NEURAL NETWORK AND GENETIC ALGORITHM TECHNIQUES FOR ENERGY EFFICIENT RELAY NODE PLACEMENT IN SMART GRID

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I dedicate my dissertation work to my family. A special feeling of gratitude to my loving parents. My siblings Mina, Maryam, Mitra and Mohammad Hossein have never left my side and are very special to me.

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ABSTRACT

Smart grid (SG) is an intelligent combination of computer science and electricity system whose main characteristics are measurement and real-time monitoring for utility and consumer behavior. SG is made of three main parts: Home Area Network (HAN), Field Area Network (FAN) and Wide Area Network (WAN). There are several techniques used for monitoring SG such as fiber optic but very costly and difficult to maintain. One of the ways to solve the monitoring problem is use of Wireless Sensor Network (WSN). WSN is widely researched because of its easy deployment, low maintenance requirements, small hardware and low costs. However, SG is a harsh environment with high level of magnetic field and background noise and deploying WSN in this area is challenging since it has a direct effect on WSN link quality. An optimal relay node placement which has not yet worked in a smart grid can improve the link quality significantly. To solve the link quality problem and achieve optimum relay node placement, network life-time must be calculated because a longer life-time indicates better relay placement. To calculate this life-time, it is necessary to estimate packet reception rate (PRR). In this research, to achieve optimal relay node placement, firstly, a mathematical formula to measure link quality of the network in smart grid environment is proposed. Secondly, an algorithm based on neural network to estimate the network life-time has been developed. Thirdly, an algorithm based on genetic algorithm for efcient positioning of relay nodes under different conditions to increase the life-time of neural network has also been developed. Results from simulation showed that life-time prediction of neural network has a 91% accuracy. In addition, there was an 85% improvement of life-time compared to binary integer linear programming and weight binary integer linear programming. The research has shown that relay node placement based on the developed genetic algorithms have increased the network life-time, addressed the link quality problem and achieved optimum relay node placement.

ABSTRAK

Grid Pintar atau Smart Grid (SG) adalah kombinasi pintar sistem komputer dan elektrik dengan ciri utama untuk pengukuran dan pemantauan masa-nyata utiliti dan tatalaku pengguna. SG terdiri daripada tiga bahagian: Rangkaian Kawasan Rumah (HAN), Rangkaian Kawasan Lapangan (FAN) dan Rangkaian Kawasan Luas (WAN). Kebanyakan kaedah yang digunakan untuk memantau SG dalam FAN, seperti optik gentian tetapi ianya adalah mahal dan sukar untuk diselenggara. Salah satu cara untuk menyelesaikan masalah pengawasan ini ialah menggunakan Rangkaian Penderia Tanpa Wayar (WSN). WSN dianggap penyelesaian berpotensi kerana ia mudah diletak atur, mempunyai keperluan penyelenggaran yang rendah, berperkakasan kecil dan berkos rendah. Walau bagaimanapun, SG berada dalam persekitaran sukar dengan tahap medan magnet yang tinggi yang menyebabkan hingar, dan letak atur WSN dalam kawasan ini menjadi satu cabaran kerana ia memberi kesan secara langsung kepada kualiti talian WSN. Penempatan nod geganti yang optimum, yang belum pernah diambil kira dalam grid pintar, mampu menambah baik kualiti talian secara berkesan. Untuk menyelesaikan masalah kualiti talian dan mencapai penempatan nod geganti yang optimum, pengiraan tempoh hayat rangkaian perlu dibuat kerana lebih lama tempoh hayat bermakna lebih baik penempatan geganti. Untuk mengira tempoh hayat, anggaran kadar penerimaan paket (PRR) adalah perlu. Dalam kajian ini, untuk mencapai penempatan nod geganti yang optimal, pertama, rumusan matematik untuk mengira kualiti talian rangkaian dalam persekitaran SG dicadangkan. Kedua, satu algoritma berasaskan rangkaian neural untuk menganggar tempoh hayat rangkaian telah dibangunkan. Ketiga, satu algoritma berasaskan algoritma genetik untuk penentuan kedudukan nod geganti yang cekap dengan mengambil kira pelbagai keadaan seterusnya meningkatkan tempoh hayat rangkaian telah dibangunkan. Hasil daripada simulasi menunjukkan ramalan tempoh hayat rangkaian neural mencapai ketepatan 91%. Sebagai tambahan, 85% penambahbaikan diperolehi untuk tempoh hayat berbanding dengan pengaturcaraan linear integer binari dan pengaturcaraan linear integer binari berpemberat. Kajian ini menunjukkan penempatan nod geganti dalam persekitaran SG berdasarkan algoritma genetik telah meningkatkan tempoh hayat rangkaian, menangani masalah kualiti talian dan mencapai penempatan nod geganti optimum.

