Simultaneous Wireless Information and Power Transfer in 5G Mobile Networks: A Survey

Yihan Liang†, Yejun He†⋆, Jian Qiao†, and Aiguo Patrick Hu‡
† Guangdong Engineering Research Center of Base Station Antennas and Propagation
Shenzhen Key Laboratory of Antennas and Propagation
College of Electronics and Information Engineering, Shenzhen University, 518060, China
‡ Department of Electrical and Computer Engineering, The University of Auckland, New Zealand
Email: 15875561843@163.com, heyejun@126.com⋆, 446941582@qq.com, a.hu@auckland.ac.nz

***Abstract*—The fifth generation (5G) mobile networks are growing vigorously. As one of the most promising technologies of 5G, millimeter-wave (mmWave) communication can provide us with multi-Gbps transmission rate. However, the ultra-high transmission rate greatly increases the power consumption of wireless devices. People begin to pay attention to the lifetime of battery-powered devices when pursuing higher quality of service (QoS) of communication. Investigating an environment friendly and energy efficiency transmission technology in 5G mobile networks is an urgent task. Simultaneous wireless information and power transfer (SWIPT) is an innovative candidate, and an effective solution to ease the contradiction between high transmission rate and long lifetime of battery-powered devices. But the propagation features of mmWave bring new challenges to SWIPT system. This paper presents an updated literature survey on the application of SWIPT technology in 5G mobile networks. Specifically, we give an overview of SWIPT technology, not only including the typical structure, but also the classical radio frequency (RF) signal resource allocation structures and the rate-energy (R-E) tradeoff of information and energy allocation. Then, we summarize the recent advances on SWIPT technology in 5G mobile networks and explore them in various scenarios of 5G. Finally, the SWIPT-enabled mmWave network is mainly discussed according to the development of SWIPT, the propagation features of mmWave and the general structure of SWIPT-enabled mmWave network. Moreover, we put forward several potential future research directions and practical challenges.**

***Index Terms*—5G, SWIPT, mmWave, resource allocation, rate-energy tradeoff.**

I. INTRODUCTION

5G mobile networks with the frequency of sub-6 GHz have been commercially launched in China in 2019. Compared with 4G, this new mobile network is a full-scale technology upgrading, especially in terms of transmission rate which can provide users with multi-Gbps experience. With the help of this high transmission rate, some new applications such as virtual reality (VR), mobile edge computing (MEC), self-driving cars, electronic wearable devices, unmanned aerial vehicles (UAVs) and etc. will all spring up. However, the applications supported by the ultra high transmission rate will lead to more energy consumption. The lifetime of devices will be greatly shortened due to the limited battery capacity. How to solve the energy retention problem when devices run with energy intensive applications supported by high transmission rate has come into focus in 5G mobile networks.

According to Shannon equation, we can increase frequency bandwidth or improve signal to noise ratio (SNR) to meet the requirement of multi-Gbps transmission rate of 5G mobile networks. Obviously, the direct method is to use mmWave band whose wavelength is in the order of millimeters (1-10 mm). It propagates with ultra-high frequencies (30-300 GHz) to alleviate the shortage of communication frequency band as well as increase the transmission rate extremely [1]. What's more, the narrow beam width and good directivity of mmWave are more suitable for line of sight (LOS) scenarios. It has been considered as one of the promising technologies for 5G mobile networks, especially for some applications desiring ultra high transmission rate and short end-end latency such as mentioned above.

We are in an era of Internet of Things (IoT). Our life is filled with a variety of mobile wireless devices and even inseparable from them. The use of mmWave frequencies can meet the capacity and transmission rate requirements of 5G mobile networks. But the high transmission rate and long lifetime of these devices are contradictory. Finding an efficient and environment friendly method is an urgent task for the smooth progress of 5G mobile networks. It is until recently, SWIPT technology which can make full use of RF resource by transmitting information and power at the same time has received public attentions. Applying SWIPT technology in 5G mobile networks offers a promising solution to prolong the life time of wireless devices with high transmission rate. It is unnecessary for people to look around for electric sources or carry the mobile power packs any time and any place. Moreover, the size and weight of all kinds of wireless devices will be greatly reduced since the battery units inside will be smaller. The application of SWIPT technology in 5G mobile networks is essential, but the use of mmWave communication in 5G-enabled SWIPT mobile network brings new challenges due to the high pathloss and narrow beam width propagation features of mmWave. Thus, this paper aims to provide a comprehensive review focusing on the researches of SWIPT in 5G mobile networksespecially SWIPT-enabled mmWave network.

