UNIVERSITI PUTRA MALAYSIA

TWO-ROUND RELAY SELECTION AND JOINT MASSIVE MIMO TRANSMISSION TECHNIQUE TO ENHANCE WIRELESS INFORMATION AND POWER TRANSFER

MESSADI OUSSAMA

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By

MESSADI OUSSAMA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

June 2021

DEDICATIONS

To my dear father, who supported me financially and morally to complete my studies.

To my beloved mother, who endured my absent. Her prayers for me have not stopped.

To my beloved wife, who was my support and aid in my trip and my years of study.

To all my teachers and mentors who have credit for my learning.

To my sisters and brother, for your everlasting love and warm encouragement throughout my research.

To all of my friend and family members for their unconditional love and support.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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June 2021

Chair : Prof. Ir. Aduwati Binti Sali, PhD
Faculty: Engineering

Wireless Information and Power Transfer (WIPT) technology has recently drawn a great deal of interest. Its ability to convey both data and energy wirelessly to the user terminals prompted her to be a key technology to power the next generation of green wireless communications. However, given the high attenuation of radio-frequency signals across distance on the one hand and the Federal Communications Commission (FCC) rules and regulations regarding safety issues and determining the maximum transmission power, makes the implementation of WIPT poses serious challenges. Over and above, the integration of WIPT with other emerging technologies, i.e., Massive multiple-input, multiple-output (MIMO) system and multi-antenna beamforming technique, raises the need to design new schemes and system architectures to achieve effective integrations. This thesis aims to improve the amount of energy harvested and enhance the system of WIPT by implementing an effective integration with massive MIMO and wireless powered cooperative communication networks (WPCCNs).

In the first part of the thesis, we focus on enhancing the throughput and analysing the outage performance of a new WPCCNs system model, where both the single source and the multi-relay have no fixed energy supply. A power-beacon is proposed in the network to assist the source and relays harvest energy from their radio frequency (RF) signals. Two partial relay selection schemes (PRS) and opportunistic relay selection scheme (ORS) are implemented and analysed for the proposed system model, where the best relay selection is picked based on the channel state information availability. The outage probability and the system throughput mathematic equations

over different relay selection schemes are derived and confirmed with Monte-Carlo simulations. The numerical results have shown that the performance of ORS relay selection scheme over the two PRS selection schemes in terms of system throughput by 39% compared to PRSII and 19% compared to PRSI. The impact of multi-relay number and the harvesting time is also investigated.

The second part of the thesis addresses another WIPT research challenge from a network-level perspective. In WIPT and in addition to the reception reliability, the amount of harvested power is important as well in the best relay selection process. Thus, in WIPT, the max-min selection criterion is not optimal since the best energy harvesting relay does not always correspond to the best relay for information transmission. A new relay selection scheme suitable for WIPT architectures referred to as two round relay selection scheme (2-RRS) is proposed and analysed. The proposed 2-RRS scheme is compared with the conventional ORS and PRS schemes. The closed-form expression for the outage probability and the throughput performance of the proposed 2-RRS scheme and the conventional PRS and ORS schemes are derived. Numerical simulations validated the theoretical results, where the system throughput with the new proposed 2-RRS scheme is enhanced by $\{15\%, 37\%, 62\%\}$ comparing to ORS, PRSI and PRSII schemes, respectively, when the PB parameters are $PPB = 10dB$ and $M = 64$. The optimal energy harvesting time values are obtained by an exhaustive search for each relay selection scheme. The impact of the number of antennas and relays on the throughput performance is studied. The best PB position for each relay selection is investigated based on the selection criteria.

In the third part of the thesis, two new transmission techniques that enable massive-MIMO and simultaneous wireless information and power transfer (SWIPT) systems integration were proposed analysed and compared. In particular, in the first technique, the BS transfers data to a scheduled group of users (S-terminals) and takes advantage of the channel matrix's null space for these scheduled users to transmit power to non-scheduled users (N-terminals) at the same time-frequency resource. This technique is referred to as joint beamforming and broadcasting SWIPT (JBB-SWIPT). The second technique is orthogonal beamforming and broadcasting SWIPT (OBB-SWIPT), where the downlink time-frequency resources are divided into two separate parts: one for beamforming information to the S-terminals, and the second part for broadcasting energy to the non-scheduled N-terminals which their CSI is not available at the BS. The closed-form expressions for the S-terminals average achievable data rate, and the N-terminals average harvested power are derived and compared for both proposed JBB-SWIPT and OBB-SWIPT, respectively. The amount of harvested energy by the proposed JBB-SWIPT reach up to three times the amount of harvested energy by OBB-SWIPT when the number of S-terminals are close to the number of BS antennas.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMILIHAN RELAY DUA PUSINGAN DAN MIMO MASIF KACUKAN TEKNIK TRANSMISI UNTUK MEMPERTINGKATKAN MAKLUMAT WAYARLES DAN PEMINDAHAN KUASA

