LINK QUALITY AWARE ROUTING ALGORITHM IN MOBILE WIRELESS SENSOR NETWORKS

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Dedicated to my beloved wife " Gashaw " and my two angels (Jina and Posho) and to the greatest man in my life, my father "Mamosta Bakhtyar " who has always believed in me.

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ABSTRACT

Wireless Sensor Network (WSN) is composed of a number of sensor nodes that interact with each other intentionally to gather information from the area of interest. The limited processing capabilities, low memory capacities and low data rate, motivate the current research studies to focus on designing energy efficient mechanisms that can extend the sensor nodes operational duration and relatively prolong the network lifetime while providing reliable data transmission. In view of the fact that the sensor nodes in wireless sensor networks are typically irreplaceable, therefore, the protocols and algorithms developed for sensor networks must incorporate energy consumption as the highest priority optimization goal. An optimal route selection will provide higher throughput and reduction in delay from the end-to-end standpoint. Link quality information can be highly useful in selecting an optimal route. The aim of this study is to develop a routing algorithm based on link quality estimator in mobile wireless sensor networks. This study investigates most of the Link Quality Estimation (LQE) approaches and identifies their strengths and weaknesses. It also investigates and identifies the limitations of some LQE mechanisms utilized in existing routing algorithms. After investigating and analyzing, a suitable LQE approach named triangle metric is found to enhance an existing routing algorithm namely RACE (netwoRk conditions Aware geographiCal forwarding protocol for rEal-time applications in mobile wireless sensor networks) in terms of delivery ratio, loss ratio and energy consumption. The enhancement is implemented in simulation environment by using simulator tool OMNeT++. The results show that RACE can be enhanced and presents better performance in terms of delivery ratio, loss ratio and energy consumption.

ABSTRAK

Rangkaian sensor tanpa wayar (WSN) merupakan salah satu teknologi terbaru yang menjadikan kehidupan lebih selesa dan menarik. Keupayaan pemprosesan yang terhad, kapasiti memori yang rendah dan kadar data yang rendah, telah mendorong kajian penyelidikan semasa memberi tumpuan untuk membentuk satu mekanisme cekap tenaga yang boleh memanjangkan tempoh opearsi nod sensor dan memanjangkan hayat rangkaian di samping menyediakan penghantaran data yang boleh dipercayai. Memandangkan hakikat bahawa nod sensor dalam rangkaian sensor tanpa wayar biasanya boleh ditukar ganti, oleh itu, protokol dan algoritma yang dimajukan untuk rangkaian sensor mesti menggabungkan penggunaan tenaga sebagai keutamaan matlamat. Satu pemilihan laluan yang optimum akan menyediakan pengeluaran yang lebih tinggi dan pengurangan kelewatan dari sudut hujung-ke-akhir. Link maklumat yang berkualiti menjadi sangat bermanfaat dalam memilih laluan yang optimum. Tujuan kajian ini adalah untuk membangunkan algoritma laluan berdasarkan pautan penganggar kualiti dalam rangkaian sensor mudah alih tanpa wayar. Kajian ini menyiasat kebanyakan Anggaran Kualiti Link (LQE) pendekatan dan mengenal pasti kekuatan dan kelemahannya. Ia juga menyiasat dan mengenal pasti batasan beberapa mekanisme LQE yang digunakan dalam algoritma laluan yang sedia ada. Selepas menyiasat dan menganalisis, pendekatan LQE yang sesuai bernama segitiga metrik didapati untuk meningkatkan algoritma laluan yang sedia ada iaitu RACE (keadaan rangkaian sedar protokol penghantaran geografi untuk aplikasi masa sebenar dalam telefon bimbit rangkaian sensor tanpa wayar) dari segi nisbah penghantaran, nisbah kerugian dan penggunaan tenaga. Peningkatan ini dilaksanakan dalam persekitaran simulasi dengan menggunakan alat simulator OMNeT++. Keputusan menunjukkan bahawa RACE boleh dipertingkatkan dan membentangkan prestasi yang lebih baik dari segi nisbah penghantaran, nisbah kerugian dan penggunaan tenaga.

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LIST OF ABBREVIATIONS

ASL	-	Asymmetry Level
CSMA	-	Carrier Sense Multiple Access
CSMA/CA	-	Carrier sense multiple access with collision avoidance
CTS	-	Clear-to-Send
ETX	-	Expected Transmission Count
F-LQE	-	Fuzzy Link Quality Estimator
IEEE	-	Institute of Electrical and Electronics Engineers
LQ	-	Link Quality
LQE	-	Link Quality Estimator
LQI	-	Link Quality Indicator
MAC	-	Medium Access Control
MANET	-	Mobile Ad hoc Network
Mobile WSN	-	Mobile Wireless Sensor Network
NED	-	Network Description
OSI	-	Open Systems Interconnection
PDR	-	Packet Delivery Ratio
PHY	-	Physical Layer
PRR	-	Packet Reception Ratio
PSR	-	Packet Success Rate
QoS	-	Quality of Service
RACE	-	netwoRk conditions Aware geographiCal forwarding protocol for rEal-time applications in mobile wireless sensor networks
RNP	-	Required Number of Packets
RSSI	-	Received Signal Strength Indication
RTS	-	Request-to-Send
Rx	-	Receiving

