SWIPT) which is a Radio Frequency (RF) energy harvesting (EH) technique, allows devices which are energy constrained to harvest energy from sources which are electromagnetic in nature. The harvested energy is required by energy constrained node for information transmission, which plays a crucial role in cooperative communication. SWIPT which has been an area of current research, minimizes the dependence on power grid supplies, making it suited for implementation in cooperative networks because RF signals simultaneously convey wireless energy and information. SWIPT which is an EH technology, in RF wireless communication has been identified as an enabling 5G technology which expands the use and opportunities of internet of things (IoT) and enriches lives to enhance social resilience in order to maximize the potential in cellular networks, since it guarantees remarkably low latency for user communication. Long distance communication can be supported between communicating nodes with the aid of SWIPT, when an energy constrained relay node harvest energy form RF signals it received in order to assist in information transmission from transmitter to receiver in cooperative communication networks. This improves the energy efficiency (EE) and spectrum efficiency (SE) or throughput of wireless communication network. This paper presents an overview of SWIPT in wireless communication network and various procedures to achieve SWIPT.

Keywords: *Energy harvesting, energy efficiency, resource allocation, SWIPT, throughput.*

1.0 Introduction

Due to recent advances in wireless communication, majorly battery life limitation has always been taken into account in the energy constrained cooperative and non-cooperative wireless network and this largely limits the performance of the network life of a battery, which can be sustained for a longer period when sustainable power supply is considered. The emergence of fifth generation (5G) technology [1] has led to the explosive integration of billions of intelligent and smart devices giving rise to new research interest and challenges as a result of the unharnessed ambient radio frequency (RF) wastage and radiation pollution. Among the viable remedies to the wastage of these abundant RF energy resources is the green communication which has paved a new path for energy explorations. This technology involves the selection of energy efficient techniques in advanced network architecture aimed at optimizing scarce network resources and providing a better network quality of service (QoS) to network users [1]. Recently resource allocation in wireless networks has been based on EH technology. This is invariably applied to Device -to-Device (D2D) technology. D2D communication is one of the major applications of 5G technology which is being used recently in achieving an efficient network resource allocation, with this technique user equipments (UEs) in close proximity can send and receive information through a direct link rather than having their RF signal transversing through the base station (BS) or central network. One of the major benefits of D2D is the extremely low communication latency as a result of a shorter signal traversal path. D2D communication is now thought to be one of numerous techniques that falls under the 5G umbrella and undergoes development, which provides a variety of opportunities in which high data rate peer-to-peer (P2P) link is established. Consequently, D2D fifth generation (5G) networks which is based on hand held devices witnessed energy constraints. RF-EH and information transfer also known as SWIPT which has been proposed to switch on energy constrained communicating nodes has brought the rationale that, RF signals simultaneously transfer information and wireless energy [2,3]. However, nodes which are energy constrained in cooperative wireless networks can use the RF signals that the energetic nodes transmit to harvest energy, which will be used simultaneously to process and transmit information [4,5]. In recent times EH has gained serious attention which has made self-

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sustaining nodes to establish, appropriate technique to charge batteries in recent and future 5G communication cooperative networks [6,7].

In light of the aforementioned, signals from nearby cellular devices may also be used as a backup source of energy in addition to those obtained by wireless energy harvester circuits. RF wireless energy can be harvested using power-cast power harvesters, these harvesters can scavenge energy or power of 3.5mW and $1\mu W$ at distances of 0.6m and 11.6m as reported by [8,9], at an operating frequency of 915MHz. The early researches on SWIPT assumed that power and information could be extracted from the same signal. Cooperative relaying techniques can be implemented in communication networks to alleviate signal fading issues, which results in placing relay nodes between a transmitter and a receiver, this results in improvement on the performance metrics of the network such as throughput and EE.

The introduction of SWIPT which implies EH from ambient RF signals permits nodes in wireless cooperative communicating nodes, that are energy-constrained to replenish their energy and, as a result, extend their lifetime, making SWIPT a promising supporting technology for wireless cooperative communication networks.

However, putting cutting-edge technologies in place to realize SWIPT in relay aided network, which is a recent paradigm in 5G technology has been an unprecedented mission. This work is to highlight the benefits brought about by SWIPT enabled D2D technologies that may be appropriately exploited within IoT ecosystems operating within future 5G systems. Based on the effectiveness of existing SWIPT-enabled cooperative communications, different techniques for achieving SWIPT will be critically examined.

1.1 Contribution

This review's commitments are outlined below:

- This study aims to investigate the existing different techniques for achieving SWIPT in terms of their implementation benefits and drawbacks.
- According to findings, the majority of existing SWIPT techniques and remedies are intended for a particular purpose, which inhibits them from adapting to changing network parameters and making them bereft of achieving certain desired objective aside from their primary goals.
- This paper highlight research gaps in SWIPT in wireless communication.

Other sections of this paper are arranged as follow:

Table 1: Summary of the work

Section	Content
2.0	Methods of achieving SWIPT
3.0	Overview of Energy Harvesting in Cooperative Networks
4.0	Conclusion

1.2 Background to SWIPT

Traditional renewable energy resources such as solar, wind e.t.c and other resource allocation techniques have been examined for objective applications and network topologies. Due to instability in the character of these energy sources, QoS cannot be guaranteed, therefore the implementation of RF-EH was established. Energy constrained node harvest energy from RF signals which come from nodes that are energetic or have fixed power supplies [7]. Furthermore, RF signals offer a cost-effective option for the maintenance and smooth running of wireless systems without requiring any modifications to the transmitter end's hardware by concurrently delivering wireless transmission that is effective and under control including energy as needed

Nonetheless, in practice, the RF-EH circuit which is used for scavenging energy from RF signals in the environment does not have the capacity to recognize the carried information instantaneously [8]. Strategically harvesting energy from the surrounding signal and from a dedicated, well-managed source, like a grid-powered BS or BS that use traditional renewable energy sources, are two ways to obtain energy. Superimposing information and power transfer, create significant benefits based on energy usage, reduction in time delay, improves throughput, and managing interference, which are achievable [9]. However, current SWIPT research has shown that designing a wireless communication system requires making trade-offs between maximizing wireless information transfer and energy transmission. An energy harvesting enabled cooperative network where the relay node is considered harvesting energy from the BS is shown in Figure 1.