Oleh

MESSADI OUSSAMA

Jun 2021

Pengerusi: Prof. Ir. Aduwati Binti Sali, PhD
Fakulti : Kejuruteraan

Teknologi maklumat dan pemindahan kuasa wayarless (WIPT) baru-baru ini telah menarik minat ramai. Keupayaannya untuk menyampaikan data dan tenaga secara wayarles ke terminal pengguna, mendorongnya untuk menjadi teknologi utama menghidupkan komunikasi wayarles hijau bagi generasi seterusnya. Namun, memandangkan kelemahan isyarat sinaran frekuensi radio yang tinggi merentasai jarak serta peraturan dan undang-undang Suruhanjaya Komunikasi Persekutuan (FCC) mengenai isu keselamatan dan menentukan penghantaran kuasa maksimum, telah menimbulkan cabaran serius terhadap pelaksanaan WIPT. Selain daripada itu, persepaduan WIPT dengan teknologi baharu yang muncul, iaitu sistem MIMO masif dan teknik pembentuk alur multiantena, menimbulkan keperluan untuk merancang skema baharu dan seni bina sistem untuk mencapai persepaduan yang berkesan. Tesis ini bertujuan untuk meningkatkan jumlah tenaga yang diperoleh dan meningkatkan sistem WIPT dengan melaksanakan penyatuan yang berkesan dengan MIMO masif dan rangkaian komunikasi koperasi berkuasa tanpa wayar (WPCCNs).

Pada bahagian pertama tesis, kami fokus pada peningkatan daya pemprosesan dan menganalisis prestasi keluaran model sistem rangkaian komunikasi koperasi berkuasa wayarless (WPCCNs) baharu, di mana sumber tunggal dan multigeganti tidak mempunyai bekalan tenaga tetap. Power-beacon dicadangkan dalam rangkaian untuk membantu sumber dan menyampaikan tenaga terkumpul dari isyarat frekuensi radio (RF) mereka. Dua skema pemilihan geganti separa (PRS) dan skema pemilihan geganti oportunis (ORS) dilaksanakan dan dianalisis untuk model sistem yang dicadangkan, di mana pemilihan geganti terbaik dipilih berdasarkan ketersediaan

maklumat keadaan saluran. Kebarangkalian keluaran dan persamaan matematik daya pemprosesan sistem terhadap skema pemilihan geganti yang berbeza diperoleh dan disahkan dengan simulasi Monte-Carlo. Hasil berangka telah menunjukkan bahawa skema pemilihan geganti ORS melebihi dua skema pemilihan PRS dari segi daya pemprosesan sistem sebanyak 39% berbanding PRSII dan 19% berbanding PRSI. Kesan bilangan multigeganti dan masa pengumpulan juga disiasat.

Bahagian kedua tesis menangani cabaran penyelidikan WIPT lain dari perspektif peringkat rangkaian. Dalam WIPT dan sebagai tambahan kepada kebolehpercayaan penerimaan, jumlah daya pengumpulan juga penting dalam proses pemilihan geganti yang terbaik. Oleh itu, dalam WIPT, kriteria pemilihan max-min tidak optimum kerana geganti pengumpulan tenaga terbaik tidak selalu sesuai dengan geganti terbaik untuk penghantaran maklumat. Skema pemilihan relay baru yang sesuai untuk seni bina WIPT yang disebut sebagai skema pemilihan relay dua pusingan (2-RRS) dicadangkan dan dianalisis. Skema pemilihan 2-RRS yang dicadangkan dibandingkan dengan skema ORS dan PRS konvensional. Ungkapan tertutup untuk kebarangkalian keluaran dan prestasi daya pemprosesan skema 2-RRS yang dicadangkan dan skema PRS dan ORS konvensional diperoleh. Simulasi berangka mengesahkan hasil teori, di mana daya pemprosesan sistem dengan skema 2-RRS yang baru dicadangkan ditingkatkan oleh $\{15\%, 37\%, 62\%\}$ berbanding dengan skema ORS, PRSI dan PRSII, masing-masing, ketika Parameter PB ialah $PPB = 10\,dB$ dan $M = 64$. Nilai masa pengumpulan tenaga yang optimum diperoleh dengan pencarian yang menyeluruh untuk setiap skema pemilihan geganti. Kesan bilangan antena dan geganti pada prestasi daya pemprosesan dikaji. Kedudukan PB terbaik untuk setiap pemilihan geganti disiasat berdasarkan kriteria pemilihan.

