ENERGY HARVESTING ENABLED COOPERATIVE NETWORKS: RESOURCE ALLOCATION TECHNIQUES, PROTOCOL DESIGN AND PERFORMANCE ANALYSIS

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UNIVERSITI SAINS MALAYSIA

2019

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by

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Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

March 2019

ACKNOWLEDGEMENT

I would like to appreciate all those who have helped me in one way or the other in accomplishing my research. Firstly, I want to heartily express gratitude to my supervisor, Assoc. Prof. Dr. Mohd Fadzli Mohd Salleh, for his unflinching support, constructive comments and suggestions during the course of this research; and for making available for me all facilities, which were required for the successful completion of this research. I felt very honoured and lucky to have learned from and worked with him. His guidance has made me a better researcher.

I want to thank all the members of staff of the School of Electrical and Electronic Engineering, University Sains Malaysia (USM) for their support and assistance from time to time while this research lasted. My sincere gratitude also goes to the Institute of Postgraduate Studies (IPS), USM, for organizing useful workshops on thesis writing and formatting, while also not forgetting to acknowledge the financial assistance I got from USM Graduate Assistance Scheme, which has really helped me in no small way during the course of my research.

I am also very grateful to the management of Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Nigeria for the study leave with pay granted me and the financial assistance provided through the Tertiary Education Trust Fund in order to pursue this programme. I also acknowledge the moral support of the entire staff of the department of Electronic and Electrical Engineering, LAUTECH, Ogbomoso, Nigeria while I was away from home while this programme lasted.

I am mostly indebted to my wife, Omobolanle, Eniola-Temi, who has always been there for me in terms of encouragement and support, making sacrifices when it

was difficult to make. You are invaluable and deeply treasured, Eniola-Temi, you are the best. Also not forgetting the sacrifices made by my children, Iyanuni and Motolani; when Iyanuni said "*daddy come home*" after spending just six months into the programme, we both cried. Her statement will continue to lingering in my heart. I will not forget to appreciate my parents for their support while this programme lasted, Mr J. K. Ojo, Mrs Elizabeth Tinuola Ojo, and Mrs Felicia Ayobami Oyeleke. I love you all.

I want to express my gratitude to my friends who have been with me throughout this journey, Damilare Oluwole Akande, Ibrahim Idris Enagi, Tunmise Ayode Otitoju and Tagwai Gregory Mathew, I really appreciate you all. Finally, my sincere gratitude goes to all the hospitable and accommodating Malaysian people, who made my stay in Malaysia 'homely' throughout the duration of my programme. Special thanks to Samsul Setumin, Halina Hassan, Norsalina Hassan, Siti Juliana Binti Abu Bakar, and Nurul Maisarah Kamaruddin. I say, Terima kasih semua.

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LIST OF ABBREVIATIONS

AF	Amplify-and-Forward
AS	Antenna Switching
AWGN	Additive White Gaussian Noise
BS	Base Station
CSI	Channel State Information
DF	Decode-and-Forward
EH	Energy Harvesting
ES	Energy Saving
ES-PSR	Energy Saving Power Splitting Relaying
ES-TSR	Energy Saving Time Switching Relaying
FD	Full duplex
HD	Half duplex
HPTSR	Hybridized Power-Time Splitting Relaying
HTC	Harvest-Then-Cooperate
IoT	Internet of Things
IT	Interfering Transmitter
KKT	Karush Kuhn Tucker
MIMO	Multiple-Input-Multiple-Output
MISO	Multiple-Input-Single-Output
MRC	Maximum Ratio Combining
PS	Power Splilitting
PSR	Power Splitting Relaying
QoS	Quality of Service

RF	Radio Frequency
RF-EH	Radio Frequency Energy Harvesting
RF-DC	Radio Frequency to Direct Current
SC	Selection Combining
SINR	Signal-to-Interference-plus-Noise-Ratio
SNR	Signal-to-Noise-Ratio
SWIPT	Simultaneous Wireless Information and Power Transfer
TS	Time Switching
TSR	Time Switching Relaying
WEHIT	Wireless Energy Harvesting and Information Transfer