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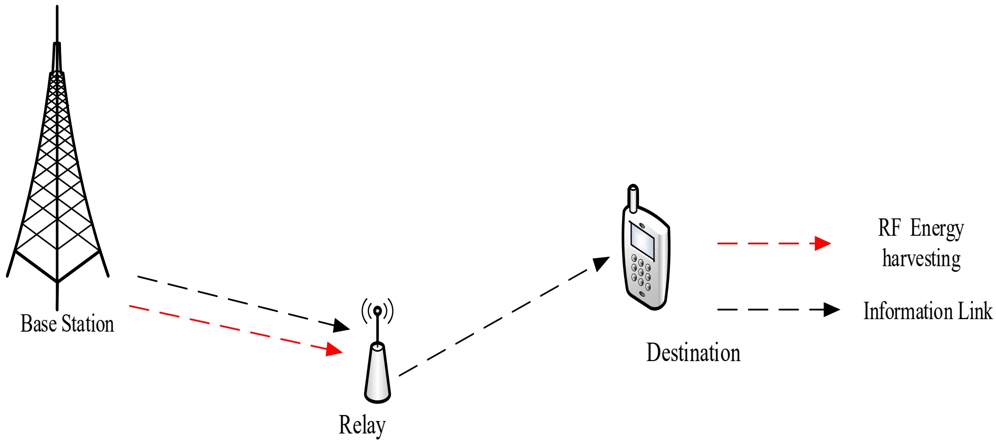

Figure 1: RF-EH enabled cooperative network [16]

2.0 Methods of Achieving SWIPT

Researchers in previous studies provided information on SWIPT, which establishes the fact that signal carry both information and energy, which invariably acknowledges the fact that there is a basic relationship between information and energy transfer. However, in practice, this assumption of synchronous transfer proves to be incorrect [4], considering that the circuits used in real applications scavenge energy in the surrounding environment from RF signals are unable to instantaneously recognize the data being transported. However, the content of the information may be destroyed by the EH operation conducted in the RF region [12]. In order to realize SWIPT, the EH receiver's function is to split the incoming signal in to two: one for EH and the other for information processing. Numerous researchers have embraced this approach at the EH enabled node [12,13]. The various methods that have been suggested to accomplish this signal splitting in the various domains are briefly enumerated in the subsequent section.

2.1 Power Splitting (PS) Technique

The signal strength P at the receiver is segmented into two fractions in the PS approach, ρ:1 – ρ, where $0 \leq \rho \leq 1$ [14]. The EH receiver circuit harvest a fraction ρ of the signal power while the other fraction 1 – ρ, is for the information decoding at the receiver [15] as shown in Figure 2. The factor ρ also known as the PS factor is been optimized to improve throughput of the channel.

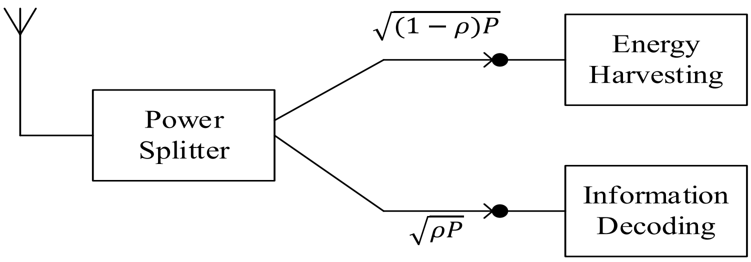

Figure 2: Power splitting architecture [16]

However, under this technique, power transfer and information decoding are done concurrently, the signal is received at the destination simultaneously during energy harvesting, this technology achieves spontaneous SWIPT, which implies that PS technique is suitable to delay constraints applications.

2.2 Time Switching Technique

This technique takes cognisance of the fact that, the receiving node is built with specificity, and uses the fractional time factor α, to complete SWIPT, which dynamically vary throughout time, for information processing and EH. In this technique, the received signal during a single slot is either used for information decoding or transfer of power. Based on this technique, when the information receiver unit is off, all of the power received from the signal is utilized for EH, at the EH receiver, while information decoding consumes all of the signal power received when the information processing unit is turned on [4]. Based on the foregoing, the implementation of TS technique at the receiver is simpler than the PS technique, but it still needs information or energy scheduling and accurate time synchronization. The SWIPT transmission block diagram employing the TS method is depicted in Figure 3.

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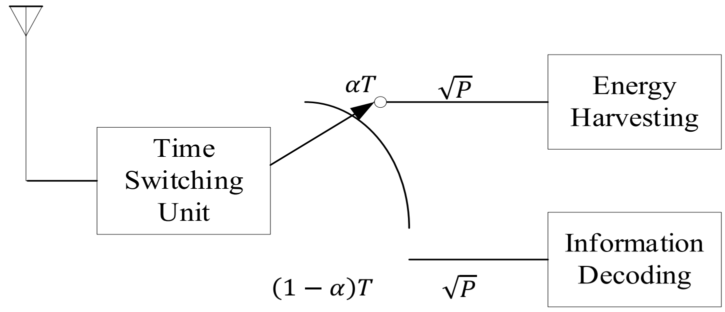

Figure 3: Time Switching Architecture [16]

2.3 *Antenna Switching*

Antenna arrays are typically utilized to provide direct current (DC) power for dependable device operation. This method served as inspiration for the antenna switching (AS) methodology, which achieves SWIPT in the antenna domain. This scheme as shown in Figure 4, involves a set of antennae deployed for information processing and another set is implemented for EH [16]. Though in this scheme, EH and information decoding are performed in a consecutive manner [12]. The AS approach determines the best antenna assigned for information decoding and energy harvesting by solving an optimization problem in each communication frame. Though, most literatures considered AS technique to be highly complex, therefore AS schemes with low complexity were devised that apply the generalized selection combining principles to make SWIPT easier.