Pada bahagian ketiga tesis, dua teknik penghantaran baharu yang memungkinkan persepaduan sistem MIMO masif dan SWIPT telah dicadangkan, dianalisis dan dibandingkan. Khususnya, dalam teknik pertama, BS memindahkan data ke sekumpulan pengguna berjadual (S-terminal) dan memanfaatkan ruang kosong matriks saluran bagi pengguna berjadual ini untuk menghantar kuasa kepada pengguna tidak berjadual (N-terminal) di sumber frekuensi masa yang sama. Teknik ini disebut sebagai pembentuk alur bersama dan penyiaran SWIPT (JBB-SWIPT). Teknik kedua adalah pembentuk alur ortogonal dan penyiaran SWIPT (OBB-SWIPT), tempat sumber frekuensi masa laluan menurun dibahagikan kepada dua bahagian yang berasingan: satu untuk membentuk alur maklumat ke S-terminal, dan bahagian kedua untuk menyiarkan tenaga kepada N-terminal bukan berjadual yang CSI mereka tidak terdapat di BS. Ungkapan bentuk tertutup untuk kadar data rata-rata S-terminal yang dapat dicapai, dan purata kuasa terkumpul N-terminal diperoleh dan dibandingkan untuk kedua-dua JBB-SWIPT dan OBB-SWIPT yang dicadangkan, masing-masing. Jumlah tenaga dituai oleh JBB-SWIPT yang dicadangkan mencapai hingga tiga kali jumlah tenaga yang dituai oleh OBB-SWIPT apabila bilangan terminal-S hampir dengan bilangan antena BS.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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6G	6th Generation
AP	Access point
AF	Amplify-and-forward
AS	Antenna Switching
BS	Base station
B5G	Beyond 5th Generation
CSI	Channel state information
DF	Decode-and-forward
DoF	Degrees of freedom
DC	Direct Current
EH	Energy harvesting
ET	Energy terminal
HTT	Harvest-then transmission protocol
HTC	Harvest-then-cooperate
HAP	Hybrid access point
ID	Information decoding
IoT	Internet of things
JBB-SWIPT	Joint beamforming and broadcasting SWIPT
Massive MIMO	Massive multiple-input, multiple-output
MR	Maximum-ratio
mmW	Millimetre-wave
TDMA	Multiple access time-division
NOMA	Non-orthogonal multiple access
ORS	Opportunistic relay selection scheme
OBB-SWIPT	Orthogonal beamforming and broadcasting SWIPT
PRS	Partial relay selection schemes
PB	Power beacon

PS	Power-splitting
QoS	Quality of Service
RF	Radio frequency
RF-EH	Radio Frequency Energy Harvesting
RFID	Radio-frequency identification
SWIPT	Simultaneous Wireless Information and Power Transfer
SISO	Single input single output
SVD	Singular value decomposition
SE	Spectral efficiency
FCC	The Federal Communications Commission
TDD	Time-division duplex
TS	Time-switching
2-RRS	Two round selection scheme
UEs	Users' equipment
WET	Wireless energy transfer technologies
WIPT	Wireless information and power transfer
WIT	Wireless information transfer
WPCN	Wireless powered communication network
WPCCNs	Wireless powered cooperative communication networks
WPBC	Wirelessly powered backscatter communication
ZF	Zero-forcing

CHAPTER 1

INTRODUCTION

First, we address the research motivation and background, then outline the major research problems, objectives, and the most significant contributions in this chapter.