The remainder of the paper is organized as follows. Section

978-1-7281-1973-1/19/$31.00 ©2019 IEEE

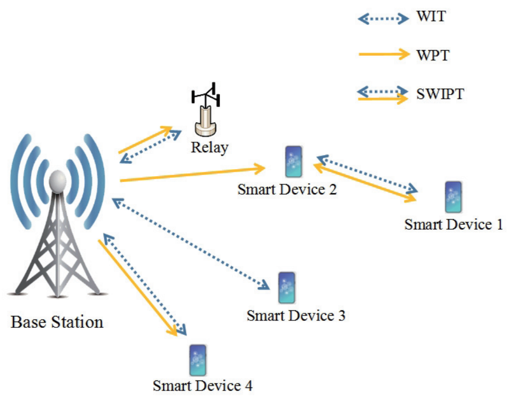


Fig. 1. A typical transmission structure of SWIPT.

II introduces a typical transmission structure, four resource allocation structures and the R-E tradeoff of SWIPT system. Section III summarizes the recent academic progresses on SWIPT in 5G mobile networks. Section IV discusses the SWIPT-enabled mmWave network and the open topic about the potential research directions and practical challenges. Finally, this paper is concluded in Section V .

II. OVERVIEW OF SWIPT SYSTEM

In this section, we introduce a typical transmission structure and four present information and power allocation structures of SWIPT. What's more, we also describe the R-E tradeoff of the system.

A. A Typical Transmission Structure of SWIPT

Fig. 1 shows a typical transmission structure of SWIPT. There are three modes of transmission, i.e., wireless information transfer (WIT), wireless energy transfer (WPT) and SWIPT. It is similar to the traditional wireless communication system which consists of one base station and multiple mobile stations. The base station is equipped with antenna arrays. RF signal resource delivered by base station can be used to carry information and energy. Each mobile station randomly switches the communication mode to harvest information or energy or both of them. Particularly, information and power can be transmitted in both bi-directions between smart devices in the scenario of device to device (D2D).

B. RF Signal Resource Allocation Structures

Four typical resource allocation structures are introduced in this subsection. Most researchers focus on different allocation strategies, and some antenna designers are interested in innovative design of antenna structures.

- **Antenna Separated**: At transmitter, multi-antennas are equipped to realize the separated transmission structure. Parts of the antennas are used for power transfer and the others are used for information transfer [2]. Beyond that, the interior structure of antenna has also received attentions. In paper [3], a dual-band antenna structure is designed to send mmWave signal with two different frequencies. High frequency is used for power transfer and low frequency is used for information transfer separately. Uniformly, the similar dual-band antenna can also be deployed on terminal devices.
- **Antenna Switching (AS)**: AS is a low complexity structure with multi-antennas. It is similar to separated antenna structure except that the receiver cannot harvest information and power simultaneously. When the energy harvesting antennas are active, all RF signal resource is used for battery charging. Conversely, the RF resource is used for decoding when the information harvesting antennas are active.
- **Time Switching (TS)**: Another low complexity structure is TS which just needs to add a switcher in front of the receiving structure. When switcher switches to decoder circuit, the device is in the state of information transfer. On the contrary, the state of power transfer is active when it switches to battery circuit. Compared with the first two methods
- **Power Splitting (PS)**: Compared with AS and TS , PS is the best way to realize the information and power transfer at the same time. The RF signal harvested by antenna is divided by PS structure with a specific PS ratio $\beta\%$, where $\beta\%$ of the signal flows to decoder circuit, and $(1-\beta)\%$ flows to battery circuit simultaneously.

The summarized of different RF resource allocation structures are listed in table I.