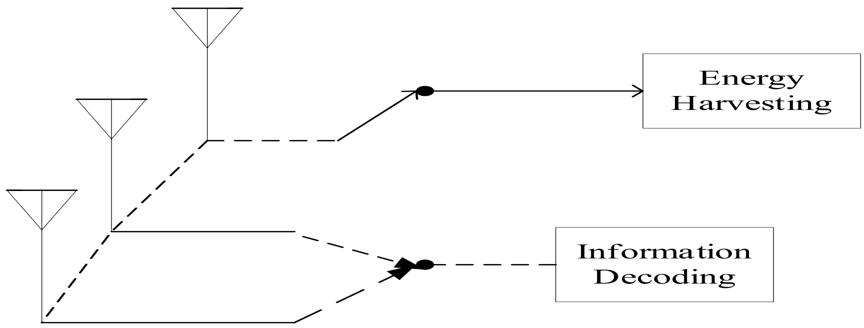

Figure 4: Antenna switching architecture [16]

3.0 Overview OF Energy Harvesting in Cooperative Networks

The main challenges for SWIPT include signal fading and reduction in throughput or energy efficiency due to long distance communication. The use of cooperative relaying can mitigate these challenging issues. As previously discussed, the most commonly considered EH scheme is the TS and PS scheme. Basically, the illustration of TS scheme is shown in Figure 5, for information decoding and energy harvesting at the relay, where, T is the time taken for a block of data to be transmitted from the transmitting node to the receiving node, and α is the fraction of that time that the relay scavenges energy from the source signal, where $0 \leq \alpha \leq 1$. Therefore, the remainder of the block time (1- α)T is used for information transmission, in this case, half of $(1-\alpha)T$ is used for transmission of information from source node to relay node, while the remaining, is used for information transmission from relay node to destination node. The relay uses up all of the energy collected during the energy harvesting phase while transmitting information source signal to the destination. The possible throughput at the destination depends on the time fraction, selected for EH at the relay node. Basically, it is of importance to note that the transmitted signal $y(t)$, is most times corrupted by narrowband Gaussian noise, $\tilde{n}_a{}^{[r]}(t)$, which is introduced by the receiving antenna and this noise can also be harvested by the EH circuit at the relay node, it is also of good importance to be aware that noise is also developed at the EH relay node, due to the conversion of the RF signal to baseband signal.

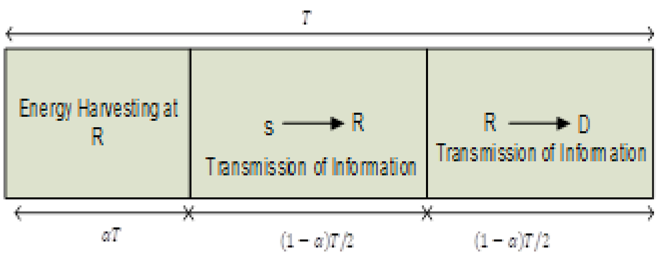

Figure 5: Transmission block structure for TS technique [22]

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The equation of the received signal at the relay in TS technique, is given by:

$$y_r(t) = \frac{1}{\sqrt{d^m}}\sqrt{P_s}\, hs(t) + \tilde{n}_a^{[r]}(t) + \tilde{n}_c^{[r]} \quad (1)$$

where h is the channel gain between the source and relay, d is the distance between the source and the relay, m which is the path loss exponent, such that $2 \le m \le 6$, P_s represent the transmitted power from the source, $s(t)$ is the normalized information signal from the source, such that $\mathbb{E}\left[\left|s|t|\right|^2\right] = 1$, $\tilde{n}_a^{[r]}$ is the additive white gaussian noise (AWGN) developed at the relay node antenna, and $\tilde{n}_c^{[r]}$ is noise due to signal conversion from RF band to baseband. The amount of energy harvested in TS technique during the time αT is obtained as:

$$E_h = \frac{\eta P_s |h|^2}{d^m}\alpha T \quad (2)$$

where η, is the energy conversion efficiency which is dependent upon the rectification process and the energy harvesting circuitry, such that $0 < \eta < 1$.

The PS scheme is illustrated in Figure 6. Observation from the block diagram shows that the power splitter divides, the received signal into ratio $\rho : 1 - \rho$, where the portion $\sqrt{\rho} y_r(t)$ of the received signal, excluding the noise due to signal baseband conversion at the relay, is sent to the EH circuit and the remaining fraction $\sqrt{1-\rho}\, y_r(t)$ of the signal strength, excluding the noise due to signal baseband conversion at the relay, is used to drive the information receiver. The equation of the received signal at the relay is given as:

$$y_r(t) = \frac{1}{\sqrt{d^m}}\sqrt{(1-\rho_i)P_s}\, hs(t) + \sqrt{(1-\rho_i)}\tilde{n}_a^{[r]}(t) + \tilde{n}_c^{[r]} \quad (3)$$

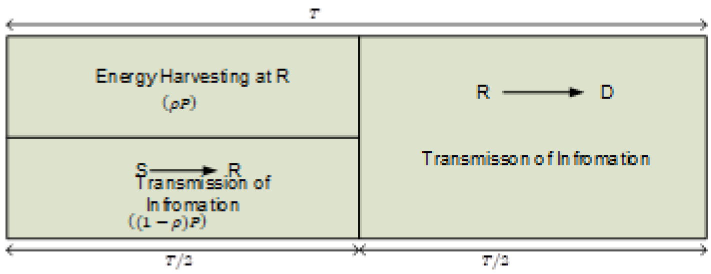

Figure 6: Transmission block structure for PS scheme [22]

Equation (3) implies that the AWGN developed at the relay node by the antenna is also harvested by the EH circuit both in TS and PS techniques. The amount of energy scavenged at the relay is obtained as:

$$E_h = \frac{\eta \rho P_s |h|^2 T}{2d^m} \quad (4)$$

where the relay harvest energy during half block of the time, $T/2$, as shown in Figure 6.