LIST OF SYMBOLS

α	Time switching factor
β	Path loss exponent
ρ	Power splitting factor
η	RF-DC energy conversion efficiency
ω	The energy fraction consumed
$\lvert . \rvert$	Absolute value operation
$\varepsilon\{.\}$	Expectation operation
$K_n(.)$	The modified Bessel function of the second kind with order n
f	Channel gain coefficient between interfering transmitter and relay
g	Channel gain coefficient between interfering transmitter and destination
L	Number of transmission blocks
T	The time duration of each transmission block
d_{ij}	Distance between nodes i and j
h_{ij}	Channel gain coefficient from node i to node j
σ_{ij}^2	Noise variance from node i to node j
$C_{\min}$	The minimum required channel capacity to meet QoS criterion
$\min(A,B)$	The minimum between A and B
$\max(A,B)$	The maximum between A and B
P_R	Transmission power of the relay
P_S	The transmit power at the source
P_T	Transmission power of the interfering transmitter

P^{av}	The power available at the relay
$P_S^{\max}$	The maximum transmitted power constraint at the source
$P_r(\Delta)$	The probability of the event Δ happens
$P_r(\Delta^o, \Delta_o)$	The probability of the events Δ^o and Δ_o happen simultaneously
R_t	The source transmission rate
S_t	Normalized transmitted signal from the source
S_x	Normalized interference signal

PENUAIAN TENAGA RANGKAIAN KERJASAMA YANG DIAKTIFKAN: TEKNIK-TEKNIK PEMBAHAGIAN SUMBER, REKA BENTUK PROTOKOL DAN ANALISIS PRESTASI

ABSTRAK

Dalam rangkaian perhubungan kerjasama tanpa wayar, teknik kerjasama geganti boleh digunakan untuk mengurangkan masalah pelunturan dan pengecilan dengan meletakkan nod geganti diantara penghantar dan penerima. Oleh itu, prestasi rangkaian seperti kecekapan, celusan, dan kebolehpercayaan boleh ditingkatkan. Walau bagaimanapun, nod kerjasama geganti tanpa wayar yang dikekang tenaga mempunyai jangka hayat boleh jaya yang terhad, yang tidak dapat mengekalkan sambungan rangkaian yang mantap, sehingga menjadikan perhubungan boleh dipercayai sukar. Baru-baru ini, penuaian tenaga (EH) melalui isyarat frekuensi radio (RF) nampaknya menjadi satu penyelesaian untuk mengekalkan jangka hayat nod kerjasama geganti tanpa wayar. Pada tahun-tahun yang lalu, penyelidik telah mencadangkan beberapa teknik peruntukan sumber dan protokol untuk maklumat tanpa wayar dan pemindahan kuasa (SWIPT) serentak dalam rangkaian komunikasi kerjasama tanpa wayar. Walau bagaimanapun, masih terdapat banyak cabaran yang dihadapi oleh para penyelidik untuk mencapai SWIPT yang cekap dalam rangkaian sedemikian. Dalam kerja ini, teknik peruntukan sumber penjimatan tenaga (ES) baharu dicadangkan untuk pemboleh RF-EH rangkaian kerjasama dengan mengguna pakai protokol geganti pensuisan masa (TSR) dan geganti pemecahan kuasa (PSR). Ini adalah berdasarkan andaian bahawa nod geganti menggunakan bahagian tertentu daripada kuasa yang dituai dalam blok penghantaran semasa dan kemudian menyimpan baki bahagian untuk blok penghantaran seterusnya. Tidak seperti kerja sebelumnya, dengan teknik peruntukan sumber dalam pemboleh RF-EH rangkaian kerjasama telah dipertimbangkan dengan anggapan bahawa geganti dikekang tenaga mesti menggunakan semua kuasa yang dituai di setiap blok penghantaran. Teknik ES yang dicadangkan kemudian dioptimumkan dengan mempertimbangkan masalah pengoptimuman. Kemudian senario rangkaian kerjasama pemboleh EH yang terletak berdekatan dengan gangguan penghantar dipertimbangkan. Satu protokol kacukan geganti berasaskan pemecahan kuasa-masa (HPTSR) juga dicadangkan bersama teknik penggegantian dibesarkan-dan-kehadapan (AF) dan nyahkod-dan-kehadapan (DF) dengan memperkenalkan pembahagi berasaskan saluran dan kuasa-masa dalam seni bina penerima geganti telah dianalisis. Keputusan berangka mendedahkan bahawa protokol ES-TSR dan ES-PSR yang dicadangkan telah mengatasi protokol TSR dan PSR sedia ada dengan peningkatan kecekapan tenaga masing-masing sebanyak 13.87% dan 8.31%, terutamanya apabila bilangan blok penghantaran $L = 10$. Hasil ini menunjukkan bahawa teknik peruntukan sumber ES yang dicadangkan adalah lebih cekap tenaga daripada yang sedia ada. Pada nilai celusan optimum, protokol AF HPTSR yang dicadangkan telah mengatasi prestasi AF PSR, TSR dan protokol berasaskan kepada penggegantian pensuisan kuasa masa (TPSR) yang sedia ada dengan peningkatan celusan masing-masing sebanyak 54.18%, 72.31% dan 10.47%. Protokol DF HPTSR yang dicadangkan menunjukkan peningkatan prestasi sebanyak 2.81% mengatasi protokol AF HPTSR yang dicadangkan. Keputusan ini menunjukkan bahawa protokol AF atau DF HPTSR yang dicadangkan boleh mencapai prestasi celusan yang lebih baik melalui protokol sedia ada, terutamanya pada nisbah isyarat-hingar yang tinggi.