C. R-E Tradeoff

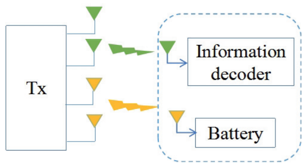
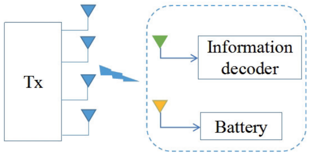
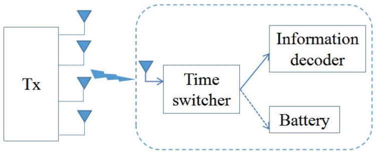
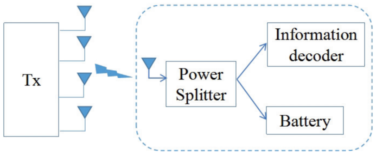
There is a traditional and essential problem throughout SWIPT system among the above RF signal resource allocation strategies: R-E tradeoff [4]. How much RF signal resource should be allocated for information decoding to maintain high communication quality, and how much for energy harvesting to prolong the lifetime of devices. No matter it is to allocate more antennas for information transmitting, increase the time duration of information harvesting or increase the signal power flowing to decoder, all of the processes lead to little RF signal left for battery charging. Thus, finding a proper allocation scheme to optimize the tradeoff is essential to SWIPT system among most of scenarios.

III. RECENT ADVANCES OF RELATED ARTICLES

The deployment of 5G mobile networks is proceeding apace. The use of mmWave in 5G mobile networks offers human with ultra high transmission rate [5]. However, there still exists multiple problems. The most fatal one is that the ultra high transmission rate will lead to a significantly increased power consumption of wireless devices in the network. Recently, the studies on SWIPT-enabled 5G mobile networks have come into focus which provide a promising method to solve the problem mentioned above.

The ultimate goal of SWIPT technology is to find a proper allocation scheme to optimize the R-E tradeoff under the premise of considering other influencing factors of the

TABLE I
RF SIGNAL RESOURCE ALLOCATION STRUCTURES.

<table>
<tr><td>Transmitter (Tx)</td><td>Antenna Separated</td><td> </td></tr>
<tr><td rowspan="3">Receiver (Rx)</td><td>Antenna Switching</td><td> </td></tr>
<tr><td>Time Switching</td><td> </td></tr>
<tr><td>Power Splitting</td><td> </td></tr>
</table>

network. As shown in Fig. 2, most researches are carried on around the parameters like energy efficiency, data rate, throughput, harvested energy power, transmit power, outage probability. Recently, SWIPT technology has been paid close attention in different 5G scenarios. In this section, we summarize recent advances of related articles on SWIPT-enabled 5G mobile networks and show in Table III.

A. mmWave Communication

To assess the feasibility of SWIPT with mmWave frequencies, the authors in [6] perform the channel measurements in the frequency of 3.5 GHz and 25 GHz. The results show that the frequency of 28 GHz is more suitable for small coverage LOS transmission and the frequency of 3.5 GHz which has a less large scale fading than 28 GHz is more suitable for long-distance transmission. According to the results, the authors further propose a dual-band SWIPT network which consists of hot-spot zone and wide-area coverage zone. In hot-spot zone, frequency of 25 GHz is used for SWIPT through LOS transmission, and the frequency of 3.5 GHz is used for information communication in wide-area coverage zone. Finally, a power-and-channel allocation algorithm is proposed to maximize the minimum harvested energy of users based on TS structure.

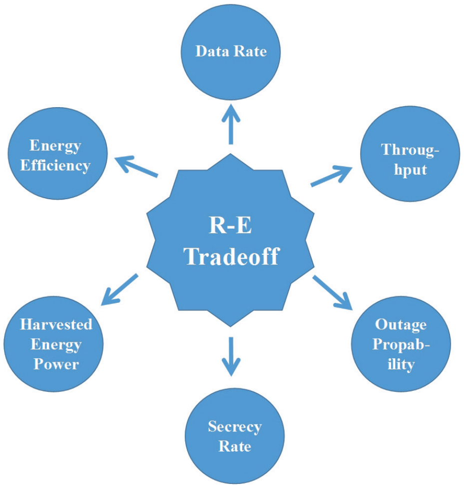


Fig. 2. Research hotspots of SWIPT technology.