3.1 Overview of Related Literatures

Recent studies have considered EH in cooperative communication networks which can either be half-duplex communication system or full-duplex wireless communication system, in which the EH model can be categorised as either linear or non-linear. The linear EH technique assumes an ideal situation of the EH model while the non-linear considers the practical behaviour of the EH circuit elements. In most cooperative communication system, the relay node is considered to be energy constrained in nature. These relay nodes transmit information based on the implementation of relaying protocols. The most common relaying protocols are amplify-and-forward (AF) and decode-and-forward (DF) protocols. These protocols exhibit it performance based on the EH techniques applied at the energy constrained relay node. Though the performance of EH-based cooperative networks is analysed based on throughput, outage probability and energy efficiency (EE). Some of the review of SWIPT in cooperative wireless network is summarised in Table 2.

Table 2 Related Works on SWIPT in Cooperative wireless communication network

Author	Method/work done	Outcome	Limitations
[17]	The objective was to reduce the total energy cost based on the implementation of EH technique, using energy efficient iteration method. Energy cost minimization problem was formulated and two kinds of resource allocation algorithms were created to address the issue of energy cost optimization problem.	The method was based on Dynamic spectrum allocation and static spectrum allocation. Dynamic spectrum allocation outperforms the static in terms of sum power consumption.	The throughput and the EE performance of the communication network was not considered
[18]	Energy efficient relay selection in multi-hop device to device (D2D) network was investigated. Two relay selection schemes namely Random Relay Selection (RRS) and SNR based Relay Selection (SRS) were used to evaluate the performance of the QoS of the network based on EE	Results showed that SRS scheme provided better end-to-end transmission success for under-studied scenarios by exploiting the proximity gain between devices and also performs better in terms of QoS for the network.	However, resource allocation and SWIPT enabled D2D communication in a relay selection scheme was not considered.
[19]	Joint resource block and power alloction algorithms were implemented to improve power and transmission rate of the D2D links as well as the D2D to cellular user (CU) matching. These algoritms were termed off-line joint and on-line joint optimisation algorithms, though only a realistic causal knowledge of the harvested energy was available at the D2D transmitter.	Result revealed that on-line algorithm is capable of achieving better performance than off-line algorithm in terms of sum-rate of the DD links	However, RF-EH technique was implemented in this D2D communication but not in relay assisted D2D mode.
[20]	Firstly, an iterative power control algorithm based on Dinkelbach method was implemented. Secondly, an energy-efficient stable matching algorithm was proposed to evaluated the EE and quantity of energy harvested at the CUEs	The proposed algorithm maximize EE in full D2D pairs and the energy harvested by CUEs simultaneously	Resource allocation in SWIPT enabled D2D communication was considered but in the absence of the relay selection scheme and the EH considered was not non-linear.
[21]	Maximization the EE with use of PS scheme under the source	Result revealed that the suggested EE	The EH model

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Author	Method/work done	Outcome	Limitations
	and relay transmit power constraints considering minimum spectral efficiency requirement.	enhancement strategies outperforms some existing schemes.	considered is not non-linear, the EH in D2D communication was also not considered. Also, EH from other CUs in the network was not considered.
[22]	Maximization of throughput using PS and TS techniques	PS scheme outperforms TS scheme at low noise powers and vice versa	The system model was non-linear model, but harvesting energy form interference signals was not considered and EE performance of the system was left for future consideration.
[23]	Maximum ratio combining (MRC) technique was used to take advantage of the diversity gain in cooperative relay network	Optimization of outage probability using PS technique in AF relaying protocol	Relay selection was considered but not in non-linear EH model

The throughput maximization problem in a dual-hop based EH relaying system was examined by [24], where an adaptive TS for AF and DF relaying schemes were implemented. The ideal TS coefficient was adjusted adaptively to achieve the highest throughput efficiency per communication block, this was based on the dual-hop channel state information (CSI), harvested power, and intended SNR. A low-complexity TS coefficient model was then suggested as a way to reduce the EH-enabled relay's CSI overhead. This was considered to achieve a better throughput performance. Though the system didn't take cognisance of the non-linear EH model.

Ou *et al.* [25] considered implementing both PS and TS techniques at the relay node, based on the linear and nonlinear energy harvesting models, the performance secrecy of the SWIPT-enabled relay network with full-duplex destination-aided jamming, was evaluated . The authors considered the presence of an eavesdropper, whereby the source signal was amplified by the relay and sends it to the destination after gathering energy from the confidential signal and artificial noise sent by the source and destination, respectively. The authors derived the closed-form expression of the lower bound of ergodic secrecy capacity (ESC) and analytical closed-form formulations of the connection outage probability (COP), secrecy outage probability (SOP), and transmission outage probability (TOP) for PS- and TS-based systems are derived. The performances of all these metrics were improved based on the simulation results which revealed the effects of the PS/TS ratio. However, the throughput performance of the system was not considered.

Nodes based SWIPT which act as relay nodes in IoT networks with cooperating eavesdroppers, in which the secrecy performance in IoT in communication network was studied [26]. Maximization of the secrecy EE (SEE) of the single relay node was implemented to increase the lifespan of IoT nodes that are not powered. The authors examined the SEE of a DF relaying system with SWIPT, taking into account the possibility of multiple eavesdroppers. The system optimal transmit power and power splitting coefficient was also examined. In order to improve SEE performance, relay selection based on the introduction of multiple relays was introduced for the maximization of SEE. Simulation results showed that the suggested technique's improved secrecy performance over both the secrecy rate maximization method and the equal power distribution scheme.

Cooperative based two-way relay MIMO systems, in which the FD AF relay is outfitted with multiple antennas, was another method used to study SWIPT [27].The authors assumed that the CSI is flawless, the best combined design of the relay node's beamforming vector and receiver PS factor was examined. The goal of the optimization was to increase the SWIPT system's achievable sum-rate. On the other hand, the optimization transmission power was overlooked.

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The joint optimization problem of two-way relay beamforming, using PS technique at the relay and transmitted power was developed in order to maximize the possible sum-rate of a SWIPT system with an FD MIMO AF relaying protocol [28].