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ABSTRACT

In In wireless cooperative communication networks, cooperative relaying techniques can be employed to mitigate fading and attenuation problems by positioning relay nodes between a transmitter and a receiver. Therefore, network performance such as efficiency, throughput, and reliability can be improved. However, energy-constrained wireless cooperative relay nodes have a limited viable lifetime, which cannot sustain steady network connectivity, thereby making reliable communication difficult. Recently, energy harvesting (EH) via radio frequency (RF) signals appears to be a solution for sustaining the lifetime of the wireless cooperative relay nodes. In the past years, researchers have proposed some resource allocation techniques and protocols for simultaneous wireless information and power transfer (SWIPT) in the wireless cooperative communication networks. Nevertheless, there are still a lot of challenges being faced by the researchers to achieve an efficient SWIPT in such network. In this work, a new energy saving (ES) resource allocation technique is proposed for RF-EH enabled cooperative networks by adopting time switching relaying (TSR) and power splitting relaying (PSR) protocols. This is based on the assumption that the relay node uses a certain proportion of the harvested power in the current transmission block and then save the remaining portion for the next transmission block. Unlike the previous works, in that the resource allocation techniques in RF-EH enabled cooperative networks have been considered under the

assumption that the energy-constrained relay must utilize all of its harvested power in each transmission block. The proposed ES technique is then optimized by considering the optimization problems. Then, the scenario of EH-enabled cooperative network with the presence of an interfering transmitter is considered. A hybridized power-time splitting based relaying (HPTSR) protocol is also proposed with amplified-and-forward (AF) and decode-and-forward (DF) relaying techniques by introducing a channel-based and power-time splitter into the relay receiver architecture are analyzed. Numerical results revealed that the proposed ES-TSR and ES-PSR protocols outperformed the existing TSR and PSR protocols with an energy efficiency gain of 13.87 % and 8.31 %, respectively, particularly, when the number of transmission block $L = 10$. These results show that the proposed ES resource allocation technique is more energy efficient than the existing ones. At the optimal throughput value, the proposed AF HPTSR protocol outperformed the existing AF PSR, TSR, and time power switching relaying (TPSR) based protocols with a throughput gain of 54.18 %, 72.31 %, and 10.47 %, respectively. The proposed DF HPTSR protocol showed a performance gain of 2.81 % over the proposed AF HPTSR protocol. These results show that the proposed AF or DF HPTSR protocol can achieve a better throughput performance over the existing protocols, especially at high signal-to-noise ratio.

