UNIVERSITI PUTRA MALAYSIA

# GREEN NETWORK PLANNING AND OPERATIONAL POWER CONSUMPTION OPTIMIZATION IN LTE-A USING ARTIFICIAL INTELLIGENCE

AIDA ISMAIL AHMED AL-SAMAWI

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**By**

**AIDA ISMAIL AHMED AL-SAMAWI**

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

**December 2015**

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**DEDICATIONS**

*To My Sister Dr. Samah Al-Samawi*

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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**December 2015**

**Chairman: Aduwati Sali, PhD**
**Faculty: Engineering**

Demands for high bandwidth and data rates put wireless communication industry in a leading position as energy demanding industry which contributes in carbon dioxide volume. Therefore, Green wireless network concept has emerged to provide the foundation of energy-efficient wireless network. Base stations in wireless network are considered as the major part responsible for the network power consumption.

Therefore, this work is dedicated to introduce a new perspective for the heterogeneous network power efficiency improvement through network planning optimization and relay station switching. A cascaded multi-objective genetic algorithm network optimization (CMOGANO) is developed to optimize the network number of base station, their location and configuration in the first stage to provide full coverage. The second stage of the developed algorithm optimizes the average number of relay station per base station and their distance from the respective base station to meet the capacity constraint of the network operator. To optimize the relay station switching, a detailed mathematical model assuming linear power consumption model for the transmitters in the network is developed. In this model, the rate of active relay stations is defined and integrated in the model as a varying function in time. Optimization of the rate of active relay stations, in this model, is treated as a variation concept. A simplified fuzzy logic solution to the optimization of the rate of active RS is introduced.

The CMOGANO optimization showed that a power reduction up to 40% is feasible in the network by reducing the number of base stations by 47% as compared to the operator plan. This reduction of the number of base stations is achieved without losses in the network coverage. The second stage of CMOGANO added a total of 516 relay stations in the network to improve its capacity up to 98%. The rate of active

relay station optimization process revealed that the optimum rate of active relay station obeys a linear first order ODE. Moreover, the optimum rate of active relay is a function of the traffic pattern, average relay station load factor, their derivatives, and the relative RS to BS capacity factor. The mathematical model yielded a significant power saving up to 30% and 46% can be achieved in RS idling and sleeping modes respectively. Moreover, the amount of power saving is a function of the number of relay stations per base station. The effect of the traffic rate derivative is to activate the relay stations for longer time resulting in less power saving in the network. Similarly, power saving up to 41% can be achieved by the fuzzy logic solution.

In conclusion, complying with green network concept in heterogeneous network systems is feasible. This compliance starts from adopting the green network concept in the planning stage of the systems and continues through the optimization of the network power expenditure during its operation. However, the introduction of the relay base stations in heterogeneous network significantly increased the complexity of the network. This complexity can be handled by developing a sophisticated heuristic mathematical tools that account for diverse parameters in the network such that the demanded Quality of Service (QoS) is achieved under the umbrella of green network operation.

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

**PERANCANGAN RANGKAIAN HIJAU DAN OPERASI PENGOPTIMUMAN PENGGUNAAN KUASA DI LTE-A MENGGUNAKAN KECERDASAN BUATAN**

Oleh

**AIDA ISMAIL AHMED AL-SAMAWI**

**Disember 2015**

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Permintaan untuk jalur lebar dan kadar data yang tinggi meletakkan industri komunikasi wayarles dalam kedudukan yang terkemuka sebagai industri tenaga yang terpenting di mana ia menyumbang kepada penghasilan karbon dioksida. Oleh itu, konsep rangkaian wayarles Hijau telah muncul untuk menyediakan asas kepada rangkaian wayarles bersifat tenaga-cekap. Stesen pangkalan di rangkaian wayarles dianggap sebagai bahagian utama yang bertanggungjawab ke atas penggunaan kuasa rangkaian.