1.1 Background and Motivation

The world is experiencing a phenomenal increase in wireless broadband usage; there are more and more devices getting connected. The fifth-generation (5G) of wireless networks must serve unusual wireless data traffic, more than six devices linked per person, including human, machine-to-machine communications, i.e., over 50 billion devices will be connected by 2020 [10]. As a result of this tremendous wireless data traffic growth, the global energy consumption will increase significantly, which in turn leads to the rising of temperature and affecting the environment with more CO2 emissions. The key solution for these challenges is enabling green communication technologies that can jointly help satisfy the increasing power demands and improve the quality of life.

Energy harvesting is a promising technique for enabling green communication systems. It helps terminals to recharge their batteries from the surrounding environment, including wind, solar, vibration, and thermoelectric, to convert it into electrical energy [11]. However, these natural renewable sources of energy are characterized by the lack of permanence and reliability, such as in the presence of clouds obscured sunlight or the absence of wind. Therefore, wireless communication systems using conventional energy harvesting sources cannot ensure sustainability and Quality of Service (QoS) requirements. In addition, in some scenarios, wireless nodes may require frequent charging or a replacement battery. They may not be accessible such as in devices hidden (e.g., in the walls, bodies or appliances), or can be deployed in toxic areas, hazardous industrial environments (e.g., in pressurized pipes or radioactive areas) that require high operating costs.

Since RF-signals in addition to carrying information, their electromagnetic waves can be harvested as well. Recently, significant interest has been drawn to RF energy harvesting technology, widely known WIPT, as it has the potential to overcome the difficulties mentioned above. WIPT can provide energy from a wireless energy transmitter through the use of the far-field radiative features of electromagnetic waves to charge devices and batteries sustainably. Besides, WIPT has characterized by its permanent presence and the ability to fully control the transmission of energy for different service requirements and weather conditions [12]. Moreover, the technologies advance in the production of wireless devices with small dimensions and low energy consumption as well as 5G millimetre-wave (mmW) communication technologies will be mainly dependent on small cell network deployment by exploiting the beamforming in massive MIMO systems [13]. Which means the RF energy harvesting will increase significantly. Given the above recent advances in wireless communication, the advantages of WIPT are regarded as a revolutionary new model for future wireless power communication systems.

1.2 Problem Statement

WIPT has become an alternative technology to power the next generation of green wireless communications. However, the high attenuation of RF signals according to the distance between the transmitter and receiver [14], and the maximum transmits power limitation established by the FCC rules and regulations regarding the safety issues [15], makes WIPT application poses critical challenges. The receivers allocate far away from the power source may not be able to charge their battery and remain active. In addition, the traditional wireless networks, which are only designed to receive data, are incompatible with the new introduced WIPT technology. This is because a practical receiver circuit can't do both information decoding (ID) and RF energy harvesting (RF-EH) at the same time, according to [16]. As follows in the subsections, the most recent problems of enabling WIPT are addressed in this relation.

1.2.1 New system model design for WPCCNs

In a traditional wireless system, terminals located far from the base station receive lower information rates than those in close proximity; this phenomenon is referred to as the double-near-far problem [17]. In a wireless powered communication network (WPCN), this effect becomes even more challenging and essential. A terminal far away from the power source harvests much less RF signal in the DL but uses more energy to transmit information in the UL compared to a terminal close to the power source. Thus, it could result in very low throughput for far terminals. In this case, an efficient design of a new system model with a dedicated energy source help WPC networks to solve the double-near-far problem caused by using a single antennas energy transmitter is needed.

1.2.2 Relay Selection in WPCCNs

Another research challenge in this thesis is manifested in the network-level perspective, where considering a wireless- powered cooperative communication network (WPCCN) harvests energy from a dedicated power source is high poses the development of new cooperative relay selection schemes. Unlike the fixed power grid cooperative networks, which mainly based on the reception reliability parameter while choosing the best relay. The WPCCN and in addition to the reception reliability, the transmission requirement consideration is important for relay selection schemes [18]. Thus, the max-min criterion will not be the diversity-optimal in WPCCN, since the best relay for energy harvesting does not necessarily coincide with the preferable relay for information transmission. The relay selection criteria should take into consideration the best channel condition for both the reception reliability and the transmission power, which is fundamentally different from conventional relay selection schemes.