CHAPTER ONE

INTRODUCTION

The ever increasing demands for wireless services over the past decades have led to the recent advancements in wireless cooperative communication systems. Cooperative communications allow resource-sharing among multiple nodes in a single communication network due to the broadcast nature of wireless networks. This can improve the network connectivity, reliability, energy efficiency, and average throughput (Hong et al., 2007; Li et al., 2012). In comparison to other emerging communication techniques that could proffer similar advantages, such as multiple-input-multiple-output (MIMO) technique, cooperative communication is preferable in implementation adaptability and hardware feasibility. These benefits of the cooperative communication make it one of the favorable techniques for future wireless communication systems.

However, since one of the factors that make a wireless communication network operational and reliable is the availability of energy, energy-constrained communication nodes have a limited viable lifetime. As a result, energy-constrained cooperative communication nodes have a limited viable lifetime and these cooperative nodes cannot sustain constant network connectivity, thereby making reliable communication demanding. Furthermore, recharging or replacing the batteries that powered such nodes of the wireless cooperative communication network results in high cost, difficulty, risk, or highly adverse effects, specifically in sensors placed inside the human body and in building structures (Nasir et al., 2013; Zhang & Ho, 2013; Zhai & Liu, 2015). This has created some fundamental research problems which require solutions. Taking into consideration the earlier mentioned cases, collecting energy from renewable energy sources in the surroundings is a safe and convenient choice.

Energy harvesting (EH) emerges to be a quick fix for sustaining the lifetime of the energy-constrained wireless cooperative communication networks. In recent years, EH has gained considerable attention among researchers (Chalise et al., 2012; Fouladgar & Simeone, 2012; Luo et al., 2013; Nasir et al., 2013; Xu & Zhang, 2014; Nguyen et al., 2017; Ye et al., 2018) and the advances made in EH technology have made self-sustaining wireless nodes achievable, thereby creating a promising and convenient technique to charge batteries in 5G wireless cooperative communication networks in the future (Liu et al., 2013a; Do, 2015; Nguyen et al., 2017).

Sequel to the advances made in EH technologies, a new emerging solution to switch energy constrained nodes on by using radio frequency (RF) signals has been proposed recently, the rationale of which is that RF signals can concurrently transfer wireless energy and information (Varshney, 2008; Nasir et al., 2013; Di, et al., 2017; Chu, et al., 2017). Thus, communication nodes with limited energy in wireless cooperative networks can harvest energy via RF signals broadcast from the energetic nodes, which will be used in the simultaneous processing and transmission of information (Varshney, 2008; Nasir et al., 2013; Zhang & Ho, 2013; Ye et al., 2018). This EH technique is termed simultaneous wireless information and power transfer (SWIPT). To achieve SWIPT in cooperative communication networks, different protocols have been proposed in the literature (Nasir et al., 2013; Krikidis et al., 2014b; Zhao et al., 2018), which are now widely adopted.

Furthermore, radio signals radiated by neighboring transmitters can be a close alternative source for wireless EH. As reported by (Zungeru et al., 2012; Ju & Zhang, 2014b), using a power-cast RF energy harvester operating at 915 MHz, the wireless energy of 3.5 mJ and 1 uJ can be scavenged from RF signals at the equivalent ranges of 0.6 and 11 m, respectively. Advances in the design of energy-saving rectifying antennas can pave the way for an efficient wireless EH via RF signals in the near future (Vullers et al., 2009).