Maka dengan itu, kajian ini adalah khusus dalam memperkenalkan perspektif baru untuk peningkatan kecekapan kuasa rangkaian heterogen melalui pengoptimuman perancangan rangkaian dan pesuisan stesen geganti. Pengoptimuman rangkaian algoritma genetik pelbagai objektif terlata,(CMOGANO), dibangunkan untuk mengoptimumkan jumlah rangkaian stesen pengkalan, lokasi dan konfigurasi pada peringkat pertama bagi menyediakan liputan menyeluruh. Pada peringkat kedua pembangunan algoritma, purata bilangan stesen geganti bagi setiap stesen pangkalan dan jarak dari stesen pangkalan masing-masing dioptimumkan bagi memenuhi kekangan kapasiti pengendali rangkaian. Untuk mengoptimumkan pensuisan stesen geganti, sebuah model matematik yang terperinci dengan andaian bahawa penggunaan kuasa linear untuk pemancar dalam rangkaian tersebut dibangunkan. Dalam model tersebut, kadar stesen geganti yang aktif ditakrif dan bersepadu dalam sebuah model sebagai fungsi perubahan dalam unit masa. Pengoptimuman bagi kadar stesen geganti yang aktif, dalam model ini, dianggap sebagai satu konsep perubahan. Penyelesaian logik kabur yang dipermudahkan untuk mengoptimumkan kadar RS aktif diperkenalkan.

Pengoptimuman CMOGANO menunjukkan pengurangan kuasa sehingga 40% boleh dilaksanakan dalam rangkaian dengan mengurangkan bilangan stesen pangkalan se-

banyak 47% berbanding dengan pelan asal. Pengurangan bilangan stesen pangkalan ini dicapai tanpa kerugian dalam liputan rangkaian. Pada peringkat kedua CMOGA-NO, sebanyak 516 stesen geganti ditambah ke dalam rangkaian untuk meningkatkan kapasitinya sehingga 98%. Proses pengoptimuman kadar stesen geganti yang aktif menunjukkan bahawa, kadar optimum stesen geganti yang aktif mengikuti peringkat lelurus pertama ODE. Selain daripada itu, kadar optimum geganti yang aktif adalah fungsi kepada pola trafik, purata faktor beban stesen geganti, hasil terbitan dan perbandingan faktor kapasiti RS terhadap BS. Model matematik tersebut menghasilkan penjimatan kuasa yang ketara sehingga 30% dan 46% yang boleh dicapai dalam mod pemelahuan dan mod tidur RS masing-masing. Selain itu, jumlah penjimatan kuasa adalah fungsi bilangan stesen geganti bagi setiap stesen pangkalan. Kesan daripada terbitan kadar trafik adalah untuk mengaktifkan stesen geganti untuk masa yang lebih lama yang menyebabkan kurang penjimatan kuasa dalam rangkaian. Begitu juga, kuasa penjimatan sehingga 41% boleh dicapai dengan penyelesaian logik kabur.

Kesimpulannya, mematuhi konsep rangkaian hijau dalam sistem rangkaian heterogen boleh dilaksanakan. Pematuhan ini bermula dari mengguna pakai konsep rangkaian hijau di peringkat perancangan sistem dan bersambung kepada pengoptimuman perbelanjaan kuasa rangkaian semasa operasinya. Walau bagaimanapun, pengenalan stesen pangkalan geganti dalam rangkaian heterogen dengan ketara meningkatkan kerumitan rangkaian. Kerumitan ini dapat ditangani dengan membangunkan alat matematik heuristik yang canggih yang mengambil kira pelbagai parameter dalam rangkaian itu supaya kualiti perkhidmatan (QoS) yang diminta dapat dicapai di bawah operasi rangkaian hijau. pensuisan stesen geganti dalam rangkaian heterogen boleh menyebabkan rangkaian peningkatan kecekapan tenaga yang luar biasa. Pengoptimuman kadar stesen geganti adalah fungsi kadar trafik dan secara setara ia adalah terbitannya. Selain daripada itu, stesen geganti berbanding dengan kapasiti stesen pangkalan adalah sama penting dalam meningkatkan kadar penjimatan kuasa.