1.2.3 SWIPT in Massive MIMO Beamforming

The basic theory behind massive MIMO is that hundreds of antennas available at a BS serve only a few scheduled user terminals. Therefore, a vast number of degrees of freedom are not fully utilized at the BS [19]. Present research interested in enabling the SWIPT technique in massive MIMO system focuses primarily on beamforming schemes design for the scheduled terminals whose channel state information (CSI) can be obtained at the transmitter side [20]. In addition to the scheduled terminals, there is a potential to exploit the rest of the non-used massive MIMO transmitter antennas to enable information/power broadcasting towards the non-scheduled terminals. However, hybrid beamforming and broadcasting techniques can pose conflicting constraints on spatial domain design and interference management. Therefore, it is essential to properly design hybrid information and energy transfer techniques with a massive MIMO system. To ensure that the amount of transferred energy is enhanced while achieving the required data rate at information users simultaneously.

1.3 Objectives

This work aims to enhance the throughput and amount of harvesting energy in WIPT systems via enabling WPCCN with relay selection and massive MIMO beamforming emerging technologies.

1. To design an efficient PB assisted wireless-powered cooperative communication network system model, that can tackle the doubly-near-far problem and improve the system throughput performance (demonstrated in Chapter 3).

2. To propose and analyse the optimal cooperative relay selection technique for a PB-assisted WPCCN system model when the max-min selection criteria is not an optimum approach. In addition, a multi-antennas beamforming technique

is applied to further enhance the proposed system throughput (demonstrated in Chapter 4).

3. To exploit the vast number of antennas available at massive MIMO base station to enhance the SWIPT technique harvested energy by designing, simulating, and analysing new joint beamforming and broadcasting strategy (demonstrated in Chapter 5).

1.4 Research Scope and Study Module

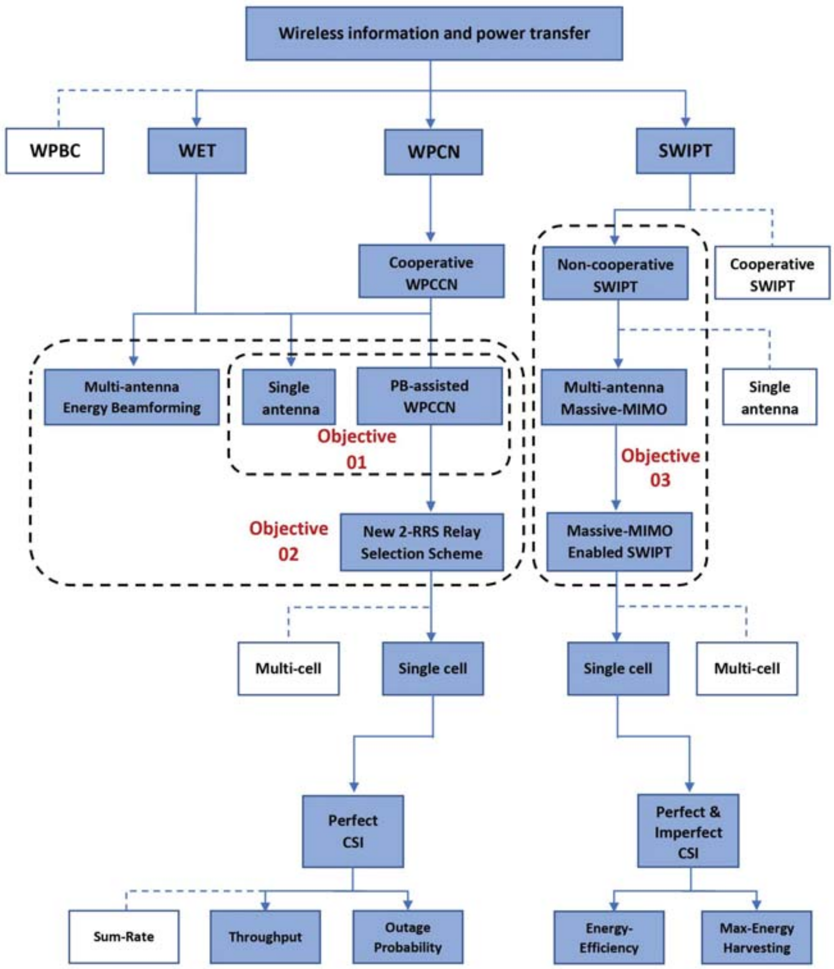

Figure 1.1: Study scope

This thesis is dedicated to studying WIPT technology and its combination with emerging technologies. i.e., cooperative networks, relay selection, and Massive MIMO beamforming. In particular, the downlink massive MIMO-SWIPT with beamforming and WPCC networks with relay selection is considered to enhance the performance of WIPT in the upcoming beyond 5th generation (B5G) or 6th generation (6G) wireless networks. The wirelessly powered backscatter communication (WPBC) technique is out of the scope of this work.

