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Green transmission for C-RAN based on SWIPT in 5G: a review

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Abstract
C-RAN is a promising new design for the next generation, an important aspect of it in the energy efficiency consideration. Hence, it is considering an innovative candidate to use it as an alternative cellular network instead of the traditional. Investigation green transmission of mobile cloud radio access networks based on SWIPT for 5G cellular networks. Especially, with considering SWIPT as a future solution for increasing the lifetime of end-user battery's, that's mean this technique will improving energy efficiency (EE). Addressing SWIPT into C-RAN is a challenging and it is needed to developing a new algorithm to use it on the cellular network with many trying to ensure the success of the system performance. C-RAN as a network and SWIPT as a promising technique with the suggesting green wireless network are discussed besides the importance of energy efficiency for the next generation. Furthermore, there was a study on fifth enabling technologies that can be used for 5G with emphasis on two of them (C-RAN and energy efficiency). Lastly, research challenges and future direction that require substantial research efforts are summarized.

Keywords Green transmission · Power transfer · Cloud radio access network · Energy harvesting (EH) · Information decoding (ID) · Time switching · Power splitting · MIMO

1 Introduction

Previous as well as the current networks have become insufficient in satisfying internet users due to exponential growth in the use of mobile internet for smart devices such as tablets, smartphones and iPad, along with the integration of internet of things (IoT) in the upcoming revolution. So, there is a need for a novel solution to address such issues. Keeping this in mind, the launch of a new network generation called 5G worldwide can be expected by 2020. This new design would provide high efficiency in terms of energy saving almost 10 times the lifetime of a battery, close to 1000 times higher in terms of capacity and spectral efficiency of more than 1000 Gb/s when compared with 4G systems [1, 2]. Hence, this next cellular network is highly anticipated to include a revolutionary architecture that satisfies the requests of the next generation. Thereby, a robust candidate for the 5G network is the Cloud Radio Access Network.

Basically, the C-RAN's design combines both cloud computing and wireless communication [3]. The Chinese Mobile Research Institute [4] had proposed this to ensure better energy efficiency. Hence, a C-RAN is composed of three key items: front-haul low-latency optical connecting, a Base Band Unit BBUs pool in a cloud and Remote Radio Head (RRHs) [5]. Moreover, a critical factor for the next-generation wireless vision is the network architecture, particularly when it comes to saving network power. Therefore, a convenient network has been considered in Cloud Radio Access Networks to quench the demand for the next generation [6]. The signal in downlink level can be segmented into two: one for power and the other for information transfer. This was referred as Simultaneous Wireless Information and Power Transfer (SWIPT) [7, 8] that employs an efficient energy harvesting technique. C-RAN can not only employ SWIPT transmission techniques but also helps enhance efficient power transfer to gather as much energy for Cloud Radio Access Networks (C-RAN) [9–11].

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This study is aimed at providing a complete discussion on Cloud Radio Access Network and its various uses as an efficient network to store energy. Based on its architecture, it can be said that it is a promising candidate for establishing next cellular networks. This way, the tradition LTE network can use a cloud, establish a relationship between the power transfer techniques (SWIPT) and the network design, and allow for critical review as presented in Tables 1 and 2. A summary is provided regarding various research challenges faced and future directions in terms of considerable research efforts. As displayed in Fig. 5, this research article is the first study to provide a review for C-RAN-based SWIPT to best of my knowledge.

The article has been organised in the following order: Sect. 2 provides a definition as well as few explanations for 5G with most of the candidates being enabler of technologies such as: C-RAN, MM-Wave, Energy Efficiency, D2D, Massive MIMO, IoT, NOMA and FRAN. Furthermore, this section provides an overview of deep background, Cloud Radio Access Network, network architecture as well as its deployment. In addition, the section gives an overview of Simultaneous Wireless Information and Power Transfer, as well as the associated taxonomy and techniques. Section 3 presents the explanation and diagram to integrate SWIPT into C-RAN to achieve the desired green transmission in C-RAN, which is required for 5G. Section 4 gives a summary of the prospective future direction and research challenges. Lastly, Sect. 5 presents the study conclusion. Figure 1 shows the flow of this study to get a better understanding.

2 Toward 5G technologies

From 2G to the 4G system, the world has very fast evolution and revolution of technologies especially in terms of computer and wireless networks. The main motivation has been the need for more energy efficiency, bandwidth, and lower latency. Hence, 4G truly makes up mobile broadband, although 3G is considered to be the first mobile broadband standard, its original design was for voice, along with some data and multimedia consideration, while 2G was meant to be the first standard for digital mobile voice communication with for enhanced coverage. There has been an improvement in the data rate from 64 kbps in 2G to 2 Mbps in 3G and 50–100 Mbps in 4G. It is expected that 5G will not only improve the speed of data transfer of mobile networks, but the network's connectivity, scalability, and energy efficiency as well. It is believed that by 2020, there will be 50 billion devices that are connected to the global IP network, which would seem to present a challenge [1]. Therefore, the following are the most important elements in describing 5G: high throughput, high reliability, low-latency, energy efficient mobile communication technology, and increased scalability [12]. Thus, end-users will experience smooth network connectivity [13].

However, the future society will be a connected society. The IoT together with intelligent, integrated sensor systems and in-home sensor networks will change the way people lead their lives [14, 15]. It also improves energy efficiency, spectrum utilisation, and cost. It also provides better scalability to handle the growing amount of connected devices. Given the vision of an all-communicating world in the current network, the general technical goal is to offer an idea that will help support high latency, data volume increasing, Machine to Machine communications and high energy with spectral efficiency [16]. Hence, 5G enabling technologies is listed to have an idea about the main pillars of next generation.

2.1 Millimetre-wave

To enable 5G era an innovation solution is needed to keep up with the dramatic growth of mobile technology soon. 1 GHz for millimetre-waves in front of 20 MHz for current cellular systems these reasons lead to use millimetre-waves [17]. So, mm-wave is one of the main candidates for the next mobile generation that ranging from (30 to 300) GHz with a possible gigabit per second coupling with Massive MIMO [18]. A real-world measurement for millimetre-waves at New-York and Texas Universities were done [19]. Conducted intensive propagation measurements at 28 and 38 GHz so that insights can be gained about RMS delay spread, path-loss, AOA, AOD [20], and building penetration and reflection characteristics for the design of future millimetre-wave cellular systems.

From the hardware, results found there is no breakdown occurred within 200-m cell radius. So, the 200-m radius suggested for the cell size in New York city for the 5G wireless cellular networks [21]. In [22] presents the outage probability characteristics of 38 GHz. The real-world measurements are done at the Austin Campus of the University of Texas to obtain urban measurements; the results show there is no outage occurs within 200 meters radii for 160 dB path-loss threshold in both of transmitters height (18 and 36) meters. In brief, Millimetre-waves will be used as a candidate technology for the next generation ultra-dense networks backhauling instead of fiber optics [23].

2.2 C-RAN

Mobile data traffic has grown significantly in recent years. To meet this demand [24] Massive MIMO [25] and heterogeneous networks (Het-SNets) [24] are considered as

Table 1 Critical review of C-RAN

References	Method/technique/approach	Descriptions	Strengths and weaknesses
[3]	By leveraging software-defined and cloud computing radio technologies, the authors were able to formulate a Baseband Unit (BBU) cluster testbed, e-Base that has the ability to consolidate several isolated BBUs into a virtualised BBU while providing unified baseband resource pool that radio access networks (RAN) can use. It also presented the implementation and architecture of the e-Base in detail	The cloud radio access network architecture is a combination of the cellular communication and cloud computing technology	Based on experiments, finding the e-Base can lower the total energy consumption by approximately 20% while meeting about 95% QoS For future studies, the centralised Gbps and LBS Ethernet would become bottlenecks. One can eventually mitigate this by taking advantage of the popularity of next-generation wideband technologies, such as 100G Ethernet and switches
[41]	The authors suggested a new framework that can be used in the design of green C-RAN, instead of only emphasizing the RRH power consumption	This paper developed a new framework that will enhance the energy efficiency of cellular networks using the new C-RAN architecture	Simulation results showed that the proposed group sparse beam forming framework offers an effective way of lessening the network power consumption Could not ignore the backhaul power consumption when designing green C-RAN
[43]	This article talked about the recent developments and challenges in H-CRAN design. It also suggested promising resource allocation techniques in H-CRAN: hybrid backhauling, coordinated scheduling, and multi-cloud association	It expects a top-down architectural change to be found at the centre of the 5G systems development	Simulations results reveal the manner by which the proposed strategies offer noticeable performance enhancements compared to methods that were taken from recent literature Coordinated scheduling, multi-cloud resource allocation, and hybrid backhauls activate a set of other interesting issues in the field of a candidate topic for future research directions
[44]	The effect of cooperative transmission on network-level achievable data rate with energy efficiency (EE) and spectrum efficiency (SE) for downlink C-RAN architecture is studied. Intensive analysis using the stochastic geometry framework verifies the superiority of cooperative transmission in C-RAN architecture	Employing the stochastic geometry framework to assess the EE and SE performance achievable using cooperative C-RAN with centralised processing was the purpose of this article	Solving the optimisation problem reveals that accounting for the cluster radius and transmit power is essential to determine the optimal amount of cooperating RRHs that maximise the EE Performance degradation will happen in denser RRH deployment for EE than SE
[46]	To accommodate such diverse technical needs simultaneously in the HCRAN, a new model of HCRAN designed to significantly reduce latency is presented	Methods that allow ultra-low-latency connections that are given in the HCRAN, which include a systematic design that possesses unique open-loop radio access that lowers the latency in the air interface	The proposed methods address several issues and open issues within the H-CRAN by presenting a new philosophy in design into the practical H-CRAN This research's future extension involves offering support to the 'heterogeneous carrier communications' over the H-CRAN
[48]	The authors proposed a new structure as well as practical circuit design for green sensors in C-RAN. The structure can enable sensors to harvest energy from radio signals transmitted by neighbour remote radio heads (RRHs) and user terminals (UTs)	This paper studied the scenario that sensors could harvest wireless energy from RRHs or UTs, and communicate with UTs in a C-RAN	Simulation and experimental results were given and used to corroborate our proposed studies Future work of this research should be with H-CRAN. Also, sensors can be an important element for future networks