B. Non-orthogonal Multiple Access (NOMA)

The combined application of massive multiple input and multiple output (massive MIMO) and NOMA in 5G mobile networks can further improve the spectrum utilization. The authors in [7] investigate the SWIPT technology in mmWave massive MIMO-NOMA system. To cope with the extra energy consumption caused by massive MIMO system, the information is precoded by a hybrid method before transmitting from the base station. At receiver, a joint optimization of information decoding and PS method is investigated by the authors to maximize the sum rate of multiple users. What's more, the authors in [8] put focus on the energy efficiency of SWIPT-enabled NOMA cellular network based TS architecture. They propose the optimal problem under the constraints of transmission power budget, transmission data rate and harvested energy power. The problem is resolved by optimizing the power allocation and TS assignment in the inner-layer and outer-layer separately.

C. Relay Network

SWIPT-enabled relay network can significantly prolong the serving time of relays in 5G mobile networks. The authors in [9] introduce a novel cache-assisted SWIPT relay network based TS architecture. They formulate two optimization problems about maximizing throughput of the link and energy stored at the relays. Some relay architectures are also deployed in 5G mobile networks to increase radiation coverage. It is a practical solution to IoT system to remedy the weakness of higher pathloss of mmWave as well as the feature which is only suitable for LOS transmission. What's more, the authors in [10], [11] put focus on the unmanned aerial vehicle (UAV)-based relay networks and considering the secrecy performance of mmWave systems. The optimizations are centred on secrecy rate of the systems.

TABLE II
COMPARISON OF DIFFERENT 5G-ENABLED SWIPT NETWORKS

Ref.	**Scenario**	**Resource Allocation Structure**	**Optimization Goal**	**Contribution**
[6]	5G new frequency network	TS	Maximize the minimum harvested energy of users	Propose a dual-band SWIPT network; Jointly optimize power allocation and channel assignment
[7]	mmWave massive MIMO-NOMA network	PS	Maximize the sum rate of users	Propose a cluster-head selection(CHS) algorithm; Jointly optimize power allocation and PS
[8]	NOMA system	TS	Optimize the energy efficiency	Propose a dual-layer iterative resource allocation algorithm
[9]	Relay network	TS	Maximize the throughput of the (serving) link and energy stored at relay	Jointly optimize the caching capacity and QoS
[10]	UVA relay network	PS	Maximize the lower bound of average secrecy rate	Jointly optimize the source/UAV relay transmit power, power splitting ratio and UAVs location
[11]	UVA relay network	PS	Maximize the average achievable secrecy rate and energy coverage probability	Consider Nakagami-m small scale fading model and the blockage to mmWave links on the ground and the 3D antenna gain
[12]	Collaborative mobile cloud	PS	Minimize energy consumption	Propose a user scheduling scheme and a beamforming design

D. *Cooperative Network*

Recently, SWIPT technology comes to be used in some cooperative networks to offer an energy support. In [12], the authors investigate the resource allocation and data offloading scheme for SWIPT-enabled collaborative mobile cloud to minimize the energy consumption of the system. And then they propose a channel assignment algorithm and beamforming design to minimize the transmit power consumption.

IV. SWIPT-ENABLED MMWAVE NETWORK IN 5G

This section, we first introduce the development of SWIPT technology and some industrial promising products. Then, we discuss the propagation features of mmWave and describe the general structure of SWIPT-enabled mmWave network. Finally, we discuss the open issue about some future research directions and practical challenges of SWIPT-enabled mmWave network.

A. *The Development of SWIPT Technology*

SWIPT technology is the combination of WIT and WPT. WPT technology was proposed as early as 1914 by Nicola Tesla. Nowadays, it has evolved into two major branches: near-field WPT based electromagnetic coupling and far-field WPT based electromagnetic radiation [13] which all gain prominence for their safety, flexibility and environment friendly. For a long time in the past, researchers have paid much attention to the transmission schemes of near-field WPT for its up to 90% power transmission efficiency (PTE) and nearly hundreds of kilowatt transmission power [14]. However, the inability to satisfy mobility is a fatal issue. Compared with wired charging, the benefit of near-field WPT seems not outstanding. Neither the concern of battery shortage nor the inconvenience of charging can be reduced. In contrast, far-field WPT, especially combined with WIT technology, offers a promising solution to ease the contradiction between high transmission rate and long lifetime of battery-powered devices in 5G mobile networks while meeting the wireless charging requirements for mobility.