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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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| | |
|---|---|
| 2G | 2nd Generations |
| 3G | 3rd Generations |
| 3GPP | 3rd Generation Partnership Project |
| BS | Base station |
| BS2BSD | Base station to base station distance |
| CMOGANO | Cascaded Mult-Objective Genetic Algorithm Network Optimization |
| CDF | Cumulative Distribution Function |
| DTM | Digital Terrain Map |
| DSM | Dynamic Sleep Mode |
| ECG | Energy Consumption Gain |
| ECR | Energy Consumption Ratio |
| EE | Energy Efficient |
| EIRP | Equivalent Isotropic Radiation Power |
| FIS | Fuzzy Logic Inference System |
| Fuzzy SM | Fuzzy Sleeping Mode |
| GA | Genetic Algorithms |
| HetNet | Heterogeneous Network |
| JUPEM | Jabatan Ukur Dan Pemetaan Malaysia |
| LTE | Long Term Evolution |
| MOE | Malaysia Ministry of Education |
| MS | Mobile Station |
| CMOGANO | Multi-Objective GA Network Optimization |
| ODE | Ordinary Deferential Equation |
| OFDMA | Orthogonal Frequency-Division Multiple Access |
| OFDM | Orthogonal Frequency-Division Multiplexing |
| PSO | Particle Swarm Optimization |
| PCI | Physical Cell ID |
| PDF | Probability density function |
| QoE | Quality of Experience |
| QoS | Quality of Service |
| RSSI | Received Signal Strength Index |
| RS | Relay Station |
| SSSM | Semi-Static Sleep Mode |
| SP | Service Provider |
| SFM | Shadow Fading Margin |
| SINR | Signal to Interference Plus Noise |
| SC-FDMA | Single Carrier FDMA |
| SFN | Single Frequency Networks |
| TPRMS | Transmission Power Root Mean Squared Deviation |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

The green concept is a rapidly growing notion in a wide spectrum of technological and industrial fields. It focuses on reducing pollution and minimizing risk to environment in all stages of products and processes. There is a particular potential for energy consumption reduction in mobile and wireless communication technology. The effect of power starving technologies and their impact on the environment represented as $CO_2$ payload is becoming a concern of researcher, despite the fact that, the information and communication technology is consuming about 2% to 10% of the total energy globally [12]. The fast increase in wireless services and the bandwidth needed for the new generation of wireless systems will potentially increase its power consumption. Base stations transmission power accounts for 60-80% of the total power consumed in the network [13]. These power consumption figures motivate the consideration of the green network planning as an essential step to reduce the impact of wireless technology on the environment, especially that there is a collective aim globally to decrease carbon footprint and total power consumption by 20% in 2020 [14]. Green Network concept aims to optimize the network energy efficiency so as the QoS demand is maintained. Achieving energy efficient wireless network starts from the initial planning of the wireless network and continues during operation of the network. The energy efficiency of the wireless network is addressed in the planning stage by optimizing the base stations number, positions, and configuration. The operational network energy efficiency, on the other hand, is mitigated based on network load variability and service demands.

The wireless signal, once it leaves the base station antenna, experiences a vast physical transformation and alteration through its propagation path. These factors are caused by obstructing objects in the channel. Moreover, the terrain topography and roughness play a significant role in the quality of the propagated signal. Buildings and large obstacles such as mountains, on the other hand, cause a severe alteration of the signal through diffraction and multipath fading. These physical phenomena should be considered by network planners to achieve the reliability of the system in terms of QoS and demands. Thus, on mega cities with large fluctuation in the number of users during the day, planning a reliable network is difficult. Network designers, typically, depend on sophisticated mathematical models and tools that accurately map the different alteration sources and assist in achieving a reliable design of the network [15].

Network power efficiency revision is a necessary task even after the planning stage. Topology changes in the region may require a modification of the antenna configuration or an addition of more antennas. Furthermore, expansion of the network may become necessary to accommodate the increased number of users. Therefore, reduction of the total energy consumed in the network is an endless process. One of the methods to achieve this is through switching off some base stations at low users traffic periods of time, and reactivating them when the network services demands are increased. The network coverage losses, during the base station off time, is mitigated by zooming the active base stations. Usually, base station switching on/off is implemented to enhance the power efficiency of the network. However, the advent of heterogeneous networks comprising of base stations and relay stations in the network urged the search for new and optimum switching algorithms. This is of particular importance in high population density areas where the base stations are required to operate permanently [16]. In such scenarios, only the relay stations are switched on/off to improve the network power performance. However, the discrepancies between the power consumption of the relay station and the base station raise the concern about the amount of power saving that can be achieved by switching off the relay stations. More importantly, satisfying the traffic rate at any moment of time is of equivalent importance to network operators. Thus, the relay station switching on/off algorithm should consider the traffic rate in the network in order to ensure a satisfactory service availability. This would cause the active relay stations to operate at higher load factors than the load that would be distributed on all the relay stations when they are active [1] permanently.