The summary of chosen approaches is described in Figure 1.1, where the blue-colored boxes and solid lines denote the followed direction to achieve determined objectives. In contrast, the uncolored boxes and dashed lines show the other WIPT techniques and protocols that are not covered in this thesis.

1.5 Brief Methodology

Based on the aforementioned objectives, the method used to achieve the enhanced WIPT is divided into three stages, as shown in Figure 1.2.

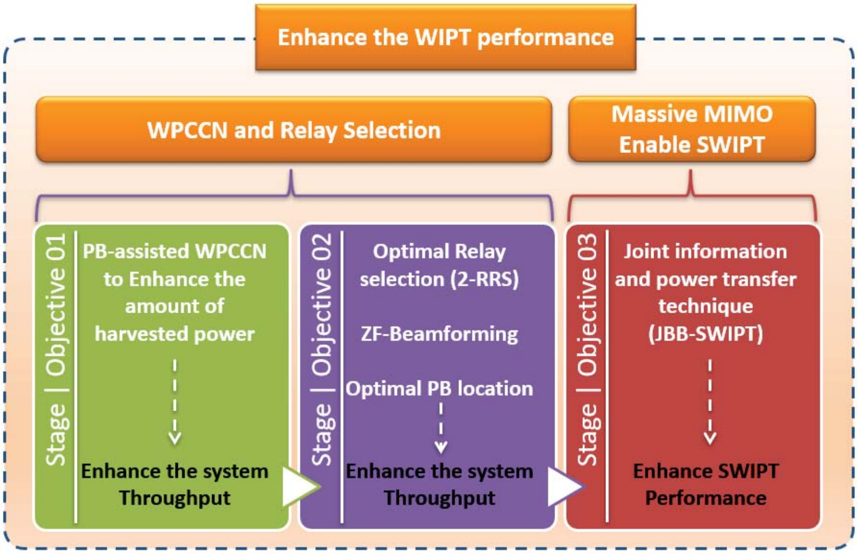

Figure 1.2: Research design

In the first stage, a new PB-assisted WPCCN system model is proposed to increase the harvested energy at the source and relays, which leads to better system throughput. In the second stage, an optimal relay selection technique referred to as 2-RRS is proposed for a PB-assisted WPCCN system model. The ZF-beamforming technique is applied, and the optimal PB location is searched to achieve enhanced system throughput performance. In the third stage, a combination of massive MIMO system and SWIPT technique is considered to examine the enhancement in the amount of the harvested energy in SWIPT.

1.6 Research Contributions

Based on the above-mentioned aims the research contributions in this thesis are summarised as following:

- A new system model is proposed, a PB assisted-wireless-powered cooperative communication network (PB-WPCCN). Both, the source and the relay terminals are not directly connected to the power grid, they rely on the harvested power from the PB to successfully support the information transmission to the destination. The proposed system outage probability and throughput were derived and confirmed with Monte Carlo simulations. The impact of number of relay and PB transmit power on the new system model were studied in addition to the optimal harvesting time allocation. The effect of source transmission date rate on the proposed system model is also investigated through different relay selection schemes.

- A new relay selection scheme referred to as 2-RRS was proposed. First, the system selects a group of relay candidates that can successfully decode the received information from the source. Then, the best relay with the maximum capability to forward the decoded message to the destination is selected from the group successfully decode the information. The average outage probability and the throughput closed-form expressions of the new proposed relay selection scheme are derived and validated by numerical simulations. The impact of the intermediate relay number and position along with harvesting time allocation are investigated. The proposed 2-RRS relay selection scheme was analysed and compared with two partial PRS and ORS. Simulation results show that increasing the PB antennas number will enhance the system performance. And the proposed 2RRS scheme relay selection shows better performance than the popular PRS and ORS relay selection schemes.