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LIST OF ABBREVIATIONS

BIP	–	Binary Integer Programming
BS	–	Base Station
DR	–	Demand Response
EN	–	End Node
ETX	–	Expected Transmission Count
FAN	–	Field Area Network
GA	–	Genetic Algorithm
GPS	–	Global Positioning System
HAN	–	Home Area Network
ICT	–	Information and Communication Technology
iHEM	–	in Home Energy Monitoring
LEA	–	Life-time Estimation Algorithm
LEF	–	Link Quality Estimation Formula
LQI	–	Link Quality Indicator
MSE	–	Mean square Error
NN	–	Neural Network
OREM	–	Optimization-based Residential Energy Management
ORPA	–	Optimize Relay Node Placement
PRR	–	Packet Reception Rate
QOS	–	Quality Of Service
RN	–	Relay Node
RNA	–	Relay Node Assignment
RNP	–	Relay Node Placement
RSSI	–	Received Signal Strength Indicator
RV	–	Random Variable
SA	–	Simulated Annealing

SG	–	Smart Grid
SNR	–	Signal to Noise Ratio
TOU	–	Time of Use
WAMR	–	Wireless Automatic Meter Reading
WAN	–	Wide Area Network
WCBIP	–	Weighted Clustering Binary Integer Programming
WMEWMA	–	Windows Mean with Exponentially Weighted Moving Average
WSHAN	–	Wireless Sensor Home Area Network
WSN	–	Wireless Sensor Network

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CHAPTER 1

INTRODUCTION

1.1 Overview

Wireless sensor networks (WSNs) are a specific types of ad-hoc network, in which the nodes are independent, small devices equipped with communication element, data computation and sensing capability (Akyildiz *et al.*, 2002a,b; Bharathidasan and Ponduru, 2002; Santi and Simon, 2004; Santi, 2005; Vieira *et al.*, 2003; Tubaishat and Madria, 2003). In this type of network, each node gathers information from same target area, and sends this information to a base station, through a multi-hop or single-hop communication network.

A WSN consists of hundred or thousands of nodes, which are deployed inside the target area. If some events occur in the environment, sensor node will collect the events from the target area and report this information to the base station. These WSNs can be utilized to many applications such as health-care, intrusion detection and natural disaster, weather monitoring, security surveillance, disaster monitoring, and ambient conditions recognition (Akyildiz *et al.*, 2002a; Calvano *et al.*, 2005; Mladineo and Knezic, 2000; Lorincz *et al.*, 2009). As an example, in forest fire early detection system, wireless temperature and smoke sensors are installed in the forest to detect fire or smoke in its early stage (Mladineo and Knezic, 2000). Battlefield can be another example of WSNs application that a soldier can be detected of the position of friendly soldiers or the availability of equipment's (Bhattacharyya *et al.*, 2010; Wang *et al.*, 2010; Ritchie *et al.*, 2009).

A sensor node is powered by battery resource hence it has a limited lifetime.

Due to limited energy availability, the energy source of wireless nodes must be managed in a best way to increase the lifetime of sensor nodes. Energy conservation is the main goal in designing of WSNs, since nodes are limited by remaining battery power. Results of many researches show that topology considerably decrease the amount of energy usage in nodes (Ramanathan and Rosales-Hain, 2000). Precisely, several algorithms have been introduced to propose an efficient topology that can reduce the energy depletion while prolonging network connectivity.

The efficient topology increases the network performance attributes such as routing efficiency, network capacity, and network connectivity (Ababneh *et al.*, 2009). Without effective topology, a randomly connected wireless nodes might affect the network lifetime, minimize the network capacity, minimize successful packet delivery, and increase node failures. For example, if the designed topology is too sparse, the network may be partitioned and if the designed topology is too dense, the network capacity will not be optimized.

Above discussion clearly shows that a good research is required to address topology design problem. During a topology design, it is desired to obtain the relay nodes in topology that has direct effect on lifetime and also network connectivity. Hence the focus of this research has been limited to deploying relay nodes in smart grid area to improve the wireless sensor network lifetime.

1.2 Background and Motivation

Smart grid in the electrical generation industry is a new technology to save energy. It is an intelligent power distribution and generation system which can increase energy efficiency. Over the time, it has developed from smart metering, transmission and distribution automation to an overall intelligent process. For monitoring power generation and consumption, and for controlling the equipment, a large amount of real-time data needs to be collected and analyzed (Lee *et al.*, 2011).