Table 1 continued

References	Method/technique/approach	Descriptions	Strengths and weaknesses
[54]	The authors suggested a joint uplink (UL) and downlink (DL) mobile users-access points (MU-AP) beamforming and association design to help in the coordination of the interference in the C-RAN so that energy can be minimised	Considered C-RAN that possess densely deployed APs that serve the shared MUs for both the DL and UL transmissions cooperatively	The proposed algorithms enhanced the energy efficiency, network reliability/ feasibility and the power consumption trade-offs between the Mus and the APs In C-RAN, the energy consumption issue is also considered as one of the main concerns for future cellular networks
[55]	The authors described imagined C-RAN that has its basis in passive optical networks (PONs) that exploit power over fibre (PoF), and describe QoE need on the envisioned network	This article dealt with the challenges that come with the QoE-guaranteed design as well as the C-RAN operation based on PON exploiting PoF	Numerical results showed the efficacy of the proposed joint control method for the RRH transmission and sleep power Consider individual subjective opinion for future work
[56]	The study suggested a downlink (DL) transmit beamforming algorithm that can be used for DL radio remote heads (RRHs), an uplink (UL) receive beamforming algorithm that is meant to be used for UL RRHs, as well as a power allocation algorithm that can be used for UL users	Emphasised the Energy Efficiency (EE) of the dynamic Time Division Duplex (TDD) based C-RAN system that offers support for both the simultaneous DL and UL transmission	EE maximisation by properly managing the interference that results from the simultaneous DL and UL transmission Development of less complicated beamforming and power allocation algorithms that can be utilised for a real-time operation within the C-RAN system
[57]	The authors proposed a linear, componentised and parameterised PM, as well as studied the individual parts that were relevant for PC analysis, specifically for the architecture of software-defined C-RAN (SDC-RAN)	The study presented the components and a parameterised PM to demonstrate the PC calculation for the SDC-RAN's extended network architecture	The results revealed that SDC-RAN raised the total PC by approximately 20% compared to the C-RAN One can use the parametrised model to assess the power saving approaches in the future for SDC-RAN
[58]	The joint load balancing mechanism was proposed by this article to achieve the joint femtocell and macrocell network optimisation by making it possible for overloaded macrocell users to handover to the femtocell	For the C-RAN wireless network, there was a proposal for a joint optimisation load balancing algorithm that has its basis on coexisting femtocells. The purpose of this is to offer better user service when all the macrocells nearby are overloaded	The suggested mechanism significantly enhances the femtocell network's user satisfaction and resource utilisation rate while lowering the blocking and dropping rates To be used for the heterogenous network in the future direction
[51]	The authors proposed a dynamic resource allocation (DRA) scheme for H-CRAN that can be utilised in TDD mode	Suggested a dynamic resource allocation (DRA) scheme for TDD that has its basis in H-CRAN	Results reveal that the DRA scheme can decrease the normalised mismatching degree effectively and enhance the bidirectional data rate that has low complexity Mitigate interference problem in H-CRAN which is a promising model in future network
[59]	Component, parameterised and linear PMs were proposed by this study to study the individual components that are related for PC analysis, specifically for C-RAN architecture	A parameterised PM and the components are given in this article, which make it possible to calculate the PC of C-RAN based on the operational parameters and the different vendor configurations	The model revealed that compared with traditional MBS architecture, the C-RAN network lowered the total PC to approximately 33.3% and it also reduced the cooling PC to approximately 87.4% As for work in the future, gathering both the C-RAN and macro BS made H-CRAN a promising architecture. It may also be used to improve the EE of future generations

Table 1 continued

References	Method/technique/approach	Descriptions	Strengths and weaknesses
[60]	This study evaluated, by mathematical and simulation methods, different splits with network level energy and cost efficiency having in the mind the expected quality of service	C-RAN is considered a potential architecture for 5G mobile networks because it offers certain cost and performance benefits	The event-based simulation captures the influence of the traffic load dynamics and traffic type variation on designing an efficient front-haul network The future definitions of the front-haul interface need to realise the benefits of centralisation and cloud calculation at the highest possible level while relaxing the bandwidth and latency needs
[49]	The study made a comparison of the two strategies' energy efficiencies by framing an optimisation problem that is related to the minimisation of the total network power consumption depending on the user target rate constraints. In this case, the total network power also includes the BS transmission power, load-dependent backhaul power, and BS activation power	The article made a comparison of the energy efficiency between the compression strategy and the data sharing strategy in downlink C-RAN	When a user target rate is low, less power is consumed by data-sharing. On the other hand, when the user target rate is high, compression is favoured since there is a significant increase in the backhaul rate for data-sharing as user rate increases It may also be possible to conduct power minimisation and joint user scheduling by considering a problem of lowering the total power consumption
[61]	The authors considered the problem of assigning users to power-zones (PZs) and managing their power levels (PLs), via the maximisation of the weighted sum-rate given the practical constraints that it is not possible to serve each user by more than one base station. However, each user can be served by one or more power-zones as long as they are located inside each base station frame	Optimisation in cloud radio access networks has become an upcoming topic of interest. This article took into account the power optimisation problem and joint coordinated scheduling in cloud-enabled networks	The cross-layer scheme proposed offered noticeable performance enhancements compared to the other schemes that are given in literature When the amount of users increases, the scheduling opportunities with power adaptation increase, which results in a noticeable performance gain
[62]	The authors formulated a joint radio remote head (RRH) activation and beamforming algorithm that could be used for a downlink slotted cloud radio access network (C-RAN). This was completed by considering time-varying channel fadings and random traffic arrivals	The authors framed a dynamic optimisation problem by taking into account the effects of time-varying channel fading and random traffic arrivals	The proposed algorithms' efficiency and the efficacy have been confirmed using numerical simulations In the future, it would be interesting to take into account the beamforming algorithms and queue-aware energy-efficient joint RRH activation for C-RANs
[37]	The study proposed an average weighted EE performance metric for H-CRANs to help in the development of schemes that demonstrate stable queues and close-to-optimal EE and for all users in the multimedia H-CRANs	The study presented an energy-efficient optimisation objective function with inter-tier interference constraints and individual front-haul capacity that can be utilised for queue-aware multimedia H-CRANs	The simulation results and mathematical analysis revealed that one can achieve a trade-off between queuing delay and EE For realistic multimedia H CRANs, one should preselect the optimal V for the optimisation of the average weighted EE performance for constrained and ideal front-haul
[63]	The authors studied C-RAN with wireless front-hauls because of their flexibility in deployment and management	Examined a cloud radio access network's performance that makes use of wireless front-haul connections	Given the derived bounds, there was a proposal for two practical power minimisation schemes that have a BLER constraint in order to lower the energy that is used up on the front-haul links It should be noted that the focus of these works is on the fixed employment of the front-haul links; for instance—the optical fibre

Table 1 continued

References	Method/technique/approach	Descriptions	Strengths and weaknesses
[64]	The study proposed a cluster content caching, which fully takes advantage of centralised signal processing and distributed caching	It also proposed a cluster content caching for C-RANs, where some local cluster content caches can be used to store some requested content	The simulation results revealed that one can improve the effective capacity and the energy efficiency by up to 0.57 Mbit/s/Hz and 0.004 Mbit/Joule respectively when the amount of needed content objects is equal to five The results need to be compared/calibrated with the other results to ensure from the percentages provided by the authors
[65]	The study first proposed a novel weighted minimum-mean square-error successive convex approximation (WMMSE-SCA) algorithm that can be used to maximise the weighted sum rate under the front-haul capacity constraints and user transmit power with single-user compression	The transmit beamforming and front-haul compression were formulated for an uplink MIMO C-RAN system	Numerical results revealed that most of the performance increase afforded by C-RAN is a result of applying successive interference cancellation (SIC) at the centralised processor (CP) The idea that this article proposed can also be applied to the more newly proposed Fog RAN and heterogeneous C-RAN and architectures
[50]	The authors formulated a stochastic geometry-based analytical approach that can be used to compute for the throughput reliability of a cloud radio access network (C-RAN)	Spectral efficient and energy efficient transmissions are of notable interest in C-RANs	The significance of this study is in utilising an optimal RRH A future direction for this work represents using of partially overlapped channels, instead of orthogonal channels and utilise the spectrum more efficiently
[66]	The authors first introduced a hierarchical framework for the design and analysis of heterogeneous radio access network (H-C-RAN) with energy harvesting	The renewable energy scheduling is studied in heterogeneous cloud radio access networks to reduce energy cost	Simulation results revealed that the suggested schemes significantly lower the energy cost Proposed framework can meet very flexible and tractable energy exchange strategy in future internet of energy

the two most promising methods to achieving this goal [26]. The cloud radio access network (Cloud-RAN) has recently been suggested as a promising network architecture that can help unite the two previous technologies so that the interference can be jointly managed via a coordinated multiple-point process (CoMP) [27] [28]. The aim is also to increase network capacity, improve energy efficiency (through network densification), and lessen both the operating expense (OPEX) (by transferring the baseband processing to the baseband unit (BBU) pool) and network capital outlay (CAPEX) [27, 29]. However, there are three main items in a Cloud-RAN: high-bandwidth low-latency optical front-haul connecting, a pool of BBUs in a cloud data centre, and distributed transmission/reception points (RRHs) [5].

An important aspect in C-RAN is its consideration for energy efficiency, because a large number of RRHs as well as the front-haul links have increased power consumption. Therefore, previous works that examined the cellular networks' energy efficiency only took into account the BS power consumption [30, 31]. Recently, the effect that backhaul power consumption had in cellular networks was studied by [32]. Subsequently, Rao et al. in [33] examined the energy efficiency and spectral efficiency trade-off in homogeneous cellular networks when the backhaul power consumption was taken into consideration. For a Cloud-RAN, the network energy efficiency will be more significantly impacted by the front-haul network power consumption. So, giving the front-haul links as well as the corresponding RRHs the opportunity to support the sleep mode is important in reducing the Cloud-RAN network power consumption. It will also be practical to apply this idea in the Cloud-RAN with the assistance of centralised signal processing within the BBU pool. So, for future cellular networks, attaining high-energy efficiency is one of the main goals [34, 35].

2.2.1 Overview

In wireless cellular networks, as can be seen clearly from the second-generation to the fourth, a new service specification is presented by each generation, including rapid

Table 2 Critical review of SWIPT

References	Methods/techniques/approaches	Descriptions	Strengths and weaknesses
[101]	Given the energy harvesting node's further transmission, the potential capacity that is generated by the transferred energy is accounted for in the SWIPT-MIMO system capacity	Examined the EE optimisation for MIMO SWIPT system using the covariance CSI feedback	Results reveal the proposed schemes on EE's superiority One can easily extend the work to the case of multiple energy harvesting (EH) receivers as well as to the increase in the amount of EH receivers
[45]	The relay makes use of a power splitting (PS) scheme in harvesting the energy that is sent from each source, which it then makes use to send the transmissions to the destinations	The application of the SWIPT to the wireless cooperative networks has been examined, where the signals sent from each source were used to power the EH relay	Compared to a scheme that uses a uniform PS ratio, the proposed scheme consistently attains a higher total transmission rate
[102]	The authors formulated a distributed iteration algorithm that is used for power allocation, relay selection, and power splitting	SWIPT is applied to cooperative clustered WSNs. Here, the energy-constrained relay nodes harvest energy and simultaneously offer benefits to the surrounding RF signal	Compared to current algorithms that do not have energy harvesting or energy efficiency maximisation, the proposed iterative algorithm is capable of achieving more remaining energy and higher energy efficiency
[107]	The authors suggested a power allocation (PA) and joint time-switching (TS) optimisation algorithm to attain the maximum end-to-end achievable rate	The joint TS and PA optimisation problem was examined for the multicarrier decode-and-forward (DF) relay network as well as the TS-based relaying	Results revealed that the joint TS and PA scheme that was proposed performed better than the scheme that has a fixed TS ratio for energy harvesting (EH)
[104]	The design of the resource allocation algorithm is meant to secure information and to transfer renewable green energy to mobile receivers that are found within distributed antenna communication systems	The design of the resource allocation algorithm was examined based on the wireless delivery of both renewable green energy and secure information to mobile receivers that are found in shared antenna communication systems	The performance of the proposed suboptimal iterative resource allocation scheme is close to the optimal scheme
[105]	The authors examined cell association and found that it has a significant effect on the DL's energy harvesting and the wireless powered HCNs' performance in the UL, in comparison to the DL and the UL	It presents a tractable analytical model of K-tier HCNs with SWIPT. Here, the MUs gather energy and simultaneously decode information in the DL. Then, the energy harvested at the MU is used for transmitting information in the UL	Increasing the BS transmit power, the small cell base station (BS) density, the energy conversion efficiency, and the time allocation factor One cannot improve the UL performance of a random MU in HCNs with its associations to the NBS and the MRP cell
[106]	The authors using the stochastic optimisation theory, a dynamic algorithm, which can trade average power consumption for wireless nodes (WNs') delay, is proposed to allocate the transmission power and time switching factor jointly	A stochastic optimisation framework was presented to examine the trade-off between power-delay for the SWIPT systems	The discrete time switching (TS) metric can achieve the same performance as the continuous TS metric by setting a large number of time-slots
[108]	The authors suggested a strategy for energy-efficient resource allocation using an iterative method. They also offered a way to converge the proposed algorithm depending on nonlinear fractional programming	The study examined the efficiency of collecting energy From radio frequency (RF) signals found in wireless networks by applying a realistic assumption for the imperfect channel state information at the transmitter (CSIT)	Attaining maximum energy efficiency while making sure that the harvested energy requirements and data rate met Proposing an efficient algorithm that has its basis in a theoretical approach may be worthwhile and useful in developing a potential technique that can be utilised in wireless sensors that have semi-permanent power lifetimes