Up to now, most manufacturers only put focus on WPT technology, especially near-field WPT technology, which has been well exploited commercially in the last few years [15]. Some major handset manufacturers have put forward their smart phones which are support couple-based WPT, and the electric vehicle (EV) developers are keen on filing patents for couple-based wireless charging. The development of far-field WPT is not considered. Therefore, we aim to introduce the commercialization progress of far-field WPT. Different from Wireless Power Consortium (WPC) which only concerns on the magnetic induction or resonation technology, AirFuel Alliance (AFA), the leading global authority on WPT technology and standard, not only contains magnetic technology but also RF technology to satisfy different scenarios. The 2019 AirFuel Alliance Developers Forum was held on March 12th-13th in Shenzhen, China. Some RF-based WPT products were displayed on forum. The products mainly include power transmitter, harvester and charging platform, where the maximum transmitting power is 1-10 W among these products. The widest charging range of these products comes from Powercast which reaches 24 m with the frequency of 915 MHz. Table III shows the summary of the existing RF-based WPT products and their technical parameters.

TABLE III
COMPARISON OF SEVERAL RF-BASED WPT PRODUCTS

Manufacturer	Products	Distance	Frequency	Maximum Transmitting Power
Energous	WattUp	4.6 m	WiFi	10 W
Ossia	Cota	9 m	5.8 GHz	1 W
Powercast	Powercaster, PowerSpot, Powerharvester	24 m	915 MHz	3 W
PowerSphyr	None	12 m	Support all current frequencies	NA

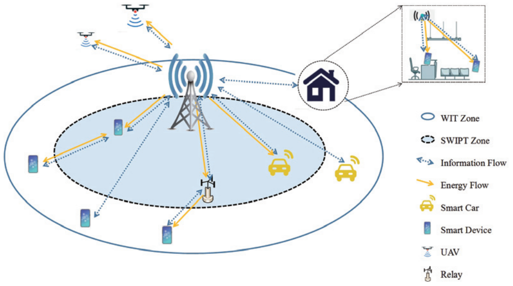


Fig. 3. A general architecture of SWIPT-enabled mmWave network.

B. Propagation Features of mmWave

The ultimate goal of 5G is to provide people with enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (uRLLC), and massive machine type communications (mMTC). In order to achieve this goal, mmWave communication is employed. It can provide wide bandwidth and achieve high spectrum efficiency. What's more, far-field WPT, especially SWIPT is also introduced to 5G mobile networks to provide good QoS of communication and maintain the wireless devices with high energy consumption a long lifetime. With the help of these various key technologies of 5G, self-driving cars can be widely used without considering the car accidents caused by the transmission delay. Rescues and exploration works in some harsh environments which are not suitable for human survival can be carried out in an orderly manner. However, there still exists some problems on account of different propagation characteristics of mmWave compared with conventional frequencies.

- **High pathloss**: In the free space transmission scenario, the ultra high frequencies have a pretty high pathloss than traditional ones. That means the transmission range of mmWave is so short that can only coverage about 100 m to 200 m.
- **Narrow beamwidth**: An extremely narrow beamwidth with weak diffraction and scattering ability is another characteristic of mmWave. The radiation coverage is greatly restricted because of the susceptibility to blockages. That means mmWave is better suited for LOS scenarios.

C. A General Structure of SWIPT-enabled mmWave Nnetwork

Considering the propagation features of mmWave, it is more suitable for LOS scenarios with small coverage and high density such as indoor hot-spots, dense urban areas and etc. Fig.3 shows a general architecture of SWIPT-enabled mmWave network. It consists of mmWave base station, terminal devices (smart devices, smart cars, UAVs), relays, etc. mmWave directional antenna arrays with beamforming are applied on the base station and terminal devices. What's more, all terminal devices are SWIPT-enabled. The mmWave network is divided into two zones, namely hot-spot zone and wide-area zone [6], where in hot-spot zone SWIPT is enabled and in wide-area zone only information communication is enabled. What's more, relays can be used as relay stations for information and energy. And it is more general that information and power transfer are both bi-directional in the scenario of D2D. The indoor scenario is also depicted in the Fig.3, and it is the same as hot-spot zone where RF resource received by terminal devices is used for two purposes, i.e., energy charging and information decoding.