To summarize, the power consumption of the network, nowadays, is increasing tremendously due to increasing demands on wireless technology services and data rates [17]. Thus, a careful planning of the wireless network to achieve high energy efficiency of the network is of a particular importance to meet the green network requirements. Usually, robust planning of networks that minimizes the network total power and provides QoS is utilized to have a reliable and efficient network plan. Furthermore, base station switching on/off is an emerging research field aiming to reduce the total power consumption in the network utilizing the variability of the traffic rate during the day. However, the dawn time of the high density heterogeneous networks comprising major base stations and relay stations motivates to rethink of such switching algorithms. This motivation is charged by the fact that, in high population density such as urban areas, the base stations are needed to operate permanently, thus, the switching algorithm should be applied on the relay stations only. With the comparative size and capacity of the relay station to the base station, the optimization of the relay station switching to maximize the power saving gain in such scenarios becomes vital.

### 1.2 Problem Statement

The escalating levels of CO2 percentage in the atmosphere due to intensive power consumption in the technology becomes a real threat. This problem has its effect in the environment and more silently on human health. International efforts are spent to regulate the emissions of CO2 by utilizing more energy efficient technology. Wireless mobile technology is one of the contributors in this epidemic phenomenon. Though the contribution of wireless technology in the total power consumption is in the range of 15% [18], it is speculated that its power consumption will increase sharply as the demand on wireless technology services is on the rise. The increasing reliance on wireless technology services in daily life motivates the introduction of the green wireless concept. The main aim of the green wireless notion is to improve the network energy efficiency. This motive creates a challenge for the network operators and designer because of the trade off needed between power consumption and the QoS requirements. To meet an eco-friendly wireless network system requirements, network designers need to utilize sophisticated mathematical models

1. The terms relay station switching on/off and relay station activation/deactivation are used interchangeably in this thesis

and tools that would assist the achievement of energy enhanced network topologies. Initially, energy efficient network design starts from the pre-planning and planning stages. During provisioning processes of the network under operation, the alteration of the network configuration also should consider the energy efficiency benchmark. In addition to that, new technologies and algorithms may be deployed to improve the operational power consumption of the network. In conclusion, power consumption awareness is an endless process in wireless technology.

In urbanized regions, wireless signal undergoes vast varieties of physical alterations that change the nature of the signal. These effects come from different objects separating the transmitter and receiver. In addition to that, terrain irregularities and ground reflections create replicas of the signal through its transmission course. The collection of these transformed and attenuated copies of the signal is what the end user receives. These environmental effects play a major role in designing energy efficient wireless network system. Moreover, changes in the manmade structures in mega cities are becoming a daily routine witnessed in modern cities. Usually mathematical modeling is used to map the physical effects experienced by the propagating signal, and provide an optimized network topology that meets the QoS requirements under the compliance with the green technology concept. However, to date, no such mathematical model is deemed the perfect choice in providing a complete and ultimate solution. Therefore, compliance with green technology is still an open research field in wireless technology.

Heuristic algorithms are typically one of the most successful research methods used to model the complicated nature of network planning [19–21]. Genetic algorithms (GA) and its variations, in particular, are among the methods that proved to be useful in addressing the optimization of the network for different topologies, environments and landscapes [22, 23]. Plenty of research based on GA addressing the optimization of wireless network is found in abundance in the literature. However, with the emerging of new technologies such as LTE, LTE-advanced and the Relay stations, new applications of such heuristic algorithms are needed. The introduction of relay stations in LTE advanced enabled network planners to adopt a new approach in optimizing the network both in terms of QoS and network energy efficiency. Initially the proper selection of the network base stations configurations and locations would greatly contribute to reducing the total energy consumed in the network and provide the full coverage required by the operator. This is because base stations are considered the major power consumer in wireless networks. To achieve this goal, more research on GA is still needed to account for the parameters that affect the planning and selection decision. Moreover, base station sleeping or zooming algorithms would, significantly, improve the power efficiency in the network during its operation. Thus, plenty of sleeping mode algorithms are introduced specifically to provide base station switching off profile that would improve the network power efficiency [24–28]. The main concern of the developed sleeping algorithms is to compromise between the power consumption and the service availability to the users. Most of the developed base station sleeping algorithms in the literature utilize the arrival rate as the main parameter to achieve the optimal base station switching.