Table 2 continued

References	Methods/techniques/approaches	Descriptions	Strengths and weaknesses
[109]	This study aims to maximise the energy harvesting efficiency (EHE) of EH FUs and the information transmission efficiency (ITE) of ID FUs by using the QoS of all users and examining their relationship	The study examined the energy efficient beamforming design in wireless-powered two-tier MISO heterogeneous cellular networks (HCN)	Results showed that compared to zero-forcing (ZF), MBF offers better ITE and EHE There are several avenues for extensions and future work. One aspect is the absence of CSI, which is vital in the performance of EHE and ITE. It also examined the extension to multi-cells using cochannel deployed Femtocells
[11]	The main goal is to design transceiver architecture and conduct the SWIPT strategy for the remote radio heads (RRHs)	The article examined an uplink C-RAN's performance	Simulation results revealed that the performance of the transmission is better compared to the conventional one Large-scale remote radio heads (RRHs) led to increase of transmission power consumption
[103]	Suggested a two-phase time-sharing protocol. During the first phase, the destination node collects energy form the source node. In the second phase, the information-bearing signal is sent through the protecting artificial noise that comes from the destination node	The secure transmission is examined in a simultaneous wireless information and power transfer (SWIPT) system	Multiple-antenna techniques and systems can be an interesting research direction in the future works for enhancing the security of the SWIPT system

increase in the supplied bandwidths, energy efficiency and data rates. So, an innovative solution is in high demand for these rapidly increasing wireless networks to allow the new spatial generation (5G). Hence, Cloud Radio Access Network (C-RAN) has become an innovative candidate and can be employed as an alternative cellular network for the traditional network [36, 37]. China Mobile Research Institute [38] was the first one to provide it due to its various advantages, particularly in the field of spectrum efficiency and energy efficiency [39, 40]. A new framework was proposed in [41] to improve the energy efficiency of cellular networks by integrating the new C-RAN architecture. As evaluated in [42], cloud radio access can be integrated with small cells for cooperative interference mitigation and handover management in HCSNet. To deal with the cell edge users' interference, an effective CoMP clustering scheme was proposed, which employs affinity propagation. Moreover, [43] provides a discussion on the recent developments and challenges associated with the design of H-CRAN.

The effect of cooperative transmission on network-level achievable data rate along with energy efficiency (EE) and spectrum efficiency (SE) for downlink C-RAN architecture is studied in [44]. In [45], the SWIPT system that is implemented in the wireless cooperative networks was also examined. Presented in [46] are methods that allow for ultra-low-latency connections within the H-CRAN. Meanwhile, the cooperative transmission technology and the power adjustment technology are the measures of compensation strategy with considering the UE association and the allocation of resources [47]. Sensors could harvest wireless energy from RRHs or UTs, and communicate with UTs in C-RAN [48]. Furthermore, the energy efficiency for the downlink C-RAN compares between the compression and the data sharing strategies [49]. A stochastic geometry-based analytical approach is formulated that can be used to compute for the throughput reliability of a C-RAN [50]. Potential resource allocation schemes within H-CRAN: hybrid backhauling, coordinated scheduling, and multi-cloud association [43], revealed the manner by which the proposed strategies offer appreciable performance improvement in comparison to methods taken from recent literature. Yu et al. [51] discussed the dynamic resource allocation (DRA) scheme that is used for H-CRAN in TDD mode. Lastly, the minimum mean square error (MMSE) is seen as the performance metrics that include energy constraint and transmit power constraint. Given the goal of MMSE, the precoders and the detectors undergo an iterative update in the suggested scheme [11]. An economical spectral efficiency (ESE) is proposed to jointly take traditional SE/EE and the impact of wired/wireless front-haul into account [52, 53]. Table 1 showed many researchers work in terms of C-RAN energy efficiency.

2.2.2 Network architecture

The main idea behind C-RAN involves pooling the BBUs from various base stations into a virtualised and centralised

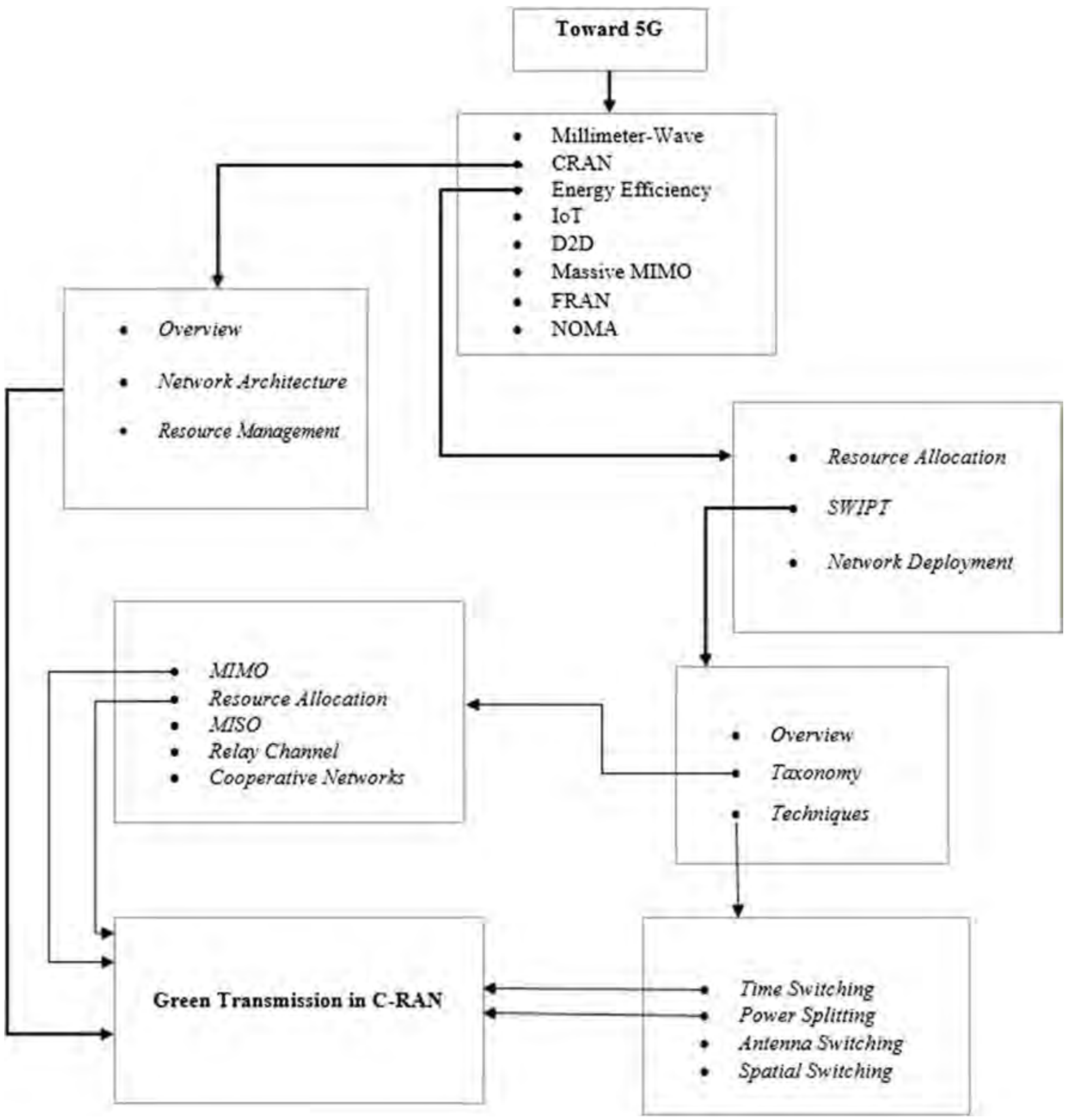

Fig. 1 Modelling Review

BBU Pool, while leaving the antennas and Remote Radio Heads (RRHs) at the cell sites [67]. C-RAN makes it possible to conduct energy efficient network operation and earn probable cost savings on baseband resources. In another word, the concept from which C-RAN moves is the splitting of traditional BSs into two functional units: a radio one called Base Band Processing Unit (BBU) and Remote Radio Head (RRH) [68]. Depending on the architecture, these units may have different functions. Moreover, it enhances network capacity by conducting cooperative processing and load balancing of signals that come from several base stations. Thus, one may deploy base stations with high deployment density and high load in C-RAN architecture. Figure 2 illustrates the C-RAN concept as well as its three major components: (1) BBU pool, which refers to a set of virtualised base stations (VBS) that are situated atop a cloud infrastructure, (2) RRH, which describes a light-weight radio unit equipped with antennas, and a (3) front-haul data distribution channel that is situated between the RRHs and BBU pool [29, 40, 69]. It also offers multi-RAT support, which includes other legacy systems, i.e. GSM, UMTS and LTE.