This work proposes a SWIPT based algorithm for 5G cooperative orthogonal frequency division multiplexing (OFDM) communication systems that is based on sub-carrier allocation. The point-to-point OFDM communication systems have historically found it impossible to improve information decoding rate for users with poor channel conditions, such as cell users. A cooperative OFDM communication system model, featuring a relay node was created in this context. In particular, the relay node's sub-carriers are split into two sections: one section is used to transfer data to receiver, and the other section is utilized to gather energy. The objective of the authors was to maximize the rate of information decoding at the relay while adhering to the minimum threshold of energy gathered [29]. Though the throughput and EE were not considered.

Implementation of SWIPT based DF two-way relay network over for 5G and future wireless communication system over Nakagami-m fading channels was proposed [30]. Two source nodes in which one transverse through the direct link and the other source transverse through a relay, makes up the cooperative network under consideration. At the relay node, a power splitting (PS) protocol based SWIPT receiver is taken into consideration for simultaneous information processing and EH. The relay node which is energy constraint, is considered to harvest energy from the source node and uses it to transmit information. At the destination node, a selection combining mechanism is used to combine the signals received via direct and relay channels. This was studied, considering Nakagami-m fading channels, in which the closed-form equation of the outage probability and throughput were derived. Considering the system performance, some parameters such as effects of fading severity, PS factor, threshold data rate, and other system factors were considered and it was discovered that the throughput of the system improved.

Lu *et al.* [31] presented resource allocation for D2D communications underlaying cellular networks over Nakagami-m fading channels. The authors considered a scenario which consist of a BS, set of CUs and D2D pairs, where the D2D pairs share the uplink resources of the CUs, a resource-abundant case was considered where in this scenario the number of CUs exceed the D2D pairs. The problem of joint optimization of Signal-to-Interference Plus-Noise Ratio (SINR) thresholds and CU-D2D pairs was investigated. This problem was solved using a two-step approach, where in the first step an annealing algorithm was used to make the number of D2D pairs equal to CUs, in which the near optimal SINR threshold was obtained for each possible CU-D2D pairing and second step involves the use of Hungarian algorithm to achieve optimal D2D -CU paring. The sum-rate of D2D networks was maximized over Nakagami-m fading channels, which was achieved by allocating resource of CUs and choosing the SINR thresholds. Simulation results show that the suggested SINR threshold performs better than the other regularly employed SINR threshold setting policies, and also when compared to a number of cutting-edge resource allocation strategies, HG allocation achieves a better sum-rate improvement. However, the work failed to consider EH enabled D2D network and relay selection scheme in D2D communication network.

Resource and power allocation in a non-linear EH model in D2D SWIPT enabled communication, was proposed [32]. The work investigated the sum EE of SWIPT enabled D2D links in an underlying cellular network, in which the uplink resources were reused by D2D links in which a piecewise linear EH model was considered for the network. However, the authors suggested that the spectrum resource sharing between D2D connections and uplink CUEs can be improved if a one-to-one constraint stable matching technique is used to increase the cumulative EE of SWIPT enabled D2D links. A two-layer energy efficient iterative algorithm (TLEEIA) was implemented in this work to solve the joint optimization of the transmission power and PS ratio for EE maximization problem based on piecewise linear EH model for SWIPT enabled D2D link applying the Block Coordinated Decent (BCD) method. Simulation results show that the sum EE is significantly greater with short D2D communication distance and more users, and the suggested techniques outperform previous work in terms of the sum EE of D2D links. The work failed to consider maximizing the sum EE by the coordinated optimization of CUE transmission power, D2D transmission power, and the power splitting ratio.

The joint resource allocation and mode selection for D2D communication underlying cellular networks was investigated [33]. The technique adopted in this work considered D2D communication-related challenges, such as dual mode selection, channel allocation, and power regulation, and strive to maximize the overall system throughput while also ensuring that the interference it generates is maintained to a minimum. Three algorithms were proposed in this work as to increase system throughput: a lightweight heuristic algorithm was used for pattern selection among the proposals; a Hungarian algorithm which serve to provide optimal solutions and Physical Resource Block (PRB) allocation problems; and a power distribution algorithm based on Deep Q-Network (DQN) that is used as a gauge for the best transmission power that should be allocated to D2D pairs. The performance evaluation of the shows that the system performance in terms of throughput was improved by combining three algorithms can effectively. However, the work failed to consider a scenario of ultra-dense network, devising a reasonable distribution scheme while taking into account interference

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between cells and also RF-EH in D2D network. Energy-Efficient power allocation in non-linear EH Multiple Relay Systems was proposed by [34]. The work investigated the scenario which consist of two-hop multi-relay cooperative DF network with SWIPT enabled relay network, in which the problem of maximizing EE was considered. The work considered a non-linear EH model was adopted at the relay for EH in which an optimal power allocation algorithm was proposed. This power allocation algorith makes use of fixed point interation algorithm which is an outer loop algorithm to obtain the joint power allocation for all relays and also the optimal transmit power of the relay,PS ratio and optimal EE of the system was obtained based on the use of an inner loop algorithm based on Dinkelbach iteration. Simulation results showed that the EE of the designed model had better perfromance than the traditional linear EH model. However, the authors considered non-linear EH model in relay asssisted communication but relay selection scheme was not considered in D2D communication. [35] presented EE resource allocation for D2D communication network based on relay selection (RS), where the BS serves as EH source for the D2D users, and the D2D source and D2D destination are connected via D2D relays, the problem of scarce spectrum resources and energy consumption increase were investigated. This work aims to maximize the EE of the network by coordinating relay selection and time allocation, while considering D2D-SNR limitations and CU rates. The problem of maximizing the EE was divided into two sub-problems: RS problem and time optimization problem. A weighted sum maximum technique to choose the optimal relay for the first sub-problem was proposed. An optimization iterative algorithm was proposed to solve the time optimization sub-problem and get the best EE solution when the relay is chosen. Simulation results indicate that the joint system utilizing relay protection selection method and time optimization algorithm had clear advantages over the exhaustive RS scheme employing particle swamp optimization (PSO) algorithm, whereby the power consumption was reduced in the communication system and EE was improved. However, EH and relay selection scheme was considered among the D2D users, but the EH model was not based on non-linear EH model.