D. Future Directions

The potential of SWIPT-enabled mmWave system is exciting. Nonetheless, the features of mmWave communication bring new challenges. For example, the system should support high mobility users, be suitable for the ultra-dense network (UDN), be effective to make decisions and be safe for information communication. In the following parts, we will talk about some future research directions and practical challenges.

1) High mobility users: Self-driving electric cars, UAVs, smart wearable devices as well as other highly mobile users are all important components of SWIPT-enabled mmWave network. Existing SWIPT technologies attempt to find a proper allocation strategy without considering the rapid change of the received signal power when user moves among cellulars in a high speed. However, combining with the propagation characteristics of mmWave, the research on high mobility users needs to be considered.

2) UDN: It is widely agreed that the most effective method to realize higher network capacity of 5G requirement is the deployment of UDN [16]. What's more, UDN helps to overcome blockage-sensitive and higher pathloss of mmWave communication. And SWIPT system helps UDN increase the effective of energy utilization. Thus, the hyper-dense deployment in mmWave coverage zones assisted by SWIPT is needed to be further studied.

3) Artificial Intelligence (AI): AI-assisted wireless communication is the future trend. Most researches concerning about the deep learning, reinforcement learning and deep reinforcement learning to help optimize wireless communication network. AI-assisted system can be more effective to find the optimization of R-E tradeoff, especially for SWIPT-enabled mmWave network which needs to make decision timely when the communication environment changes quickly.

4) Information security (IS): Security is always a major concern in all communication systems, especially in the era of IoT. The capacity of 5G is up to 1000 times compared with 4G, which means a plenty of wireless devices will connect to the network. The data privacy and security concerns of SWIPT-enabled 5G mmWave network is more complex compared with conventional one. It requires more information exchange. Thus, the problem of IS needs to be reconsidered.

E. Practical Challenges

- Experiments have shown that mmWave signal power harvested by terminal devices is in the range of 1 μW to 5 μW under the source power range 1 W to 4 W [13]. The power level is too low to maintain the operation of wireless devices. Due to the pretty high power consumption of wireless devices, existing studies of SWIPT just put focus on low-power devices such as small relays and sensors. The commercialization of SWIPT in mmWave network also needs the support of hardware development.
- The electromagnetic compatibility (EMC) of devices should also be concerned in SWIPT-enabled mmWave network. Ensuring the stable information and power transfer without interfered by electromagnetic among the ultra-dense wireless devices in the network is important. That means the devices should be designed with the ability to withstand the electromagnetic interference and low electromagnetic disturbance to others.
- One of the most important practical challenges is the impact of RF radiation on human health. To maintain a higher QoS of SWIPT-enabled mmWave network, much higher density of base stations deployment and transmission power are required. However, intense RF exposure can cause disease in the tissues of human body. Thus, investigating the healthy concerns on deploying SWIPT-enabled base station is needed.

V. CONCLUSION

This paper has explored the deployment of SWIPT technology in 5G mobile networks. A typical transmission structure of SWIPT, existing information and power allocation structures as well as the vital problem of R-E tradeoff throughout SWIPT system have been described. Recent advances of related articles of SWIPT in 5G mobile networks have been summarized. Finally, the SWIPT-enabled mmWave network in 5G has been discussed in detail. Specifically, the development of SWIPT technology and some cutting-edge technology products of RF-based WPT have been introduced. Further more, the features of 5G mmWave system and a general architecture of SWIPT-enabled mmWave network as well as some potential research directions and practical challenges in SWIPT-enabled mmWave network have been introduced.

ACKNOWLEDGMENT

This work was supported in part by the National Natural Science Foundation of China under Grants 61372077, 61801299, and 61871433, in part by the Shenzhen Science and Technology Programs under Grants GJHZ20180418190529516, JCYJ20170302150411789, JCYJ20170302142515949, JSGG20180507183215520, and GCZX2017040715180580, and in part by the Guangzhou Science and Technology Program under Grant 201707010490.

REFERENCES

[1] S. A. Busari, K. M. S. Huq, S. Mumtaz, L. Dai, and J. Rodriguez, "Millimeter-Wave Massive MIMO Communication for Future Wireless Systems: A Survey," *IEEE Communications Surveys and Tutorials*, vol. 20, no. 2, pp. 836–869, 2018.