Because a characteristic BBU pool hosts 10-1000 base stations, a high front-haul capacity is needed to transport the in-phase and quadrature (I/Q) data generated from BBU to RRH. Therefore, based on the VBS/BBU architecture and the front-haul capacity, a different functional split may be found between BBU and RRH so that the data rate may

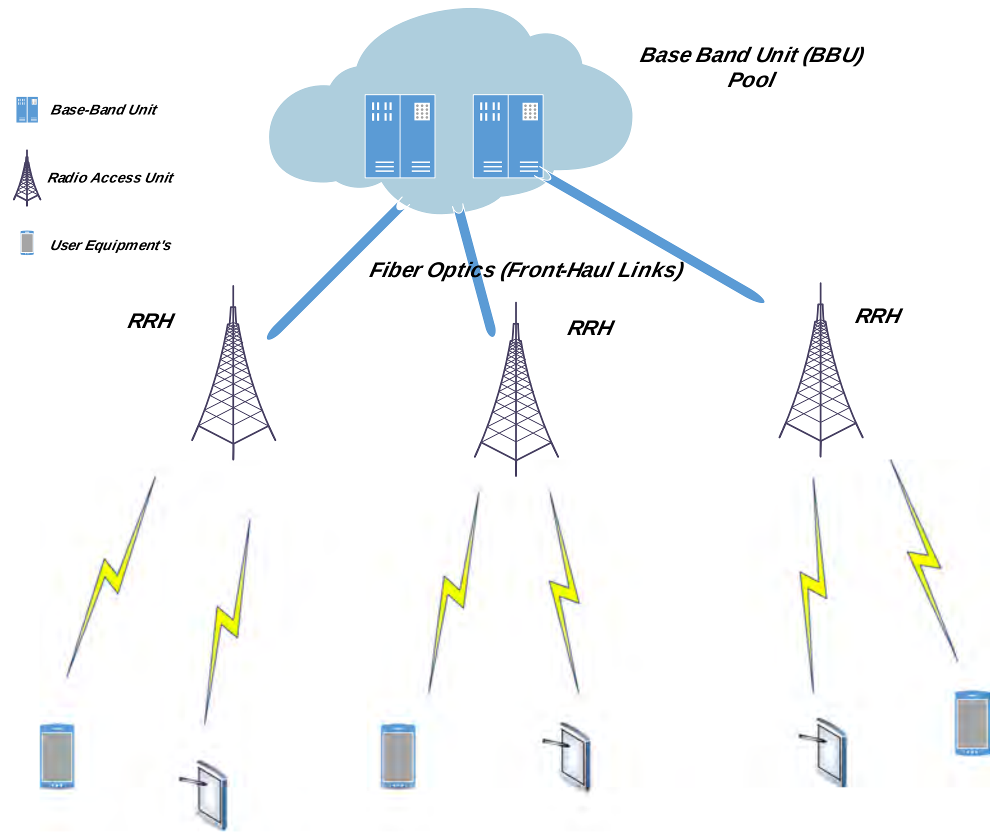

Fig. 2 C-RAN network architecture

be reduced in front-haul, which ranges from all-in-BBU to all-in-RRH. Another characteristic is the clustering or mapping that is observed between the BBUs and RRHs that are found in the front-haul. This type of mapping can be dynamically executed based on various factors including traffic load, energy efficiency [40, 69, 70]. Several limits exist because of the basic synchronous links as well as the high precision clock that is required in the current standard [71, 72]. Therefore, finding ways to attain an inexpensive, low latency, high bandwidth wireless signal optical fibre transmission will become an important challenge in the completion of the future deployment of the LTE network by C-RAN.

2.2.3 Resource management

Besides coordinated signal processing, coordinated resource management, and coordinated scheduling, RRH association now becomes possible because of the centralised C-RAN architecture. However, the optimal frequency, time, and RRH allocation problem is a combinatorial optimisation problem [69]. The study in [73] presented different approaches to implement hybrid fibre-radio infrastructures suited for cloud radio access networks, that will provide a framework for advanced cooperation, interference control/alignment, network virtualisation, and cognitive schemes [74]. Describing the current research status and some difficulties of broadband wireless access system for High-Speed Railway (HSR) and to demonstrate recent developments and challenges in H-CRAN design, [43] suggested promising resource allocation systems in H-CRAN: hybrid backhauling, coordinated scheduling, and multi-cloud association.

However, a novel resource management and resource sharing are proposing in [75, 76] for future C-RAN systems. Proposed in [75] is a resource management scheme that makes use of the news vendor game model, which also examined a resource allocation problem that has bargaining solutions, to be used as a promising technology for 5G cellular networks.

2.3 Energy efficiency for next generation

Despite the fact that studies by information theorists on energy-efficient communications date to at least 20 years ago, it gained more activity during the past 10 years [77, 78]. The current trend of radio access techniques deals with the ability to handle with the explosive traffic growth and the continuously rising demands on network capacity [79, 80], and the realisation of the importance of energy

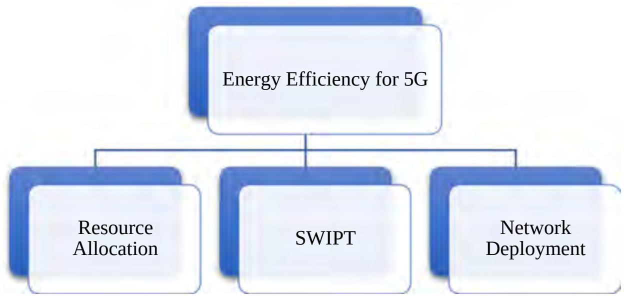

Fig. 3 Energy Efficiency for 5G

efficiency (EE) within wireless networks [81]. For practical systems, spectrally efficient techniques have proven to not be necessarily energy efficient. Furthermore, there may even be a trade-off between EE and SE or between EE and other measures [82], such as EE-deployment cost, EE delay, and quality of service (QoS) [83].

However, increasing network capacity 1000-fold [24] is achievable by large-scale antennas, numerous small cells, and significantly wider bandwidth in millimetre wave bands. However, lowering energy consumption simultaneously is still very challenging [68, 80, 84]. Hence, a 5G mobile network is needed to simultaneously have significant SE and EE improvements. It expected that by 2020, over 50 billion devices will be connected [85]. i.e. over 6 connected devices for every person, which includes both human and machine communications. The idea is to create a connected society with sensors, drones, cars, wearable, and medical devices [24] for wireless networks in the future. As Fig. 3 shows, most of the useful approaches for improving the energy efficiency of wireless networks can be categorised as follows:

2.3.1 Resource allocation

The operations of most systems have always relied on resources such as bandwidth, power and spectrum, which are used and form the backbone of wireless communication systems [86]. Since these resources are generally non-ubiquitous, parameters such as their design, the mechanisms employed or administered to allocate their scarce resources need to be factored when developing various wireless communication models in order to maintain seamless operations and enjoy maximum gains. For all wireless communication networks, resource allocation (RA), which helps to address that need, has become an important aspect. In fact, RA has been a rather active research topic for various conventional wireless communication systems like the orthogonal frequency division multiple access (OFDMA)-based wireless networks [87].

However, the first step to enhance the energy efficiency of wireless communication system is to allocate the system radio resources in a manner that the energy efficiency, instead of just the throughput, is amplified. This approach achieved large energy efficiency gains; however, a moderate throughput reduction follows with it [88]. A wireless system's radio resources are traditionally optimised in a manner to enlarge the system throughput or the data rate. Instead, with energy efficiency popularly being considered as a main indicator to rate the performance for 5G, a shift in trend followed, where the wireless network models that were throughput-optimised started shifting towards the ones that are energy-efficiency-optimised. Here, to achieve maximum energy efficiency, distribution was done for both the power transmission and radio resources. This method provided huge gains in terms of energy efficiency when compared with traditional resource allocation schemes with a moderate reduction in throughput [84]. Study in [89] examined the power allocation in a heterogeneous small cell network and energy-efficient wireless backhaul bandwidth allocation. It showed that a unique globally optimal energy efficiency solution is present, which offers an iterative algorithm to achieve this optimum. The study in [90] examined the power allocation in the NOMA two-way relay wireless networks and secure communication (SC) assignment by keeping an eavesdropper, with and without cooperative jamming (CJ).

2.3.2 SWIPT

Collecting energy from the environment and transforming this energy to electrical power is becoming an appealing possibility for the operation of wireless communication systems. As a matter of fact, even though this method does not directly lower the amount of energy required to run the system, it makes it possible for renewable and clean energy sources to power wireless networks [91]. In the context of wireless communications, two major types of energy harvesting have so far emerged: Environmental and Radio Frequency [92–95]. Furthermore, radio-frequency energy harvesting also provides an intriguing possibility, which helps in lessening the randomness associated with a wireless power sources. The concept involves combining energy harvesting and wireless power transfer techniques. This makes it possible for energy sharing among network nodes [96], extending the lifetime of nodes when they have low battery energy [97, 98]. This approach can even be taken further by the superimposition of the energy signals on regular communication signals, which leads to the so-called "simultaneous wireless information and power transfer" (SWIPT) [99, 100].

2.3.2.1 Overview It has been recently shown that harvesting both solar and wind energy can be used to operate communication systems [92, 93]. The emphasis should be on how this technique does not directly improve the system energy efficiency, because the amount of energy that is required to operate the system is not reduced. However, it is still an attractive option because it makes it possible for renewable and clean energy sources to power wireless networks, thereby offering an energy supply that is virtually unlimited, while reducing CO_2 emissions. However, one can also harvest energy from the radio signals over the air [94]. Doing so allows the network nodes to use wireless power transfer techniques to share energy with one another, with the goal of wirelessly recharging nodes that have low battery power [84, 97, 100]. However, the objective of current and future cellular networks is to supply higher data rates, high safety and universal communication with ensured quality of service (QoS).

Nevertheless, the information and energy that are sent at the same time cannot be achieved in reality, because the energy harvesting operation carried out in the radio frequency domain destroyed the information. To realise SWIPT, there is a method wherein the received signal must split to two different parts. The first part involves the energy harvesting part and the other part involves information decoding. SWIPT method provides higher energy efficiency because it has the ability to use the harvested power again for further transmission (Krikidis [9]). This makes it possible to optimise the energy efficiency (EE) problem for the power transfer (SWIPT) MIMO systems and simultaneous wireless information with statistical channel state information (CSI) feedback. Given the energy harvesting node's further transmission, the potential capacity that is generated by the transferred energy is calculated in the system capacity [101]. Besides the fact that harvesting results reveals the proposed schemes' superiority on EE, the EE system can still be enhanced further [101]. The SWIPT system and its application to wireless cooperative networks was also examined in [45], where the signals sent from each source were used to power the energy harvesting (EH) relay. However, consider the application of SWIPT in cooperative clustered wireless sensor networks (WSNs) [102, 103]. In [104], the resource allocation algorithm was also formulated for the wireless delivery of renewable green energy and secure information to mobile receivers within the distributed antenna communication systems. Furthermore, the simultaneous wireless information and power transfer (SWIPT) was also conducted for heterogeneous wireless networks [105, 106]. Table 2 reveals the critical techniques of SWIPT.

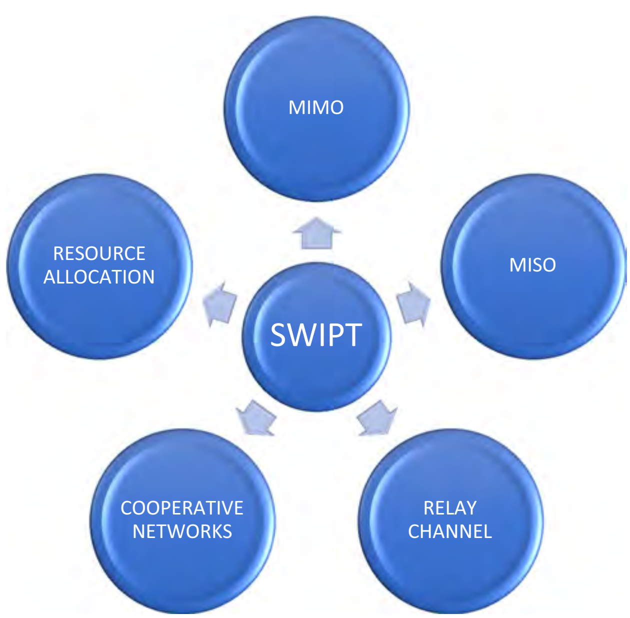

Fig. 4 SWIPT Based Channels and Networks

2.3.2.2 Taxonomy of SWIPT From an extensive critical review done on SWIPT for more than 90 articles, we find the technique is mainly related to five channels and networks (MIMO, MISO, Relay Channel, Cooperative Networks and Resource Allocation) as shown in Fig. 4. Then we separate the main critical review table to five tables according to it is a relation to SWIPT.