- Provide an analytical framework to explore the performance of JBB-SWIPT technique. Where the base station sends information to the scheduled users and exploits the vast number of antenna elements available at the BS massive MIMO to further sends energy to the non-scheduled users, respectively. The harvested energy at the non-scheduled users is enhanced, and information rate toward the scheduled information users' requirements was satisfied under total power transmission constraint. The proposed joint information and power transfer technique were analysed and compared with OBB-SWIPT for perfect and estimated channel state information. The simulation results demonstrate that the interference term due to joint beamforming and broadcasting can be beneficial to the energy harvesting user even in the absence of CSI.

1.7 Research Outcome

The work accomplished in this dissertation has led to the following publications:

Journals Papers

1. **Oussama Messadi**, Aduwati Sali, Vahid Khodamoradi, Asem A Salah, Gaofeng Pan, Shaiful J Hashim, Nor K Noordin, 2020. Optimal Relay Selection Scheme with Multiantenna Power Beacon for Wireless-Powered Cooperation Communication Networks. *Sensors, MDPI*, 29 December 2020, DOI: 10.3390/s21010147.

2. **Oussama Messadi**, Aduwati Sali, Vahid Khodamoradi, Shaiful J Hashim, Nor K Noordin. Nullspace Power Broadcasting for Multiuser Massive MIMO Enabled Separate Receiver SWIPT. *Submitted to IEEE TVT 2021*.

Conferences Papers

1. **O. Messadi**, Aduwati Sali, Gaofeng Pan, Zhiguo Ding, Nor Kamariah Noordin, Shaiful Jahari Hashim, 2019. Outage Performance for Power Beacon-Assisted Wireless-Powered Cooperative Communications. *IEEE 89th Vehicular Technology Conference (VTC2019-Spring).* May 2019, Kuala Lumpur, MALAYSIA. DOI:10.1109/VTCSpring.2019.8746437.

1.8 Thesis Organization

In this chapter, a brief background about WIPT technology and its most recent problems and challenges is highlighted, research objectives and contributions are also presented. The rest of this thesis is organised as follows:

In Chapter 2, the literature review covers the historical background of WIPT. Light is shed on WPCCN technologies enabled by intermediate cooperative relay. The principles design of SWIPT, combined with a massive MIMO system, is introduced. Then the classifications of RF-EH enable SWIPT receiver design are described. Finally, the most related works in massive MIMO enabled SWIPT and WPCCN were introduced and compared.

Chapter 3, a new four-node PB-assisted wireless powered cooperative communication network system model, is proposed (PB-WPCCN). The PB send energy to the source and the set of relays in the first stage. The harvested energy is used to enable data transmission from the source to destination, crossing the best relay. Three relay selection schemes were considered and compared.

The related background knowledge is firstly presented, including the fundamental concepts of cooperative networks. The best relay is selected via the well-known ORS and PRS relay selection schemes. The communication protocol is described in the system model section, followed by the outage probability and system throughput derivations for each relay selection scheme. Numerical comparisons confirm the analytical derivations of the new proposed PB-WPCCN system model under different relay selection scheme.

In Chapter 4, a new two-round relay selection scheme was introduced and analysed, referred to as (2-RRS). Both source and (N) relay candidates have no embedded energy equipping; they need to harvest energy from the RF broadcast signals radiated from PB. The system model shows the proposed system model configuration, where the PB is equipped with multi-antenna and performs beamforming technique. In the proposed 2-RRS first stage selection, the relay candidates that can correctly decode the received signal from the source are selected for the second-round selection. The second stage chooses the best channel condition relay among the set of M relays successfully decoding the source's information. Numerical results provided confirm the analytical derivations of the proposed 2-RRS and the conventional ORS and PRS relay selection schemes. The impact of system parameters, such as time portion, PB antennas number, number and position of relays on the throughput performance, is investigated.

Chapter 5 develops an analytical framework to allow the joint beamforming and broadcasting technique in massive-MIMO to enable the SWIPT system. The effect of perfect and imperfect channel state information scenarios on energy harvesting is studied and compared with OBB-SWIPT. Then, the simulation results are compared with lower bounds derivation. Finally, the impact of harvesting time and number of BS antennas is studied

Chapter 6 concludes the thesis, where the main conclusions of the presented research are written. Furthermore, future extensions of this work are also mentioned.

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