As the energy efficient network plan aims to optimize the number of base stations, the network capacity, particularly in areas with large fluctuation in the users demand, is improved by deploying smaller base stations or relay stations that would assist in handling higher services rate. This concept introduces the heterogeneous or high density network topologies. Recently, these network topologies form the backbone of the wireless network systems in high populated areas. Apparently, deployment of relay stations to improve the network capacity would deteriorate the power efficiency of the network during its operation. The variability of user's density during the day causes the relay stations to be idling for a considerable amount of time. The power consumed by idling relay stations during low traffic rate periods is considered a waste. Thus, switching off the idling relay stations at low traffic rate would improve the energy efficiency of the network. This relay station switching routine should consider the availability of service at any moment in time and it should be optimized to maximize the power saving gain. The optimization of the relay station switching is of high importance due to its smaller power supply as compared to the base station. Nevertheless, a comprehensive understanding of the parameters that influence the design of optimum relay station switching profile is still an open question. The answer to this question needs a detailed mathematical model that would describe the variables that affect the sleep mode optimization for different scenarios and environments. Moreover, the mathematical model is required to provide the limits of the maximum energy saving that could result from applying the switching algorithm for a given scenario. Understanding the concept of relay station switching and its controlling parameters would lead to the design of a simple and robust relay switching algorithm. Fuzzy based algorithms are a perfect choice to design a simple and effective sleeping mode algorithm. The low computational complexity of fuzzy systems makes them one of the candidate choices to design relay station sleeping mode to be deployed in such a resource starving technologies.

## 1.3 Motivation

The increase in the spread of smart hand held devices led to a sharp increase in the wireless services in terms of bandwidth. In high density network technology, relentless increase of user demands alerted the concerns about the power consumption of these technologies. Reduction of the total power consumption becomes evident to ensure power efficiency in future networks. However, the reduction of total power consumption should take into account the QoS provided by operators in terms of coverage and bandwidth. This compromise between total power consumption and QoS forms the real challenge facing the network designer and operators. Thus, more research is needed to find the suitable algorithms and efficient procedures that would provide green network compliance and QoS demands. To meet this requirements, the number of base stations in the network and their configuration are optimized to have energy efficient network infrastructure that meets the operator coverage demands. A set of relay stations is, then, associated with each base station to boost up the network capacity. During network operation, robust relay station switching algorithm is implemented to maximize the energy efficiency in the network.

## 1.4 Research Objectives

The main objectives of this research are as follows:

- To develop a multi-objective Genetic Algorithm tool to optimize the planning of wireless heterogeneous network through the selection of the wireless network base stations configuration to ensure the coverage criteria. Verification and validation of the optimized network QoS in terms of area coverage, safety index and SINR perceived by the users is accomplished through a simulation tool.

- To formulate a mathematical model to identify the parameters that optimize the Relay Station switching to ensure the minimum power consumption, network capacity and service integrity.The solutions of the mathematical model provides the validation of the parameters of Relay Station switching and determine the bounds of power saving achieved by applying the Relay Station switching schemes in different scenarios.

- To develop and validate a simplified fuzzy logic based solution to Relay Station switching schemes.

## 1.5 Research Scope

This work is dedicated to study and verify the wireless network energy consumption efficiency options. As the wireless services are of high demands in modern life, the power consumption of the network is of great concern. Thus, reducing the total power consumed is a necessity. Power aware network planning is the first step toward achieving the energy efficient wireless network system. Achieving this goal obligates the development of sophisticated mathematical tools to address the complexity of wireless network planning and design. Following the planning stage of the network, operating network power efficiency improvement is a challenge to operators and designers. Development of a comprehensive mathematical model to address the network power efficiency enhancement would enable the design of a robust switching solutions so as the network operation is maintained within the standard levels.

## 1.6 Research Contributions

This work investigates the power efficient wireless network opportunities. In the planning stage, a remarkable power saving could be achieved by selecting the proper base station configuration and locations that would guarantee a full coverage of the network. Upon the optimization of the base station configuration, relay stations are distributed in the network to enhance its capacity. During the operation of the wireless network, the power consumed is further enhanced by applying relay station switching profile. A mathematical model has been derived to optimize the relay station switching. The summary of the contribution of this work is as follows:

- The parameters and configuration, such as the antenna height and transmission power, of the wireless network base station are identified and optimized to provide energy aware wireless network topology. The initial parameters and configurations of the network base stations are provided for a real operating network through the MCMC. Then, a multi-objective Genetic Algorithm tool has been developed that takes into account the wireless network coverage, safety index, SINR and received power as QoS measures, and provide the optimized wireless network base station parameters. As compared to without

GA implementation, power saving of 40% can be achieved by reducing the number of base stations and optimizing their configurations such that the full coverage of the network is maintained.