The five Tables 3, 4, 5, 6 and 7, contain the name of authors with the year of publications also have the methods, techniques and approaches used in the articles reviewed to achieve the objectives of the researches. Besides brief description about the articles just giving a general idea to the reader about the research. Finally, the last and most important part of the critical review table it is strengths and weaknesses points of the researches. Which focuses on the main findings of the research through the article, with critical analysis of the whole article body to select the weakest part of the research with ethical criticisms; not just to show that the research analyzed is nonsense. So, the tables below showing the critical reviews for SWIPT with MIMO, MISO, Relay Channel, Cooperative Networks and Resource Allocation.

The transmit power of the information carrying signal can be amplified to allow energy to transfer from the transmitter to the receivers. However, a larger susceptibility for information leakage follows with a higher transmit power because of the wireless channels' broadcast nature. Therefore, in communication systems with next wireless generations, a critical issue would be SWIPT.

As can be seen, the studied literature is categorised with five tables to present a critical review regarding the different efficient techniques to save energies in the promised generation. Along with some performance trade-offs in SWIPT systems, some of the basic concepts of SWIPT are discussed as well. Specifically, the study investigates the application of SWIPT and related technologies, including MISO, MIMO, cooperative networks, relay channel and

Table 3 Critical review of SWIPT based MIMO channel

References	Methods/techniques/approaches	Description	Strengths and weaknesses
[110]	The authors suggested a multiple-input multiple-output (MIMO) wireless broadcast system that is made up of three nodes. Here, the energy is harvested by one receiver while the other receiver separately decodes information from the signals that a common transmitter sends	Studied the limits of performance of emerging "wireless powered" networks of communication through opportunistic energy harvesting using the surrounding radio signals	The study exposed certain fundamental trade-offs in the design process of wireless MIMO systems for the maximisation of SWIPT efficiency It might be of interest to extend the characterisation of the rate-energy region to include more general MIMO broadcast systems that possess more than two receivers
[111]	The authors cooperatively designed the receivers at the IDs and the precoder at the source based on two criteria. For the first criterion, the worst case mean square error (MSE) is minimised under harvested energy constraints and source transmit power. For the second criterion, the total harvested energy at the EHs was maximised under worst case MSE constraints and source transmit power	The designs of the IDs receivers and joint source precoder are examined for MIMO multicast channels in SWIPT. Specifically, the linear receivers are assumed at the IDs and two criteria were considered in the calculation of the IDs receivers and source precoder	Demonstrating the importance of transceivers that are designed to achieve a required trade-off among the MSEs, source transmit power, and harvested energy within the EHs Choosing a node for energy harvesting or information decoding can be a function of the link quality, available battery power
[101]	Examining the energy efficiency (EE) optimisation problem used for SWIPT-MIMO systems using feedback from statistical channel state information (CSI)	The article examined the EE optimisation that is used for MIMO SWIPT system that has covariance CSI feedback	Results revealed the proposed schemes' superiority on EE One can extend this work easily to cases of multiple energy harvesting (EH) receivers while taking the growth of the amount of EH receivers into account
[112]	Introducing a non-iterative norm-based algorithm and an iterative AS algorithm to optimise the transmit covariance matrix and the antenna selection (AS) matrices for SWIPT in MIMO broadcast systems	To examine the antenna selection (AS) design problem. One can frame the as transmit covariance matrix design and joint AS	The simulation results revealed that the proposed algorithms' achievable rates approach that of the AS scheme, which the exhaustive search optimised
[113]	With the use of the SCA method to serve as a cornerstone, the study developed an iterative precoding algorithm to solve it	This article examined the secrecy precoding problem used for SWIPT given a cognitive MIMO broadcast channel	Results demonstrate that the developed algorithm is capable of achieving a near-optimal performance that has guaranteed convergence
[114]	Theoretically examine a new method for SWIPT in MIMO point-to-point using abilities for radio frequency energy harvesting	SWIPT was theoretically examined in the spatial domain for a MIMO channel that possesses abilities for radio frequency (RF) energy harvesting (EH)	It presented a polynomial complexity algorithm that generates a near-optimal solution for a broad series of parameter configurations In the future, practical implementations of these systems have to be examined
[115]	The authors jointly designed the power splitting ratio and precoding matrix, artificial noise (AN) covariance matrix, given the constraints of harvested energy at receivers and total transmit power for maximising the worst-case secrecy rate	It proposed a robust secure transmit design for MIMO channels that have SWIPT, which is capable of maximising the worst-case secrecy rate based on the total transmit power constraint	Simulation results revealed that the robust secure transmit design that was proposed performed better than existing methods
[116]	It proposed an iterative algorithm that also has a semi-closed form solution to manage the problem of energy harvesting maximisation (EHM)	It studied the approximate optimum transmission solutions that can be used for MIMO wiretap channels with SWIPT	Results revealed that the design performed better than some current methods with energy harvesting

Table 3 continued

References	Methods/techniques/approaches	Description	Strengths and weaknesses
[117]	Made use of the two designs for practically viable relay receiver, specifically 1) the power splitting receiver as well as 2) the time switching receiver. Furthermore, it derived asymptotic signal-to-interference-plus-noise ratio (SINR) expressions for an unlimited amount of antennas at the relay	It studied power transfer and simultaneous wireless information in massive MIMO amplify-and-forward (AF) multi-way relay networks (MWRNs) using time switching relays and power splitting	When a massive relay antenna array is used, the effect that inherently low radio frequency-to-direct current (RF-to-DC) conversion efficiency had on the harvesting of wireless energy on the SINR and sum rate metrics can be mitigated effectively
[118]	This study presents a joint optimisation problem of relays beamformers and source under the constraints of their transmit powers and the energy-harvesting constraint of the user	It proposed a full-duplex (FD) MIMO amplify-and forward (AF) relay SWIPT system for the minimisation of the total mean-square-error (MSE) criterion	Numerical results for the BER and MSE revealed that the proposed schemes had a good performance for this system
[119]	The authors suggested turning the quadratic EH constraints into linear matrix inequalities that are combined with two equality constraints	This study proposed a robust transceiver design that can be used for two users MIMO IFC system with SWIPT. Here, there are precoding matrices within the two transmitters as well as the postprocessing matrices that are found at two ID receivers	Simulation Results revealed that the robust transceiver design that was proposed had significant performance gains compared to the non-robust one In the future, the shared optimisation of postprocessing and precoding matrices could be an interesting study
[120]	The authors derived the optimal transmit direction and the asymptotic-optimal transmit covariance matrix through the maximisation of the average harvested energy and the achievable ergodic secrecy rate, respectively	The study addressed the maximisation problem for the ergodic secrecy rate depending on a harvested energy constraint for the MIMO wiretap channel with SWIPT by only assuming statistical CSI at the BS	One can achieve a bigger rate energy region when there is an increase in the Rician factor or a decrease in the path loss exponent. It also revealed an increase in the harvested energy as well as a decrease in the achieved ergodic secrecy rate, when the transmit correlation goes up
[121]	First, the authors proposed a semidefinite relaxation based alternating optimisation (SDRAO) solution in order to get closer to the problem's optimal solution. They then semi-decoupled the joint optimisation using the derived diversity interference alignment (DIA) technique so that a lower complexity solution can be obtained	It studied the transceiver design problem for PS enabled co-located SWIPT used in MIMO interference channel (IFC) networks	Simulation results confirm the theoretical analysis and revealed various impacts of SINR thresholds For future work, the robust implementation with imperfect CSI stays as an open problem
[122]	Tools taken from stochastic geometry can be used in the quantification of the information rate against harvested power trade-off. This study reveals ultra-dense deployments and large-scale antenna arrays of base stations	A tractable approach was introduced for examining the viability of multiple-antenna cellular networks	Analysed SWIPT for MIMO used in cellular networks The results that were collected were only for LOS, and did not include NLOS

resource allocation. However, for various network topologies, SWIPT systems have been examined.

2.3.2.3 SWIPT techniques Initial information theoretical studies about SWIPT were done under the assumption that the same signal can transfer both information and energy without incurring any losses, unveiling a fundamental trade-off between power and information transfer [158]. However, it is not possible to conduct simultaneous transfer in practice since the energy harvesting operation that is conducted in the RF domain damages the content of the information. To accomplish SWIPT, one has to split the received signal in two distinct parts: one for information decoding and one for energy harvesting. The following will discuss the techniques that were proposed to help complete this signal splitting in various domains (time, antenna, power, space) [9, 159]. The four techniques which can realise the signal splitting into distinct domains will be introduced [160, 161].

Time switching (ts) When time switching is utilised, the receiver will switch to a different time. For this situation, the signal splits in a time domain. Therefore, the signal

Table 4 Critical review of SWIPT based MISO channel

References	Methods/techniques/approaches	Description	Strengths and weaknesses
[123]	The authors examined multicasting MISO systems and its utilisation in SWIPT. They also proposed transmitting beamforming and power splitting (PS) ratio optimisation algorithms that is applicable for both imperfect and perfect CSI cases, with the use of semidefinite relaxation (SDR) techniques	Examined the joint multicast transmit beamforming and received the power splitting problem for the minimisation of the transmit power of the BS given the energy harvesting and signal-to-noise ratio (SNR) constraints at each receiver	It provided simulation results to demonstrate the efficacy of the suggested algorithms One can extend this work to MIMO multicasting systems
[124]	The study tackled a new secrecy communication problem within a multi-user multiple-input single-output (MISO) SWIPT system. In this system, a multi-antenna transmitter simultaneously sends energy and information to one information receiver (IR) and multiple ERs, with each one having a single antenna	This article attempts to address the important concern of physical layer security that is present in the emerging simultaneous wireless information and power transfer (SWIPT) system	It solved this non-convex optimisation problem using a two-step algorithm and revealed that the SDR technique produces the optimal beamforming solution
[125]	Jointly designed transmit beamforming vectors and received PS ratios for every MS based on their given harvested power constraints for energy harvesting and signal-to-interference-plus-noise ratio (SINR) constraints for information decoding	It studied receive power splitting design and joint transmit beamforming for a multi-user MISO broadcast system that is utilised for simultaneous wireless information and power transfer (SWIPT)	It first derived the adequate and necessary condition that will ensure the feasibility of the problem. This non-convex problem is then solved by applying the semidefinite relaxation (SDR) technique and proving its optimality
[126]	The authors suggested a new relaxation method called the second-order cone programming (SOCP) relaxation. This method is used to handle the joint beamforming and power splitting (JBPS) problem	Took into consideration the joint transmit beamforming and receive power splitting that is used for multi-user MISO SWIPT IFC	One can solve the former by using the sub-gradient method while one can solve the latter using the coordinate descent method Merging these two signal splitting systems for SWIPT may be an interesting field for future research
[127]	It designed joint information and energy transmit beamforming for a multi-user MISO broadcast system that can be used for simultaneous wireless information and power transfer (SWIPT)	The aim of the study is the maximisation of the weighted sum-power that is sent to all EH receivers depending on given different information decoding (ID) receivers and minimum signal-to-interference-and-noise ratio (SINR) constraints	It provided numerical results to assess the proposed optimal beamforming designs' performance for MISO SWIPT systems For practical optimisation of the performance of multi-antenna SWIPT systems with energy transmission and receiver-location-based information
[128]	The authors introduced a lower bound-based rank-one suboptimal (LB-Sub) solution using Charnes–Cooper transformation. The authors also suggested the suboptimal Gaussian randomised (GR)	Collected the rank relaxation upper bound for the MISO SWIPT system when the imperfect CSI of the channels is found in the transmitter	Simulation results demonstrated that the proposed suboptimal GR solution and LB-Sub solution outperformed the non-robust scheme based on the rank relaxation upper bound
[129]	The study classified the SWIPT interference channels (IFC) systems into two categories. First, it considered the IFC with *partial cooperation*. Second, it examined the IFC with *signal cooperation*	Examined the SWIPT system that is used for two users MISO IFC. Here, the information is decoded by one receiver while the other receiver harvests energy opportunistically from the received signal	The numerical examples were able to confirm that the proposed optimal beamforming offers a lager R-E region compared to conventional schemes
[130]	The study characterised the capacity area for ID receivers by finding a solution to the sequence of weighted sum-rate (WSR) maximisation (WSRMax) problems given a set of minimum harvested power constraints for individual EH receivers and a maximum sum-power constraint for the AP	Studying in this article a MISO-BC that is used for SWIPT, where information and energy is simultaneously a multi-antenna AP delivers by a multi-antenna AP to multiple single-antenna receivers	The proposed algorithms offer useful insights on addressing general WSRMax problems with both MinLTCCs and MaxLTCCs