[2] R. Zhang and C. K. Ho, "Mimo broadcasting for simultaneous wireless information and power transfer," *IEEE Transactions on Wireless Communications*, vol. 12, pp. 1989–2001, May 2013.

[3] M. Del Prete, F. Berra, A. Costanzo, and D. Masotti, "Exploitation of a dual-band cell phone antenna for near-field wpt," in *Proc. 2015 IEEE Wireless Power Transfer Conference (WPTC)*, pp. 1–4, May 2015.

[4] B. Clerckx, R. Zhang, R. Schober, D. W. K. Ng, D. I. Kim, and H. V. Poor, "Fundamentals of wireless information and power transfer: From RF energy harvester models to signal and system designs," *IEEE Journal on Selected Areas in Communications*, vol. 37, no. 1, pp. 4–33, 2019.

[5] L. Tu and M. Di Renzo, "Analysis of millimeter wave cellular networks with simultaneous wireless information and power transfer," in *Proc. 2017 International Conference on Recent Advances in Signal Processing, Telecommunications Computing (SigTelCom)*, pp. 39–43, Jan 2017.

[6] D. Zhai, R. Zhang, J. Du, Z. Ding, and F. R. Yu, "Simultaneous wireless information and power transfer at 5G new frequencies: Channel measurement and network design," *IEEE Journal on Selected Areas in Communications*, vol. 37, no. 1, pp. 171–186, 2019.

[7] L. Dai, B. Wang, M. Peng, and S. Chen, "Hybrid precoding-based millimeter-wave massive MIMO-NOMA with simultaneous wireless information and power transfer," *IEEE Journal on Selected Areas in Communications*, vol. 37, pp. 131–141, Jan 2019.

[8] J. Tang, J. Luo, M. Liu, D. K. C. So, E. Alsusa, G. Chen, K. K. Wong, and J. Chambers, "Energy Efficiency Optimization for NOMA with SWIPT," *IEEE Journal on Selected Topics in Signal Processing*, vol. 13, no. 3, pp. 452–466, 2019.

[9] S. Gautam, T. X. Vu, S. Chatzinotas, and B. Ottersten, "Cache-aided simultaneous wireless information and power transfer (SWIPT) with relay selection," *IEEE Journal on Selected Areas in Communications*, vol. 37, no. 1, pp. 187–201, 2019.

[10] X. Sun, W. Yang, Y. Cai, R. Ma, and L. Tao, "Physical Layer Security in Millimeter Wave SWIPT UAV-Based Relay Networks," *IEEE Access*, vol. 7, pp. 35851–35862, 2019.

[11] X. Sun, W. Yang, Y. Cai, Z. Xiang, and X. Tang, "Secure transmissions in millimeter wave swipt uav-based relay networks," *IEEE Wireless Communications Letters*, vol. 8, pp. 785–788, June 2019.

[12] Z. Chang, J. Gong, Y. Li, Z. Zhou, T. Ristaniemi, G. Shi, Z. Han, and Z. Niu, "Energy efficient resource allocation for wireless power transfer enabled collaborative mobile clouds," *IEEE Journal on Selected Areas in Communications*, vol. 34, pp. 3438–3450, Dec 2016.

[13] X. Lu, P. Wang, D. Niyato, D. I. Kim, and Z. Han, "Wireless networks with rf energy harvesting: A contemporary survey," *IEEE Communications Surveys and Tutorials*, vol. 17, no. 2, pp. 757–789, 2015.

[14] M. K. Uddin, G. Ramasamy, S. Mekhilef, K. Ramar, and Y. Lau, "A review on high frequency resonant inverter technologies for wireless power transfer using magnetic resonance coupling," in *Proc. 2014 IEEE Conference on Energy Conversion (CENCON)*, pp. 412–417, Oct 2014.

[15] X. Mou and H. Sun, "Wireless power transfer: Survey and roadmap," in *Proc. 2015 IEEE 81st Vehicular Technology Conference (VTC Spring)*, pp. 1–5, May 2015.

[16] H. Peng, Y. Xiao, Y. N. Ruyue, and Y. Yifei, "Ultra dense network: Challenges, enabling technologies and new trends," *China Communications*, vol. 13, no. 2, pp. 30–40, 2016.