Resource allocation for SWIPT systems with non-linear EH model was developed in [36]. The work investigted the impact of the practical non-linear EH model's saturation feature. A less complex resource allocation technique which is based on TS sheme was used to maximize the average achievable trasnmission rate, which, in the medium SNR zone, the receiver switched to energy harvesting while information decoding is carried out in the higher or lower SNR regions. Simulation results demostrated that the proposed scheme significanlty improves system performance in terms of EE and also system performance is more susceptible to the variation of the pathloss exponent m,than the distance d, between the source and destination. This work did not consider the non-linear EH model in D2D communication with relays and also harvesting energy from other CUs.

Performance analysis of dual-hopAF relaying with non-linear/linear EH was investigated by [37]. The work developed a RF-EH as an efficient startegy to overcome the energy constraint of IoT devices and sensor networks. A dual-hop wireless powered AF relaying system,in the absence of direct communication between the source and destination was considered. The source and relay nodes were both considered harvesting energy, where a piecewise linear model was considered to provide practical perfromance analysis of the network over a Racian channel. A comprehensive perfromance analysis was considered for both linear and non-liner EH models. The Bit Error Probability (BEP) , outage probability and throughput of the system were analytically derived and compared with Monte Carlo simulation , to verify the theoretical derivations. Simulation results showed that linear EH model do misinterprete the system performance at high amounts of energy harvested and produces acceptable result at low amounts of energy harvested, while non-linear EH model, both at low and high harvested energy produces a realistic result for system perfromance. However the optimal system performance based on EE was not considered. [38] investigated an efficient resource optimization scheme for D2D communication. The work investigated the problems of co-channel interference and EE optimization in long term evolution network. The suggested approach divides D2D users into many groups using the fuzzy clustering method, which makes use of minimal outage probability to increase system throughput and lessen user interference. In addition, to enhance user energy efficiency, an effective game-theoretic power control technique was also suggested to maximize user transmission power within each group. Simulation results showed that, these suggested methods can successfully increase EE, decrease co-channel interference, and increase system throughput. However, RF-EH in D2D, which can extend useful life span of the battery of mobile devices was not considered, in addition, cooperative D2D was not deployed in this work. [39] proposed a resource allocation for D2D communication underlying cellular networks: a distance- based grouping strategy. A one-to-many D2D communication system model was built in this work as a means of enhancing spectrum utilization and resolving issues with co-frequency interference. On the basis of the correlation between user distances and interference levels, a distance-based resource allocation algorithm that distributes channel resources reasonably and effectively was developed. This algorithm minimizes interference between D2D users (DUs) and CUs by allowing D2D users to reuse CUs channel resources within a reasonable distance in the group. In addition, the improved Particle Swarm Optimization

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(PSO) algorithm was used to solve the optimal power, to achieve the maximum transmission rate of the system. Simulation results showed that enhanced PSO algorithm improves system throughput and performance, also, since CUs give DUs additional reusable resources, the throughput of the system improves as the number of CUs does. However, the work only concentrated on enhancing the system throughput in D2D based on reusable cellular resources and did not consider SWIPT enabled D2D with the presence of a relay assisted node. Multiple input multiple output (MIMO) non-Orthogonal Multiple Access (NOMA) with non-linear EH and imperfect channel information was suggested by [40]. Antenna array processing was implemented at the relay and destination to achieve better system performance by analysing the throughput and outage probability of NOMA networks. Simulation results revealed that though non-linearity of energy harvester and imperfect CSI degrade system performance considerably. Though target performance can be achieved by a group of parameters and notably MIMO NOMA with EH can achieve optimal performance with optimal selection of quantity of antennas, power of transmitter, power splitting factor and time division ratio. However non-linear EH was considered, the relay was considered harvesting energy from the transmitted signal but relay selection was not considered. In conclusion it can be observed from the foregoing that SWIPT enables energy constrained nodes to be in operation while communication link is sustained and assist in long distance communication for cooperative communication

3.2 Throughput Performances of SWIPT Techniques

Throughput performances of the SWIPT techniques such as TS, PS and AS against variable transmitted power is P_s is depicted in Figure 6.0. Values of simulation parameters were set as in [41]. The number of antennas at the EH enabled relay node was set to 3 for the AS techniques, also it can be observed from Figure 6.0, that the PS scheme outperforms both the AS and TS schemes in terms of throughput. Therefore, the PS scheme offers a better trade-off between cost of transmitted power and throughput. Based on Figure 6.0, the TS technique has the lowest throughput since it requires proper time synchronization and energy scheduling. These reasons suggest why most implementation are based on PS techniques.