SF	-	Stability Factor
SINR	-	Signal to Interference-plus-Noise Ratio
SNR	-	Signal to Noise Ratio
SPRR	-	Smoothed Packet Reception Ratio
TCP/IP	-	Transmission Control Protocol/Internet Protocol
Tx	-	Transmission
UDP	-	User Datagram Protocol
VANET	-	Vehicular Ad Hoc Network
WMEWMA	-	Window Mean Exponentially Weighed Moving Average
WSN	-	Wireless Sensor Network

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Self-configured wireless networks consisting of a kit of supportive, small battery driven equipment attached with communication and detection qualities are called Wireless Sensor Networks (WSNs). The purpose of these equipments is gathering environmental data like movement, sound, pressure, temperature and so on from their close environment. These data are then reported via radio links to a base station (also known as a sink node). They are created under means of insufficient cost and terrible limitations as they are frequently over used. Together with the desire for a huge array of real applications and the advent of developments in wireless communication and microelectronics technologies have quickly resulted in the creation of WSNs (Boukerche, 2008; Labrador and Wightman, 2009).

A number of detection and observation based sectors like medical, safety, agriculture, environment detection, house automation and military reconnaissance have combined steadily with this innovative technology, benefitting from small expenditure and unparalleled flexibility present nowadays. Because of its wireless condition, restrained means, low dependency of the sensor nodes, node concentration, disseminated system design and frequent movement, there are several challenges in research and practice to enable high performance of WSNs in terms of throughput and energy-productivity. The issues of classical wireless ad hoc networks are dissimilar as compared to these issues (Akyildiz *et al.*, 2002; Sichitiu and Ramadurai, 2004).

Typically wireless links are not reliable medium for communication. So use of wireless links in WSNs make the communications unreliable, particularly due to the unpredictable differences of their quality over a period of time (Woo and Culler, 2003; Zhou *et al.*, 2004). Link Quality Estimation (LQE) is an essential method of coping with this unworthiness at higher layer protocols mainly routing protocols (Baccour *et al.*, 2009).

In reality, the differentiation between links possessing good, average and poor quality is made easier with link quality estimation. Hence, by avoiding poor quality links which causes packet losses and retransmissions power consumption in WSNs can be minimized. Also, the throughput and energy-efficiency of the network performance improves as data is transmitted by sensor nodes over good quality connections. Further, estimating quality of the link allows sensor nodes to transmit their data over good quality links which develop the network performance in terms of throughput and energy-efficiency. A guarantee for such performance is strongly associated to the accuracy of link quality estimates. Undeniably, a network output can experience a reduction of 200% or more due to poor link quality approximates (Couto *et al.*, 2005).

1.2 Problem Background

The selection of the route for packet forwarding is to be determined by the routing layer in OSI (Open System Interconnection) or TCP/IP (Transmission Control Protocol/Internet Protocol) design. An optimal route selection can provide higher throughput and reduced end-to-end delay. Selection of a routing path highly depends on the lower layer's information (Zhou, 2010) including link layer. LQE can provide information related to a certain link that can help in selecting an optimal route.

1.2.1 Link Quality Estimation (LQE)

Based on earlier efforts, the widely used hop count method in wired network has been proven to be not conducive in wireless network. This is a result of the wireless network has a dissimilar link quality and link quality condition is specific to every link. The selection of route based on link quality will operate greater compared to pure hop count routing metric (Zhou, 2010). In addition, wireless communication connections are said to be untrustworthy as their performance differs erratically over a period of time. Inclusion of such unreliable links in routing or other higher layer protocols is not good for the overall network performance. Specifically, in order to proficiently sustain network connectivity, sophisticated routing protocols aim to overcome link unreliability. To accomplish this, in routing the most reliable routes for data delivery were chosen based on LQE (Lim *et al.*, 2002; Li *et al.*, 2005). Choosing connections with superior quality and discarding poor quality ones are preferable in selecting routes.

Establishing such steady routes will surely enhance the network throughput and maximize its lifetime. In truth, benefits of data transfer along established steady routes are (Baccour *et al.*, 2009):

1. Improving the probability of end-to-end delivery rates, which promotes the accuracy.
2. Evading extreme re-transmissions over poor quality connections; thereby reducing cost by effectively reducing energy intake at each node carrying out its routing job.
3. Reducing the route re-selection process caused by botched connections, thereby promoting stability.