In smart grid, many technology has been used that one of them is wireless sensor network. Wireless sensor nodes are installed on the critical equipment to monitor the parameters of their condition. The collected information enables the smart grid system to adjust on changing conditions in fast and timely manner. WSN plays an important role in creating a high level reliability in smart grid that rapidly responds to any event with convenient actions such as alarming, reporting or making decisions. The existing applications of WSN on smart grid cover a wide range of tasks, including wireless automatic meter reading (WAMR), remote system monitoring, equipment fault diagnostics, etc. However, the realization of these currently designed and envisioned applications directly depends on efficient and reliable communication capabilities of the deployed WSNs (Gungor and Lambert, 2006). However, harsh and complex electric power system environments pose great challenges in the reliability of WSN communications in smart-grid applications (Gungor *et al.*, 2010).

Smart grid can divided to three main parts. Home area network, filed area network and wide area network are those main parts that each has own challenges. For example in field area network with a 500 kVa transformer can generate a strong magnetic circle that can known as noise for radio frequency. This noise has direct effect on link quality and it can cause that packet reception rate and signal to noise ratio are not in good condition. Reducing PRR and SNR has direct effect on network life-time.

There are many approaches to maximize life-time in the WSN. The network design (Kulkarni *et al.*, 2012), routing protocols (Quan *et al.*, 2011), coverage area (Zamalloa and Krishnamachari, 2007) and many more can have effect on life-time hence extensive research has been done on these areas. One of the most important parts that has effect on life-time is WSN design. However, design is a very important but main concept of WSN deploy sensor nodes randomly in target area. For approach to network design other ways have been presented such as clustering, relay node station and multi-base station. Relay node station and network design research background are presented in this section.

Relay node station plays a critical role in WSN design. Because two important factor has an effect on this, first relay assignment and second relay placement (Sobuz, 2011; Guo *et al.*, 2008). Relay assignment talk about how many relay nodes needs for the better results. Actually, it’s very important because it has a negative effect on cost. Relay node placement concept is very familiar in research area and also industry. Many algorithms available for relay placement such as mathematical (linear programming, binary program) and non linear programming (Aslam and Robertson, 2007). Choose the algorithm is depended of complexity of topology and resources. However, the most important part is that relay node placements techniques that were used in the wireless sensor network cannot use directly for relay node placement in the smart grid because smart grid environment has it own challenges and difficulties.

1.3 Problem Statement

Due to the importance of up time in the sensor network that has been deployed in the field and also almost change battery in sensor node is impossible hence network life-time play a very important role in sensor network design. As mentioned many algorithms are available based on the network deign and protocol design. However, some relay node algorithm can improve network life-time in sensor network but lack of a network design for smart grid is completely made sense. On the other hand no simulation is available for smart grid. Hence the problem statements of this research are as follows:

(i) How link quality can be precisely assessed in smart grid environment?

(ii) How network life-time can be accurately estimated it base on location of relay nodes?

(iii) How to determine the base location of relay nodes within smart grid to attain fully connectivity and increase the network life-time on the different conditions?

1.4 Research Aim

The aim of the research is to increase the network life-time of sensor nodes within the smart grid environment through effective placement of relay nodes using soft computing techniques and achieve full connectivity of network with single-hop or multi-hop data transmission.

1.5 Research Objectives

Based on the research questions, the research objectives of this research are as follows:

(i) To propose a mathematical formula to measure link quality of the network in smart grid environment.

(ii) To develop an algorithm based on neural network that can estimate network life-time.

(iii) To develop an algorithm based on genetic algorithm for efficient positioning of relay nodes under different conditions that can increase the life-time of neural network.

1.6 Research Scopes

The scopes of this research are defined as follows:

(i) Sensor nodes are deployed in smart grid field with several conditions,

(ii) Smart grid field is high-voltage (above 500 kVA) environment with high level of noise (-90 dB) and powerful magnetic field,