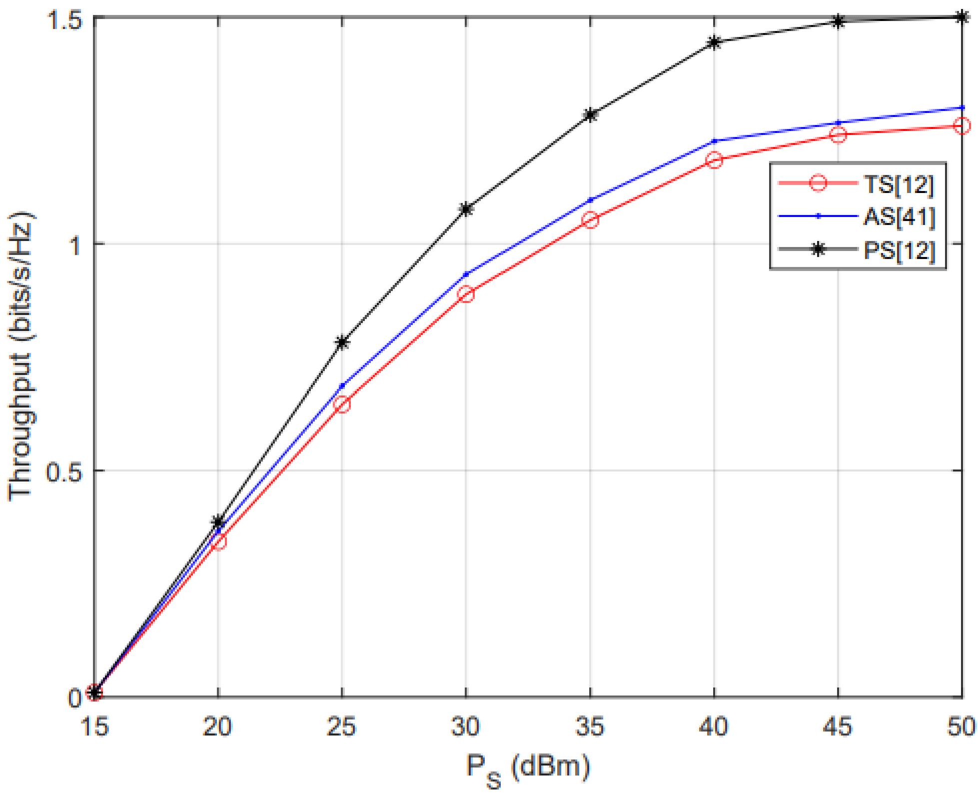

Figure 6: Performance of different SWIPT schemes based on throughput against transmitted power from the source

4.0 Conclusion

In this report, we reviewed the state of the art regarding RF–EH and information transfer in cooperative communication networks, which can either be linear or non-linear, highlighting current research challenges and their accompanying modern solutions. The EH techniques that are mostly implemented were analysed and the less complex scheme was suggested for RF-EH implementation. Recently, existing works also proves that non-linear EH model based on piecewise linear model is more accurate than linear EH model based on the amount of power harvested. Future studies might look at the system performance such as throughput, based on non-linear EH model, in a cooperative D2D communication system, where the D2D relay node is considered to harvest energy from the transmitter, which is based on non-linear EH, using commonly used SWIPT techniques.

References

[1] Vinay, M., & Rudresh, Y. (2018) [Online]. A Review on Green Communications, Int. Journal of Engineering Research Technology. 6(13), 1–18. Available: www.ijert.org

[2] Malik, N.T., Abdulsadda, A.T., & Al-Yasiri, A.J.(2019). Relaying protocols for wireless energy harvesting and information processing, International Journal of Engineering Advanced Technology. 9(1), 1740–1746. doi: 10.35940/ijeat.F9015.109119.

[3] Varshney, L.R. (2008). Transporting information and energy simultaneously. IEEE International Symposium in Information Theory - Proceedings. 1612–1616. doi: 10.1109/ISIT.2008.4595260.

[4] Zhou,X., Zhang, R.,& Ho, C.K. (2013). Wireless information and power transfer: Architecture design and rate-energy tradeoff, IEEE Transactions on Communication. 61(11), 4754–4767.

[5] Chalise, B. K., Zhang, Y. D., & Amin, M. G. (2012). Energy harvesting in an OSTBC based amplify-and-forward MIMO relay system. In Proceedings of the 2012 IEEE International Conference on Acoustics, Speech, and Signal Processing , ICASSP 3201–3204.

[6] Xu, J., and Zhang,R. (2014). Throughput optimal policies for energy harvesting wireless transmitters with non-ideal circuit power," IEEE Journal of Selected Areas in Communication.,32(2).322–332. doi: 10.1109/JSAC.2014.141212.

[7] Fouladgar. A.M., & Simeone, O.(2012). On the Transfer of Information and Energy in Multi-user Systems, IEEE Communication Letters. 16(11), 1733–1736. doi: 10.1109/LCOMM.2012.091212.121660.

[8] Zungeru, A.M., Ang, L.M., Prabaharan, S.R.S., & Seng,K.P. (2016). Radio frequency energy harvesting and management for wireless sensor networks, Green Mobile Devices and Networks: Energy Optimization and Scavenging Techniques, 341–367. doi: 10.1201/b10081-17.

[9] Wang, R., & Brown, D.R. (2015). Throughput Maximization in Wireless Powered Communication Networks with Energy Saving. Asilomar Conference on Signals, Systems,and Computers. 1, 516–520.

[10] Lu, X.,Wang, P., Niyato, D., Kim, D.I., & Han, Z. (2015). Wireless networks with RF Energy harvesting:A Contemporary Survey, IEEE Commununication Surveys and Tutorials. 17(2), 757–789,

[11] Xue, L., Wang, J. L., Li, J., Wang, Y.L & Guan, X.P. (2019). Precoding Design for Energy Efficiency Maximization in Mimo Half-Duplex Wireless Sensor Networks with SWIPT, Sensors (Switzerland), 19(22). doi: 10.3390/s19224923.

[12] Krikidis, I., Timotheou, S., Nikolaou, S., Zheng, G., Ng., D.W.K & Schober, R. (2014). Simultaneous wireless information and power transfer in modern communication systems. *IEEE Communications Magazine,* 52(11), 104-110.

[13] Xiang, Z., & Tao, M. (2012). Robust Beamforming for Wireless Information and Power Transmission. IEEE Wirel. Commununication Letters, 1(4), 372–375.

[14] Liu, Y., Zhang, R., & Chua, K.C. (2012). Wireless information transfer with opportunistic energy harvesting. IEEE International Symposium in Information Theory - Proceedings ., 950–954, 2012, doi: 10.1109/ISIT.2012.6284703.

[15] Nguyen, S.Q., & Kong, H.Y. (2016).Generalized Diversity Combining of Energy Harvesting Multiple Antenna Relay Networks: Outage and Throughput Performance Analysis. Annals of Telecommunications, 71(5–6), 265–277.

[16] Ojo, F.K., Akande, D.O & Salleh, M.F.M. (2018). An Overview of RF Energy Harvesting and Information Transmission in Cooperative Communication Networks, Telecommunication Systems, 70(2), 295-308. doi: 10.1007/s11235-018-0483-8.