Table 4 continued

References	Methods/techniques/approaches	Description	Strengths and weaknesses
[131]	The authors suggested a 1-D and 2-D robust artificial noise (AN)-aided secure Transmission scheme that has SWIPT in the MISO channels	One can find the optimal solution to the problem using a two-dimensional (2-D) search. Because the 2-D search algorithm possesses high computational complexity, the study suggested ignoring the correlation that the channel confusions had from the transmitter to the receiver, which is responsible for information-decoding	The robust AN-aided secure transmission scheme that was proposed exhibited significant performance gain compared to the non-robust AN-aided secure transmission scheme One can perform future work on the robust AN-aided secure transmission scheme for the SWIPT in the MIMO channels
[132]	The authors developed designs for the chance constraints (CC)-BFPS and optimal robust worst case (WC)-BFPS for downlink MISO SWIPT systems	The two robust joint beamforming and power splitting (BFPS) designs were developed under the assumption of an imperfect channel state information (CSI) at the base station	Simulations revealed that the proposed SDP relaxation's tightness is generally not always guaranteed. Analytically deriving the conditions that make these relaxations tight would be interesting In the future, generalisations of the proposed approaches to channels of multi-cell MIMO might also be an interesting direction
[133]	Introduced a low-complexity suboptimal algorithm that has its basis in the genetic algorithm so that the original problem can be solved	It proposed a secure beamforming scheme for the multi-user MISO broadcast channel having confidential messages. This can lessen the total transmit power and meet the energy harvesting constraints and secrecy rate at the same time	It provided simulation results to show the proposed algorithm's performance
[134]	The authors introduced the cooperative-jamming (CJ) that helped in the robust secure transmission scheme used for SWIPT in MISO channels	The authors in this study proposed decoupling the problem into three optimisation problems before using alternating optimisation algorithm to obtain the locally optimal solution	Simulation results revealed that although the locally optimal transmit covariance matrix gained is ranked one or two, the CJ aided robust transmission scheme proposed after GR approaches the upper bound of the performance
[135]	The authors suggested using a JANTPS scheme for MISO secure communication system equipped with SWIPT	Included an equality constraint that will help in the conversation of the constraint on information rate that is observed from the transmitter to eavesdroppers as they are transformed into linear matrix inequalities	Simulation results revealed that when there is more than one eavesdropper, the JANTPS scheme achieves a significantly higher achievable secrecy rate average compared to the JTPS scheme
[136]	Twp Gaussian channel misgivings were incorporated to frame the robust power minimisation problem	This article examined the robust power minimisation problem of SWIPT within a MISO downlink system	It provided numerical results to certify these proposed robust schemes' performance
[109]	The authors were able to maximise the energy harvesting efficiency (EHE) of EH FUs and information transmission efficiency (ITE) of ID FUs. They used the QoS of all users and examined their relationship	This paper examined the design of energy efficient beamforming that is used in wireless-powered two-tier MISO heterogeneous cellular networks (HCN)	Simulation results illustrated that MBF offers better EHE and ITE compared to zero-forcing (ZF). Furthermore, there is also a trade-off between EHE and ITE in general There are numerous avenues for extensions and future work. One such aspect is the absence of CSI. Another aspect involves the extension to multi-cells using cochannel deployed Femtocells
[137]	The authors addressed the simplified EEO problem by proposing a Lagrangian relaxation (LR) method that is coupled with Dinkelbach method	Examined the EE-based joint ZF beamforming and received power splitting that is used for multi-user MISO SWIPT systems	Numerical results have verified the excellent efficiency that the proposed algorithms exhibited Antenna selection may enhance the multi-user MISO SWIPT systems' system energy efficiency with large-scale antenna arrays at BS. It is therefore worth studying in the future

Table 5 Critical review of SWIPT based relay channel

References	Methods/techniques/approaches	Description	Strengths and weaknesses
[138]	The authors introduced a new spread energy beamforming scheme that can be used for simultaneous power transfer and wireless information in the AF TWRC. It proposed the optimal transceiver design to maximise the achievable sum-rate	This paper formulates a new spread energy beamforming scheme for performing simultaneous power transfer and wireless information in the two-way relay channel (TWRC)	Numerical results revealed that the proposed schemes performed better than the conventional SWIPT One can also apply the proposed scheme to full-duplexing and frequency-division duplexing systems
[139]	A high-rate beamformer that offers support for multiple Communication pairs is was developed for SWIPT in wireless relay networks	In order to attain a high sum rate, the study designed a new relay beamformer to simultaneously support an energy receiver and multi-pair source–destination communication links	Simulations revealed the fast convergence of the reformulated problem as well as the higher sum rate that is achieved by the proposed beamformer compared to other polynomial-time schemes
[140]	The authors introduced the local optimal solution, globally optimal solution, and low complexity suboptimal solution for the EH-constrained relay beamforming optimisation problem that is present for SWIPT given a two-way multi-antenna relay network that is non-regenerative	The study considered the relay beamforming design problem that is used for the SWIPT scheme in a two-way multi-antenna relay network that is non-regenerative	Simulations demonstrate that when the EH constraint is considered, a proposed scheme performs better than the conventional relay beamforming schemes presented in the literature
[141]	The study proposed an iterative algorithm based on the constrained concave-convex procedure (CCCP) that is capable of achieving a local optimum	In this correspondence, the authors introduced three SRB algorithms that can be used for the SWIPT that is in the nonregenerative relay network	Simulation results demonstrated that the proposed CCCP-based iterative algorithm was able to attain a lower computational complexity and higher average secrecy rate compared to the convectional secure relay beamforming (SRB) schemes
[142]	The authors developed a shared power splitting framework by utilising game theory to obtain a profile for the power splitting ratios for every relay. This framework is capable of achieving a good network-wide performance	Developing a game-theoretical framework that will manage the shared power splitting problem often observed in simultaneous wireless information and power transfer (SWIPT) for relay interference channels	The numerical results revealed that the proposed algorithms are capable of converging to the matching NEs from various starting points This demonstrates that at high SNR, one should jointly consider the power control at the sources with the power splitting taking place at the relays so that the sum-rate can be improved further. This may be performed in a future work
[143]	Based on the coupled resonator filter theory, one can derive mathematical equations for bandwidth and transmission efficiency for an arbitrary amount of relays. One can verify improved efficiency and bandwidth using simulation, equations, and experiments	The study proposed the relay scheme for intermediate-range SWIPT. It suggested that one can widen the bandwidth by increasing relays, with acceptable efficiency for power transfer	Experimental results revealed that below the distance of twice the resonator's diameter, the efficiency of the system increases from 5.43% (no relay) to 29.47% (one relay) and 38.02% (two relays) This study's future research direction will focus on the relays design for SWIPT of variable transfer distance
[107]	The authors suggested a joint time-switching (TS) and power allocation (PA) optimisation algorithm that can be used to attain the maximum end-to-end achievable rate	The joint PA and TS optimisation problem was examined for the multicarrier decode-and-forward (DF) relay network that is equipped with TS based relaying	Simulation results show that the proposed joint TS and PA technique performed better than the scheme that has a fixed TS ratio for energy harvesting (EH)

Table 5 continued

References	Methods/techniques/approaches	Description	Strengths and weaknesses
[144]	A relay beamforming and energy harvest design is proposed to for the maximisation of the chance of the Signal-to-Noise-Ratio (SNR) of the user larger than a pre-defined threshold	This study tries to address the vital concern of physical-layer security in a new and emerging type of wireless relay network with SWIPT	Simulation results confirm the efficacy of the proposed algorithm, which can achieve a better trade-off between the user's SNR and the power consumption of relays It can readily extend the model and algorithms presented in this paper to multiple users. Another interesting extension would be to include common interference in D2D (Device-to-Device) communication
[145]	To examine the limit of system performance, the authors proposed an effective resource allocation (RA) algorithm to maximise the system's achievable information rate	Studied the power splitting (PS) based SWIPT for its usage in the two-hop OFDM decode-and forward (DF) relay system	Simulation results illustrated how the proposed algorithm can achieve the system's maximum achievable rate and also show that to achieve a better system performance
[146]	Introduced an effective joint time-switching (TS) and power allocation (PA) optimization algorithm that can be used in the OFDM amplify-and forward (AF) two way relay networks (TWRNs) that have SWIPT	By jointly designing information processing at the relay and TS ratios of energy harvesting (EH), as well as the allocation of power over all the subcarriers at the relay and the two terminals, the aim of the research is to maximise the two-way relay networks' end-to-end achievable rate	Simulation results display that the proposed Algorithm performed better and with fast convergence speed For decode-and forward (DF) relaying, one can use the dynamic time allocation for IT to improve the system performance further. Also, such a scenario may be studied in the future
[147]	The optimisation problems of power splitting ratios at the relays are framed for both amplify-and-forward (AF) and decode-and-forward (DF) relaying protocols. Efficient algorithms are proposed to establish the optimal solutions	This article studied simultaneous power transfer and wireless information in multi-relay helped two-hop cooperative communication	Simulation results demonstrate that the proposed schemes significantly performed better than the traditional best relay selection schemes
[148]	For the cognitive radio (CR) networks that are considered with simultaneous wireless information and power transfer (SWIPT), the authors derived analytical expressions that they could use for the outage probability including their high signal-to-noise ratio (SNR) estimates that are presented in closed form	The cooperative CR networks' outage performance with an energy harvesting relay was examined	The analytical results developed showed that using SWIPT will not lead to any losses in diversity gain A significant future direction will be examining the multiple user pair's scenario, where game theory is ideally used in modelling user interaction
[149]	The authors propose a two-hop co-located robust precoding optimisation design with presence of channel confusion in SWIPT radio relay networks	Joint robust precoding design of the information and power transfer that can minimise the overall relays' power consumption while meeting the predefined energy-harvest and quality-of-service requirements provided	simulation results confirm the efficacy of the proposed design compare with the non-robust precoding design Devising and examining the operation policies is also vital for the multi-hop relay networks at future
[150]	The authors consider guaranteeing the i security of the information transmission of a multiple-input multiple-output non-regenerative relay system that has SWIPT in its physical layer. They did this by designing relay beamforming and source to enlarge the system's security rate	Consider guaranteeing a SWIPT MIMO relay system's physical layer security of, and designing the signal of the source's AN beamforming and relay to increase the system's secrecy rate	Simulations reveal that the 'joint design' algorithm is able to accomplish higher performance compared to the 'alternating optimisation' algorithm

arrived at receiver during the one time-slot is employed to transmit power or decode information. The time switching technology can equip the receiver with a simple hardware. If it uses time switching (TS), the receiver will have to switch in time between energy harvesting and information decoding [110]. In such a case, it performs signal splitting in the time domain. Therefore, the entire signal that the one time-slot receives is used for either power transfer or