(iii) Sensor nodes are static,

(iv) Relay nodes are static,

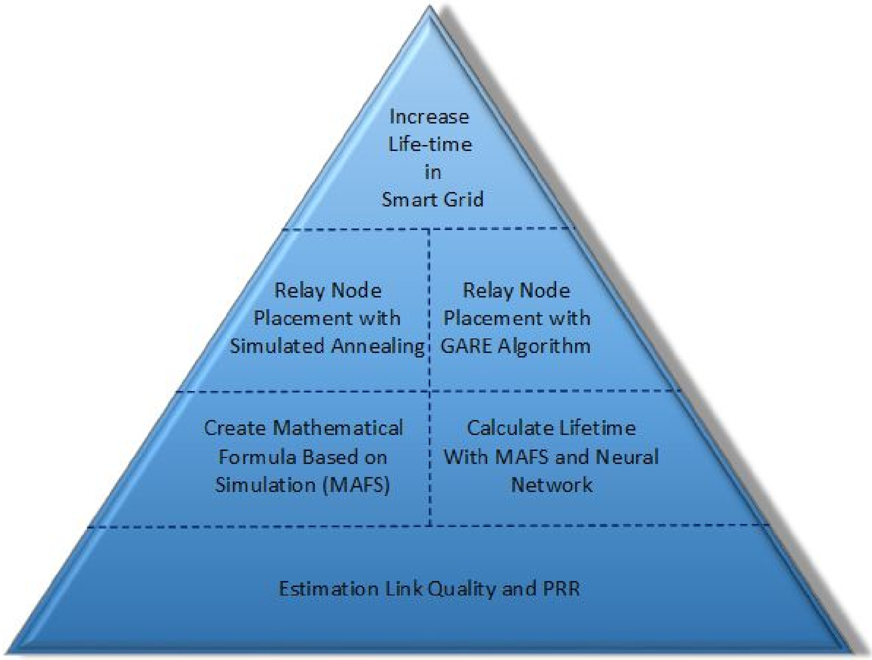

Figure 1.1: Research Contributions

1.7 Research Assumption

Some of the assumption for simulation, energy usage and other elements are defined as follow

(i) Relay can communicate with base station directly,

(ii) energy for sending one packet is $50 \times 0.39 \times e^{-4} J$,

(iii) receiving energy for one bite is $0.15 \times e^{-6} J$,

1.8 Research Contributions

This section shows the contributions of this research and Figure 1.1 illustrate it. The main contribution of research is introducing new techniques to increase networks life-time in smart grid. For achieving this purpose link quality in smart grid has been calculated and a formula has been created for helping to estimate life-time in

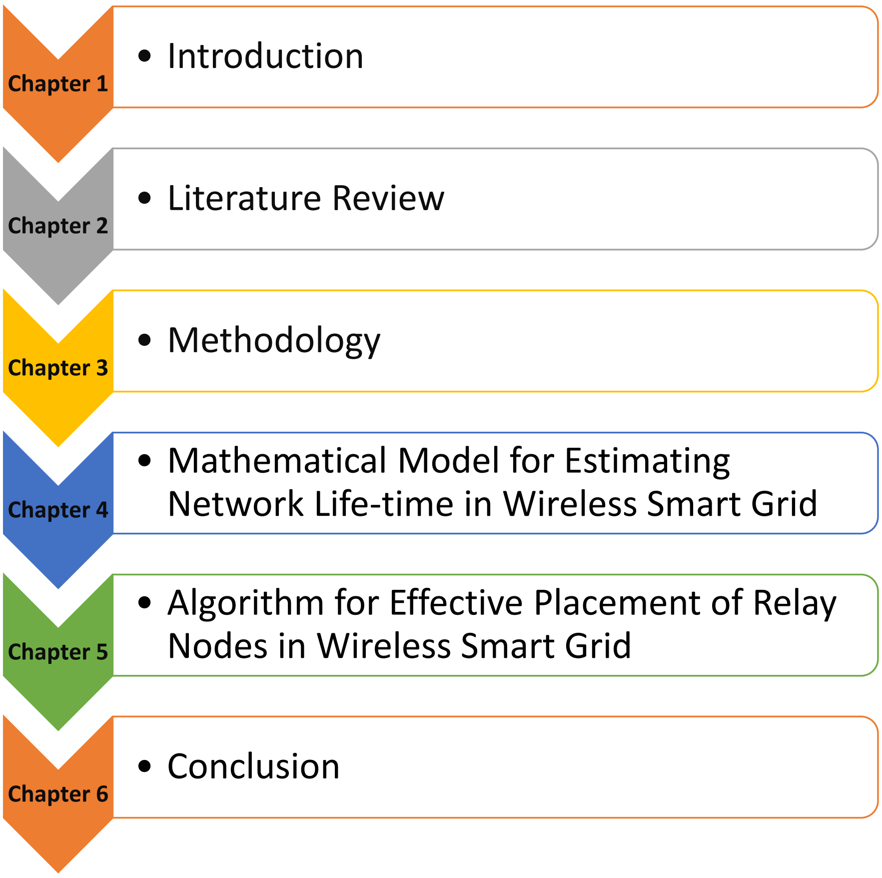

Figure 1.2: Thesis Organization

network. New relay node placement algorithm is final step to reach the main goal of this research.

1.9 Thesis Organization

The organization of this research is as shown in Figure 1.2. Chapter 1 presents a general discussion on the topic of the research and the issues that need to be solved by introducing the statement of problems, set of objectives, and the scopes of research. The related available literature are reviewed and discussed to achieve the necessary knowledge for developing the research objectives are in Chapter 2. Chapter 3 discusses the research methodology that is employed to execute this research. Estimation of link quality and how to calculate topology life-time with neural network are presented in chapter 4. This chapter also discusses simulation techniques in details. The developed relay node placement in the smart grid with simulated annealing (SA) and genetic algorithm (GA) are presented in Chapter 5. Chapter 6 presents simulation results along with a comprehensive analysis of the results. Finally, this research is concluded by highlighting the contributions of this work and introducing the possible future works.

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