[17] Ding, J., Jiang, L., & He, C. (2016). Dynamic Spectrum Allocation for Energy Harvesting-Based Underlaying D2D Communication. IEEE 83rd Vehicular Technology Conference (VTC Spring), 1–5.

[18] Ansari, R.I., Hassan, S.A., & Chrysostomou, C. (2016). Energy Efficient Relay Selection in Multi-Hop D2D Networks, *International Wireless Communications and Mobile Computing Conference (IWCMC)*, Paphos, Cyprus, 620-625.

[19] Gupta, S., Zhang,,R., & Hanzo, L.(2017). Energy Harvesting Aided Device-to-Device Communication Underlaying the Cellular Downlink.. IEEE Access. 5, 7405–7413.

[20] Zhou,Z., Gao, C., Xu, C., Chen, T., Zhang, D., & Mumtaz,S. (2017). Energy-Efficient Stable Matching for Resource Allocation in Energy Harvesting-Based Device-to-Device Communications. IEEE Access. 5, 15184–15196.

[21] Zhou, X., & Li, Q. (2018). Energy efficiency for SWIPT in MIMO two-way Amplify-and-Forward Relay

Networks. IEEE Transactions on Vehicular Technology, 67(6),4910–4924.
[22] Lu, G., Shi, L., & Ye, Y.(2018). Maximum Throughput of TS/PS Scheme in an AF Relaying Network with Non-Linear Energy Harvester. IEEE Access, 6, 26617–26625.
[23] Mahama, S., Asiedu, D.K.P., & Lee, K.J. (2017).Simultaneous Wireless Information and Power Transfer for Cooperative Relay Networks with Battery, IEEE Access, 5, 13171–13178.
[24] Ding, H., Wang, X., Da Costa, D.B, Chen, Y., & Gong,F. (2017). Adaptive Time-Switching Based Energy Harvesting Relaying Protocols. IEEE Transactions on Communications 65(7), 2821–2837.
[25] Ou, J., Shi, H., Wang, L., Ma, R., & Wu,H. (2021). Analysis of SWIPT-Enabled Relay Networks with Full-Duplex Destination-Aided Jamming, Hindawi. Security and Communication Networks, .1-18.
[26] Song, K., Nie, M. Jiang, J., Li, C., & Yin, Y. (2021) . On the Secrecy for Relay-Aided SWIPT Internet of Things System with Cooperative Eavesdroppers. IEEE Access, 9, 28204–28212.
[27] Okandeji, A.A., Khandaker, M.R.A., & Wong, K.K. (2016). Wireless information and power transfer in full-duplex communication systems. *IEEE International Conference on Communications (ICC),* 1-6,
[28] Okandeji, A.A., Khandaker, M.R.A., & Wong, K.K. (2016). Two-way beamforming optimization for Full-Duplex SWIPT Systems. *24th European Signal Processing Conference (EUSIPCO)*, 2375-2379.
[29] Na, Z., Wang, Y., Li, X., Xia, J., Liu, X., Xiong, M., & Lu, W. (2018). Subcarrier Allocation Based Simultaneous Wireless Information and Power Transfer Algorithm in 5G Cooperative OFDM Communication Systems. Phys. Commununication, 29, 164–170.
[30] Kumar, D. Singya, P.K., & Bhatia, V. (2012). Performance Analysis of SWIPT Enabled Decode-and-Forward based Cooperative Network. *IEEE 11th International Conference on Communication Systems and Network Technologies (CSNT)*, 476-481.
[31] Lu, B., Lin, S., Shi, J. & Wang,Y. (2019). Resource Allocation for D2D Communications Underlaying Cellular Networks over Nakagami-m Fading Channel. IEEE Access, 7, 21816–21825.
[32] Yang, H., Ye, Y., Chu, X & Dong, M. (2020). Resource and Power Allocation in SWIPT-Enabled Device-to-Device Communications Based on a Nonlinear Energy Harvesting Model. IEEE Internet Things Journal, 7(11), 10813–10825.
[33] Du, Y., Zhang, W., & Wang, S. (2021). Joint Resource Allocation and Mode Selection for Device-to-Device Communication Underlying Cellular Networks. IEEE Access, 9, 29020-29031.
[34] Pan, H., & Zhu, Q. (2021). Energy-Efficient Power Allocation in Non-Linear Energy Harvesting Multiple Relay Systems. *Algorithms*, *14*(5), 155, 1-17.
[35] Feng, G., Qin, X., Jia, Z., & Li, S. (2021).Energy Efficiency Resource Allocation for D2D Communication Network Based on Relay Selection. Wireless Networks, 27(5), 3689–3699.
[36] Hu, Y., Liu, M., & Feng, Y. (2021). Resource Allocation for SWIPT Systems with Nonlinear Energy Harvesting Model. Wireless Communications and Mobile Computing, 2021(1),1- 9.
[37] Babaei, M., Durak-Ata L, and Aygölü, U. (2022). Performance Analysis of Dual-Hop AF Relaying with Non-Linear/Linear Energy Harvesting, *Sensors*, 22(16), 5987, 1-24.
[38] Zafar, M.H., Khan, I., & Alassafi, M.O.(2022). An efficient resource optimization scheme for D2D communication. Digital Communication Networks, vol. 8(6), 1122–1129, 2022.
[39] Gao, J., Meng, X., Yang, C., Zhang, B., & Yi, X. (2023). Resource Allocation for D2D Communication Underlaying Cellular Networks: A Distance-Based Grouping Strategy. Wireless Communication and Mobile Computing. 2023(4),1-13.
[40] Le-Thanh, T., & Ho-Van, k. (2023). MIMO NOMA with Nonlinear Energy Harvesting and Imperfect Channel Information. Arabian Journal for Science and Engineering, 49, 6675–6693.
[41] Ali, A. N., Zhou, X., Durrani, S., & Kennedy, R. A. (2013). Relaying Protocols for Wireless Energy Harvesting and Information Processing. IEEE Transactions on Wireless Communications, 12(7), 3622–3636.