This thesis presents resource allocation techniques, protocol design and performance analysis of a RF EH-enabled cooperative network that comprises a source node, an energy-constrained cooperative relay node and a destination node. The source node sends RF signals to the destination node with the assistance of the energy-constrained cooperative relay node. Since the relay node has no embedded energy supply, it harvests energy from the RF signals broadcast by the source node, which can be stored in a rechargeable battery and concurrently process the received signals. The relay can then utilize the harvested energy to deliver the information signal at the destination node. However, wireless communication networks are prone to interference due to their broadcasting feature. This condition can result in the degradation in system performance. Therefore, the effects of the presence of an interfering transmitter in the neighbourhood of the RF EH-enabled cooperative network is also investigated. This is done in order to show the benefit of interference in the SWIPT systems.

1.1 Problem Statement

In wireless communications, researchers have investigated conventional renewable energy resources (e.g., solar, mechanical vibration, and wind) and studied a number of resource allocation techniques for different goals and network topologies (Krikidis et al., 2014b). However, the unpredictable and periodic character of these energy sources cannot promise good quality of service (QoS), thereby motivating the use of EH via RF signals. This drawback can be overcome in a wireless network with the use of RF signals by using SWIPT. The energy-constrained nodes can renew their energy from RF signals that come from more energetic nodes (Lu et al., 2015). Specifically, the demand for RF–EH can be predictable, thereby making it suitable for QoS-based application support (Mishra et al., 2015).

In the past, several protocols have been proposed to virtually realize SWIPT, namely, time switching relaying (TSR), power splitting relaying (PSR) and antenna switching (AS) protocols and these protocols have been widely adopted (Nasir et al., 2013; Liu et al., 2013a; Hu et al., 2015; Wang et al., 2017b). Previous works on SWIPT have considered a number of resource allocation techniques for different objective orientations (e.g. throughput and energy efficiency enhancement) in EH-enabled cooperative networks under the assumption that the energy-constrained relay must utilize all of its harvested power in each transmission block. Hence, the relay's power causality was neglected. However, the ability to find the most efficient technique to utilize the harvested power optimally and satisfy certain requirements for the system QoS is still a critical issue for the researchers.

According to (Nasir et al., 2013), in PSR protocol utilization, the time switching (TS) factor is set to remain constant for throughput optimization, while the power splitting (PS) factor is not considered in TSR protocol. Thus, optimal throughput based on a single constraint (i.e. time or power) is regarded as a local optimization parameter. To tackle this challenge, (Do, 2016) proposed time-power switching relaying (TPSR) protocol for determining both the TS factor and the PS factor subject to maximizing throughput performance. However, the optimal TS or PS factor is affected by the channel statistics of the channel state information (CSI), thereby results in rapid changes of received signal strengths over a short period of transmission time and distances traveled.

1.2 Research Objectives

This research focuses on RF-EH as a means of sustaining the lifetime of energy-constrained wireless cooperative networks. The major objectives of this research include:

i. To propose a new and efficient energy saving (ES) resource (e.g. power) allocation technique for EH-enabled cooperative networks on the basis of the TSR and the PSR protocols.
ii. To propose a hybridized power-time splitting based relaying (HPTSR) protocol for an efficient SWIPT in EH-enabled cooperative networks.
iii. To determine the optimal system parameters that maximize the system energy efficiency in (i) and the throughput performance of the proposed HPTSR protocol in (ii) for the considered EH-enabled cooperative network.

1.3 Scope of Work

This thesis centers on exploitation of the RF-EH in wireless cooperative networks. The main targets are to propose an ES technique and an efficient SWIPT protocol for power allocation in EH-enabled cooperative networks. The cooperative network being used is a single-source node, a single-relay node, and a single-destination node. Furthermore, the ES resource allocation problem being addressed in this thesis is based on the TSR and PSR protocols, which are widely adopted in the