- A mathematical model has been formulated, and the parameters that are effecting the optimization of relay station switching have been established. The optimum relay station switching profile is related to the arrival rate and load factor of the relay station and their derivatives through the first order linear ordinary differential equation (ODE). The solutions of the equation are the optimum switching profile.

- Applying the derived solution in the heterogeneous wireless network comprising different transmitter types with different capacity yielded a significant power saving up to 45% in certain scenarios while maintaining the service availability. A simplified fuzzy logic based solution has been developed to reduce the complexity of relay station switching in real time application.

## 1.7 Research Difficulties

The main obstacles faced during this work are related to the collection of data and the availability of simulation tools. In brief, the difficulties faced are:

- The unavailability of simple and handy simulation tool is a main difficulty that impacted the progress of this work. This concern obligated the development of the necessary tool to perform the simulations required which elongated the accomplishment of the results.

- Requests of the data from operators have been denied due to confidentiality claims. Thus, the data are delivered by going through a complicated routine of the governmental authentication and verification procedures.

- Furthermore, some of the data needed are not available through governmental channels. The confidentiality claim of operators and their denial to provide a sample of the requested data was a major difficulty faced in accomplishing this work. Instead, this sort of data has been synthesized to provide a satisfactory results.

## 1.8 Thesis Organization

The rest of this thesis is organized as follows:

Chapter 2 a brief historical network evolution with emphasize on the HetNet and LTE-A systems is introduced and discussed. Then, the network QoS parameters are concisely discussed and energy aware network optimization criteria is identified followed by a discussion of different methods developed for energy aware optimization. Also, the rule of GA in network optimization is highlighted. Moreover, different BS sleeping modes algorithms are discussed. Coverage aware BS sleeping mode algorithms are presented and discussed followed by identification of the role of traffic aware base stations sleeping algorithm. The chapter is concluded and a brief discussion of significance of this research is presented in the summary.

Chapter 3 describes the general methodology followed in this work. The formulation of the multi-objective GA to optimize the base station location and configuration is discussed, followed by the mathematical formulation of the base station switching problem. The fuzzy implementation of the sleeping mode is also investigated.

Chapter 4 discussed the GA validation, verification and optimization. The cascaded concept in the developed GA optimization technique is investigated and highlighted based on the developed network model. Moreover, the development of heterogeneous network total power consumption model is presented in details and discussed concisely. Finally, the proposed network topology of the GA and its power efficiency are, also, discussed and concluded in the chapter summary.

Chapter 5 the theoretical base station sleeping mode is investigated and the parameters that affect the sleeping mode are identified and their effect is studied.

Chapter 6 the fuzzy based sleeping mode efficiency is highlighted and proposed to extract a simplified solutions to the relay station switching in contrast to the mathematical model results.

Chapter 7 The final conclusion of the thesis is introduced with suggestions and recommendations based on the results of this work. Future work directions are emphasized.

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## LIST OF PUBLICATIONS

### International Refereed Journals

Aida Al-Samawi, A. Sali, Liyth Nissirat, Nor Kamariah Noordin, Mohamed Othman, and Fazirulhisyam Hashim. 2015. Wireless Network Power Optimization using Relay Stations Blossoming and Withering Technique. Transactions on Emerging Telecommunications Technologies (IF: 1.354).

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### International Refereed Conferences

Al-Samawi, Aida, Aduwati Sali, Nor Kamariah Noordin, Marini Othman, and Fazirulhisyam Hashim. Base station location optimisation in LTE using Genetic Algorithm. In ICT Convergence (ICTC), 2013 International Conference on, pp. 336-341. IEEE, 2013.

A. Al-Samawi, A. Sali, N. K. Noordin, M. Othman, and F. Hashim, Base Station Blossoming and Withering Technique for Heterogeneous Wireless Networks Using Fuzzy Logic, (ISTT), 2014 International Conference on, IEEE, 2014.

**Keynote Speakers**

Green Communications, International Conference on Green Computing and Internet of Things (ICGCIoT) , October 2015.

**Invited Presentations**

Green Network Optimisation for Wireless Networks, MCMC, 19 June 2013. Green Radio Optimisation for Wireless Networks, MIMOS,20 October 2013.