Table 6 Critical review of SWIPT based cooperative networks

References	Methods/techniques/approaches	Description	Strengths and weaknesses
[45]	The relay makes use of a power splitting (PS) scheme in harvesting the energy that each source sends, which it then utilises to send the transmissions to the destinations	It studied the application of the SWIPT system to wireless cooperative networks, where the signals sent from each source powered the EH relay	The proposed scheme was consistent in achieving a total transmission rate that is higher compared to a scheme that has an uniform PS ratio
[151]	When there is only a schedule for a single user, the development of the analytical results is down to demonstrate the diversity gain that is attained by the max–min criterion. This is only equal to (M+1/2), which is significantly less compared to the maximal diversity gain M	It considered an energy harvesting cooperative network having one relay *and* M source–destination pairs, and where the relay only schedules m user pairs for transmissions	It provided simulation results to demonstrate the developed analytical results' accuracy and simplify the comparison of the performance One potential future direction would involve studying how to accomplish a balanced trade-off between user delay and reception reliability
[152]	It proposed a new cooperative SWIPT NOMA, where near nonorthogonal multiple access (NOMA) users near to the source serve as energy harvesting relays to offer assistance to NOMA users that are far	It considered the SWIPT application to NOMA. It also proposed a new cooperative SWIPT NOMA protocol that has three varying users' selection criteria	Results verified that the opportunistic utilisation of node locations for choosing users can deliver superior throughput and achieve low outage probability compared to the random selection scheme
[153]	A Rician fading environment is assumed to jointly optimise relay placement (RP), power allocation (PA), and power splitting (PS) in order to minimise outage probability given the harvested power constraint that is observed at the destination node	Studied the optimisation of RP, PA and PS in two-hop energy transfer and information relating to lessen the outage probability in SWIPT through the Rician channels	Numerical results revealed that the joint optimal solutions are able to achieve 64 and 100% outage improvement respectively compared to the fixed allocation scheme for those without and those with direct link
[154]	The authors derived new closed-form expressions for the end-to-end signal-to-noise ratio 's (SNR) probability density function (pdf) and the average bit error rate (ABER) of the considered SWIPT cooperative scenario	Analysing the performance of DM in SWIPT cooperative AF networks over Rayleigh channels	Numerical results show that the relay terminal's optimum location is nearer to the source than to the destination

information decoding. The TS technique makes simple hardware implementation possible at the receiver but it also needs information/energy scheduling and accurate time synchronisation [9].

Power splitting (ps) The technology of power splitting realises SWIPT through dividing the received signal into 2 distinct power level parts. The first part is sent to the rectenna circuit so that energy could be harvested and the second part is exchanged into the baseband so that information can be decoded. There is a difference between TS and PS that the PS technology brings a higher receiver complexity and needs the power splitting factor α to be optimised. Nevertheless, it makes use of instantaneous SWIPT, since the signal that the 1 time-slot receives applies to decode information and transmit power [9, 100, 110, 162].

Antenna switching (as) The function of antenna arrays is to produce DC power to ensure dependable equipment operation. Given this method, the technology of antenna switching switches each antenna component for rectifying/decoding for the realisation of SWIPT in the antenna domain. In AS technique, receivers are separated into two parts, where one part is used for decoding information and the other part is applied to harvest energy. There is a need for AS technology that the solution should be optimised problem for every communication frame. The objective is to judge the optimal allocation of the antenna elements [9, 163]. However, given a MIMO decode-and-forward (DF) relay channel, where the harvested energy is used by the relay node to send the received signal again, the optimisation problem was presented as a knapsack problem and then solved with the use of dynamic programming in [163].

Spatial switching (ss) One can apply the spatial switching (SS) technique in MIMO configurations and then be able to achieve the SWIPT in the spatial domain through the exploitation of the interference channel's multiple degrees of freedom (DoFs) [164]. Given the MIMO channel's singular value decomposition (SVD), it transforms the

Table 7 Critical review of SWIPT based resource allocation

References	Methods/techniques/approaches	Description	Strengths and weaknesses
[155]	The authors proposed a design a resource allocation algorithm and a practical non-linear energy Harvesting (EH) model for use in systems of simultaneous wireless information and power transfer (SWIPT)]	This letter examined a practical EH model that can be used to capture the EH circuits' non-linear characteristics in SWIPT systems	Numerical results revealed that a substantial gain in performance is achievable
[108]	The authors suggested an energy-efficient resource allocation technique with the use of an iterative method. They also provided the proposed algorithm's convergence given the nonlinear fractional programming	It studied the efficiency of gathering energy from RF signals in wireless networks under a realistic assumption that there is an imperfect channel state information existing at the transmitter (CSIT)	The results of the simulation revealed that the proposed algorithm functions in an energy-efficient manner, thereby attaining maximum energy efficiency Proposing an efficient algorithm that has its basis on a theoretical approach may be worthwhile
[156]	An algorithm is designed to integrate three major system design objectives: energy harvesting efficiency maximisation, total transmit power minimisation, and interference-power-leakage-to-transmit-power ratio minimisation	It studied the design of the resource allocation algorithm for CR secondary networks having simultaneous secure communication and wireless power transfer based on a multi-objective framework for optimisation	Numerical results revealed an interesting trade-off among the conflicting system design objectives that were also considered
[157]	The authors proposed the subcarrier-separation (SS) scheme for resource allocation in a multi-user OFDM system with capability of SWIPT and study joint optimisation for power allocation and subcarrier assignment	The optimal design for resource allocation (i.e. power allocation and subcarrier assignment) is studied to maximise the sum rate with a minimum transferred power constraint	The proposed SS scheme (with both optimal and suboptimal solutions) outperforms the existing time-sharing (TS) scheme when high power is needed to be transferred

communication link into parallel Eigen channels that are capable of transferring either energy or information. At each Eigen channel's output, a switch drives the channel output to either the correcting circuit or the conventional decoding circuit. The assignment of Eigen channel and power allocation in various Eigen channels is considered to be a challenging nonlinear combinatorial optimisation problem. Timotheou and Krikidis [164] proposed an optimal polynomial complexity algorithm for the special case of having unlimited maximum power in every eigenchannel [9].

2.3.3 Network deployment

The design of typical network deployments is done in such a way that it will expand coverage and throughput. However, one can obtain significant energy savings by re-thinking conventional network models and taking the energy efficiency in the covered area into account. In this research area, the trend is headed towards dense networks. Indeed, two robust 5G candidate technologies are going towards this direction, namely massive MIMO [165] and heterogeneous networks [166]. Here, the latter densifies the amount of infrastructure nodes, while the former densifies the amount of placed antennas. It has been proven by several studies that network densification is a technique that is very energy-efficient, as it lessens the 'physical and/ or electrical' distances within the communicating nodes, therefore allowing higher data rates without incurring extra energy consumption [167, 168]. Furthermore, on/switch-off algorithms, base station (BS) switch, and antenna muting techniques to adjust to the traffic conditions are helpful in reducing energy consumptions further [169, 170].

2.4 IoT

Internet of Things (IoT) refers to the main concept that is altering numerous perspectives in the landscape of 5G cellular networks. IoT describes the network of everyday physical objects, appliances, vehicles, buildings, devices, etc. Some examples of devices that could be considered as parts of the IoT are microwave ovens, wearable smart watches, washing machines, and health monitors. These devices can detect certain information and transmit it to a remote server, a process that mostly takes place through the Internet [171, 172]. However, the server also has the ability to issue commands remotely in order to control the device. The information that the server collects is then processed so that information about the underlying process can be gained. One can then use this knowledge to construct smarter systems like smart homes, intelligent transport systems, smart cities, health care systems, etc. [173]. Given its applications in a number of diverse areas, the advent of IoT will allow the connection of a multitude of devices to the Internet. This shift in the model, from the idea of connected people to the concept of connected things, has led to the prediction that by 2020, about 50 billion devices will be contained in the network [174]. Given the sheer capacity of IoT devices that are predicted to be connected and the numerous applications that one could use them in, IoT devices have a significant role in the design of 5G systems as well as several components of the 5G network.

2.5 D2D

Traditional cellular communication makes it possible to have communication among user equipment (UEs) via the base station (BS). However, the UEs may be within the range to perform direct communication. This implies that it is possible to have communication between the UEs without passing through the core network. This kind of communication leads to improvement in energy efficiency and spectral efficiency enhanced throughput, and reduced delay. D2D communication has an important role in addressing the subscribers' requirements. D2D allows for the merging of centralised and ad hoc networking. Taking advantage of the ad hoc network [175, 176], one can use D2D communication in conjunction with other technologies such as cognitive radio, cooperative communication, and Internet of Things (IoT), to enhance the spectral efficiency. With the use of centralised networking, D2D communication helps in the overall improvement of the network performance, given the operator's control [177]. With cellular networks being underlain by D2D communication, content sharing even with a large number of users is possible as long as local caching and sharing zones are set up. This supports network management in a manner that is distributive. Also, it is possible to relay data using device to device (D2D) communication. Furthermore, device-to-device (D2D) communication was determined by the METIS research project to be a key enabler for different 5G services [178].

2.6 Massive MIMO

Massive MIMO refers to an evolving technology that has undergone upgrades from the existing MIMO technology. The massive MIMO system makes use of arrays of antenna that have few hundred antennas which serve as frequency slots that service many tens of user terminals [179, 180]. The massive MIMO technology mainly aims to extract all the MIMO benefits on a larger scale. Generally, massive MIMO is a changing technology of next-generation networks (5G), which is robust, energy efficient, secure, and spectrum efficient [165]. Furthermore, massive MIMO relies on spatial multiplexing, which further relies on the base station possessing channel state information, for both the uplink and the downlink. It is not easy in cases where there is downlink. However, it is easy in case of uplink, since the terminals transmit pilots. Each terminal's channel response is estimated based on pilots. In conventional MIMO systems, the pilot waveforms are sent by the base station to the terminals. However, based on these, this is not a viable process for massive MIMO systems, particularly in high mobility conditions given these two reasons. Thus, compared to the conventional MIMO system, massive MIMO systems now need a large number of similar slots [181].

2.7 FRAN

With the evolution of the cloud radio access networks, fog radio access networks (F-RANs) were put forward as a promising paradigm for the 5G wireless communication system [182]. It is an advanced mobile networking architecture that is socially aware and provides energy efficiency and a high spectral while also minimising the backhaul burden. Specifically, F-RANs leverage edge computing and social information to efficiently remove the end-to-end latency. Taking into account the benefit of edge and cloud processing, key issues of F-RAN technique include caching, radio resource allocation and service admission control [183]. The findings in [184] elaborately summarise all the recent advances related to radio resource allocation and performance analysis for F-RANs. In particular, in a bid to enhance EE and SE as well as maintain a low latency level, we present the adaptive model selection and advanced edge cache schemes. Thus, radio resource allocation strategies were proposed to optimise EE and SE in F-RANs. A few open issues were also identified with regards to the social-awareness technique and the F-RAN-based 5G architecture [185].

2.8 NOMA

A promising radio access technique is the non-orthogonal multiple access (NOMA) to improve the performance in next-generation cellular communications. In comparison to orthogonal frequency division multiple access (OFDMA), NOMA provides a set of desirable benefits such as higher spectrum efficiency [186, 187]. The concept of NOMA heterogeneous network was put forward by researchers in [188], who also evaluated the issue of energy efficient user scheduling as well as power allocation in 5G NOMA heterogeneous network by taking into account both imperfect and perfect CSI. They also addressed issues with resource optimisation by employing convex optimisation. Also, a power optimisation and two-step user scheduling scheme was proposed and the proposed schemes' effectiveness was compared with that of the existing scheme, which were confirmed via simulations by considering energy efficiency. The F-RANs architecture enhanced with NOMA for 5G networks was presented in 1 [189], and investigation was done for power and sub-channel allocation issues in NOMA-based F-RANs to maximise the net utility by taking into account the co-channel interference. Full advantage can be enjoyed via NOMA-based F-RANs architecture with the edge of networks.

3 Towards green in C-RAN

The aim of this article is to provide green transmission for next-generation 5G through the C-RAN scenario. Figure 5 demonstrate C-RAN scenario combined with the wireless link between RRH and user equipments. Furthermore, the wireless link signal represent SWIPT system which is separated into two parts: the first one is for information while the second one is for the power transfer because of we couldn't use radio frequency for both of them at the same time [108]. However, performing this main technique combining with the sub-techniques and algorithms to use the wireless signals for transfer power besides information as shown in introduction section Fig. 1. As well, Fig. 6 shows SWIPT system model to clarify the link between RRH and end-user in Fig. 5. Further, the green transmission proposed in this article is not obsessive for C-RAN, but also can be for different types of another wireless cellular networks like LTE, Wi-Fi, Wimax and WSN.

4 Research challenges and future direction

4.1 Massive MIMO for SWIPT

Two distinct benefits to SWIPT networks can be reaped by making use of massive MIMO. On one hand, more harvested energy can be yielded by employing additional antennas at the receiver as a result of the broadcast nature of wireless transmission. On the other hand, for beam forming, exploitation of extra transmit antennas can be done in order to considerably improve the efficiency of information as well as energy transfer. The idea behind employing massive MIMO is to densify the number of antennas that are deployed. In massive MIMO, hundreds of small antennas, fed by low-cost amplifiers and circuitry, substitute the conventional arrays with just a few antennas that are fed by bulky and expensive hardware.

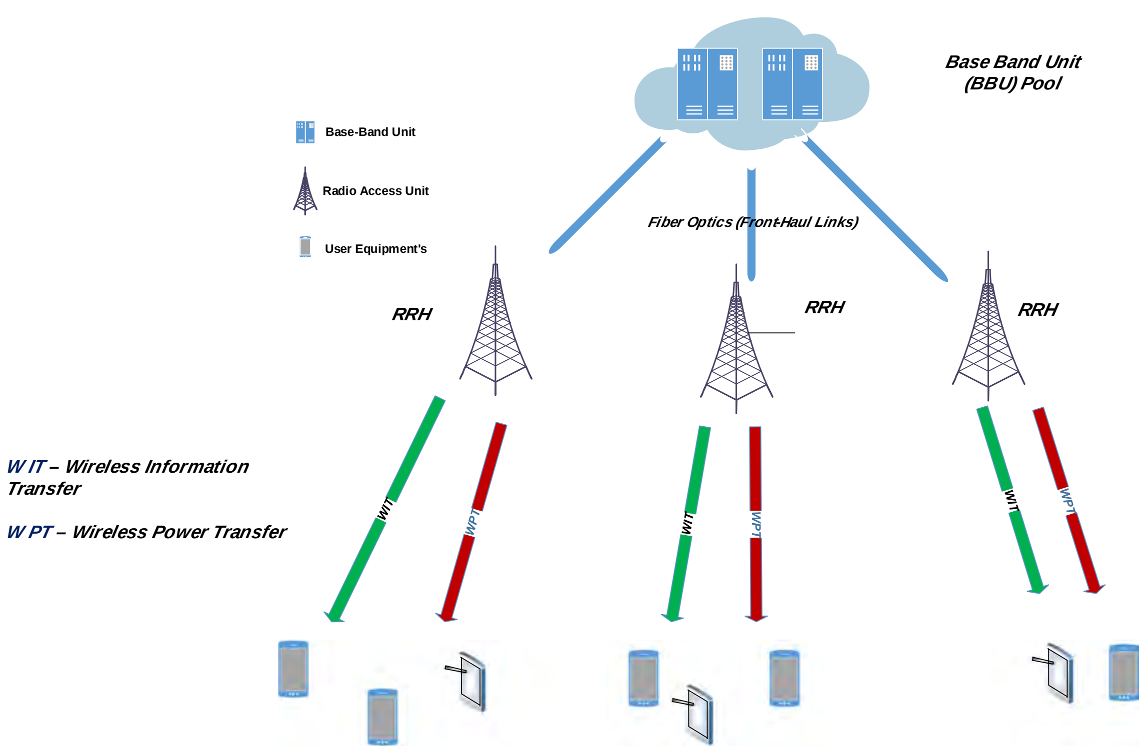

Fig. 5 C-RAN Based on SWIPT

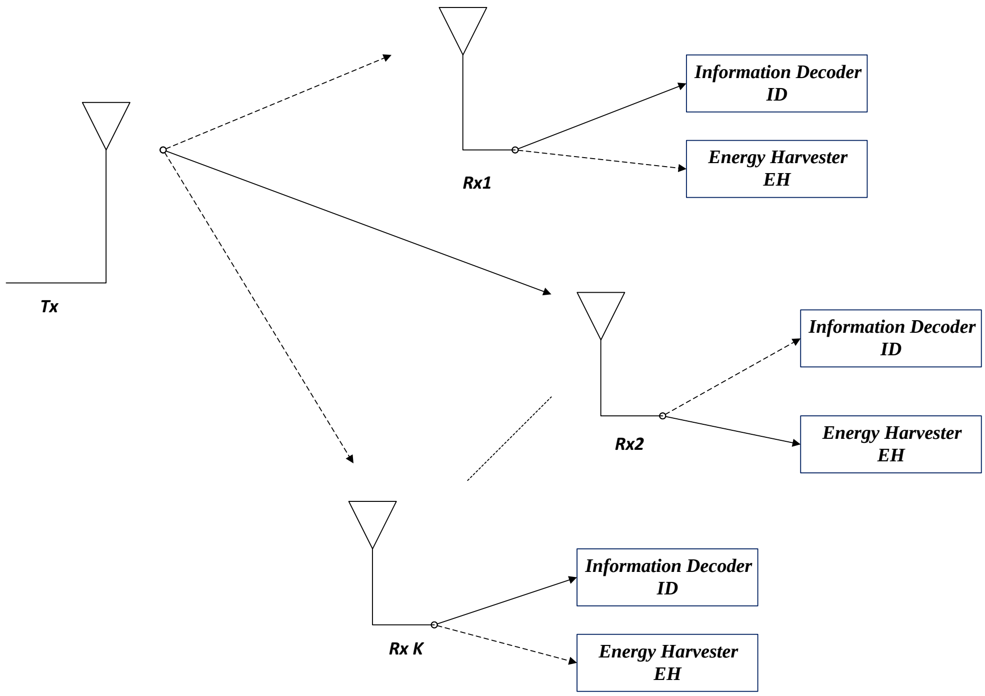

Fig. 6 SWIPT System Model

4.2 Harvesting energy from Heterogeneously environment

It can be expected that 5G systems have renewable energy supply, such as wind or solar sources, in order to reduce operational costs as well as energy consumption. However, the intermittent nature of renewable energy makes its availability dependent in terms of time and space when compared with conventional energy from the grid. For 5G systems, traditional methods for energy storage employing capacity-limited and expensive batteries are not sufficient for managing fluctuations. However, as a promising new paradigm, the heterogeneous cloud radio access network (HCRAN) has been put forward to get high energy efficiency and spectral efficiency performance by integrating cloud computing with HetNets.

Most of the research works regarding optimisation of energy efficiency (EE) and spectral efficiency (SE) performance assume the transmission power to remain fixed and stable. However, the energy harvesting process is subject to various availabilities over time and space, and further research is needed for this topic. To summarise, by employing ultra-dense RRH with energy harvesting in H-CRANs, optimising the SE and EE performance has established itself as a promising and challenging research area, in which the transmission power of nodes need to be adaptive with the radio channel fading, packet traffic, user's QoS and offered energy.

4.3 Dense deployment

With the rapid influx in the number of electronic device users, re-designing of the wireless networks meeting these needs has become important. Hence, a key challengeable research item in the 5G era is the dense deployment, which requires considering numerous factors to optimise the performance of the existing networks. However, for C-RAN, the Base Band Units (BBU) issue has to be kept in mind, since various constrains are found. So, this area has gained a lot of interest for general 5G wireless networks design apart from the Cloud Radio Access Networks (C-RAN) design.

4.4 Resource sharing and performance optimisation

To enable communication over the network, resources should also be available. Thus, allocating radio resource is crucial to improving the spectral efficiency and performance of C-RAN communications, as well as underlying cellular communication. The SWIPT system's resource allocation algorithm includes: energy and information scheduling, joint power control and user scheduling and interference management [9, 190].

4.5 Front-Haul constraints in C-RAN

A challenging bottleneck hindering the performance of the system is the Front-Haul capacity limitations. Hence, in C-RAN, wired and wireless fronthauls have now become significant infrastructures, which can not only impact the availability of data throughput to UEs but also in evaluating C-RAN's overall performance. Larger scale cooperative processing and networking can be enabled with fronthaul having high bit rate and low latency, which in turn facilitates more effectual use of available scarce resources. However, the practical fronthaul solutions do not possess adequate end-to-end performances that meet the QoS requirements everywhere. To overcome the issues related to the non-ideal fronthaul, there is a need for new cooperative processing and resource allocation strategies that are efficient, as well as evolution of improved EE performance metrics which take into account constraints of fronthaul.

5 Conclusion

In this article, we have provided a review of the energy efficiency optimisation for Cloud Radio Access Networks (C-RAN) using SWIPT. The Cloud Radio Access Network is believed to be a powerful candidate for the 5G cellular networks. We discussed SWIPT techniques and identified the channels it works with according to its taxonomy. We also performed it in C-RAN, to be compatible with the aim of this article for reducing energy consumption. Future networks will need to be deployed based on energy-efficient criteria. Furthermore, the need is to be able to collect clean energy from the environment and use the available energy efficiently through energy-efficient resource allocation or other similar techniques.

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