The goodness-of-decision created by routing procedures in choosing established routes will be influenced by the accuracy of the link quality approximation. Transfer rates are enhanced by established routes which in turn are enhanced by an increase in the approximation. Hence, accurate link quality estimation is a criteria for effective routing processes that is able to eliminate difficulties caused by untrustworthy connections (Baccour *et al.*, 2009).

A dilemma is evident where a huge quantity of packet samples are needed to accurately approximate a channel in reduced-power wireless, but just some samples should only be utilized because of restricted energy means. This is dilemma is very clear in mobile wireless sensor networks, as the approximation has to be conducted under tight time lines strictly imposed by big differences of the medium (Boano *et al.*, 2010).

To study the issues of the quality of low-power connections, some previous studies were used to conduct broad analysis on them. For instance, in (Cerpa *et al.*, 2003; Zhao and Govindan, 2003; Zuniga and Krishnamachari, 2004; Zuniga and Krishnamachari, 2004; Tang *et al.*, 2007), connection quality measurements have been conducted by detecting the PRR between two nodes positioned at different distances. The target was to study PRR's development.

Connected, transitional, and disconnected are three dissimilar reception areas that have been noted with regards to aforementioned measurements (Cerpa *et al.*, 2003). The nearest to the receiver is the connected area. Steady good reception rates, for example more than 90%, for a large number of the connections reflect this area. In comparison, steadily poor reception rates, which do not surpass 10%, is seen with the disconnected area which is farthermost to the receiver. The "gray area" or the transitional area, which is seen as between the above two areas, mostly has bigger width as compared to the other areas. Reception rates are average in this area, for example between 10% and 90%; and coupled with a great difference, which reflects the presence of unbalanced, medium quality and irregular connections (Woo and Culler, 2003; Zhao and Govindan, 2003). The most essential perspective to evaluate the performance of LQEs is the transitional area, according to Baccour *et al.*, (2011).

Packet Reception Ratio (PRR), also known as PSR (Packet Success Ratio), RSSI (Received Signal Strength Indicator), SNR (Signal to Noise Ratio) and LQI

(Link Quality Indicator) were a set of rudimentary metrics investigated via earlier firsthand analysis to seize low-power link properties (Baccour *et al.*, 2012). The community has put forward some metrics for connection approximation, based on the four rudimentary noticeable values, by taking into account the variance or mean of PRR (Cerpa *et al.*, 2005; Couto *et al.*, 2005), LQI (Polastre *et al.*, 2005; Boano *et al.*, 2009), RSSI (Lin *et al.*, 2006; Srinivasan and Levis, 2006), and to a smaller degree SNR.

There are three significant drawbacks in the aforementioned approaches. For instance, distinguishing the connection quality becomes inaccurate because of the variance and mean being vulnerable to sound brought about by a small number of samples. Functional results can be gained by a rather significant number of analyses through the PRR-based method, and the RSSI- and LQI-based methods are capable of mapping precisely to PRR but only to a certain degree. Secondly, these metrics are mostly studied separately or in pairs rather than depending on the integrated knowledge as each metric provides a different kind of information. In addition, no initiative is done to guess the forthcoming PRR as the PRR and the investigated LQI/RSSI statistics are often computed on a similar set of packets (Boano *et al.*, 2010). Despite their advantages, these metrics are inept at presenting a precise link quality approximation separately because of their drawbacks highlighted above (Baccour, 2012).

Routing protocols are able to reduce and solve low-power link unreliability due to link quality estimation. For example, by evading poor quality connections, the productivity of advance routing protocols will be enhanced by its reliance on link quality approximation. Steady topologies that are unaffected by link quality variations are also determined by topology control processes that rely on link quality estimation (Boano *et al.*, 2010; Zhou, 2010).

1.2.2 Routing Protocol Based on LQE Metrics

Guidelines and parameters that indicate the quality of a route from a source to destination can be divided into two major categories (Baccour *et al.*, 2009; Renner *et al.*, 2011):

1. Hardware metrics: where the information of such metrics can be recovered from the hardware of the node. Cases in point are: RSSI , LQI and SNR (Baccour *et al.*, 2009; Baccour *et al.*, 2012).

2. Software metrics: where a specific condition to abide by is attained through a calculation. Cases in point are: Expected Transmission Count (ETX), RNP (Requested Number of Packets) and 4 bit (Four- bit) (Baccour *et al.*, 2009).

Examples of suggested metrics for WSN routing protocols are the classes highlighted above. Software metrics are at a disadvantage compared to hardware metrics on the basis of calculation difficulty as the information of similar metrics are taken directly from the corresponding hardware node. The accuracy of software metrics enhances as the guidelines are calculated before it can be utilized. But with the presence of movement, WSNs outcomes are not satisfactory with higher calculations (Al-Jemeli *et al.*, 2012).

Scholars have applied those metrics on several occasions and find out the results. some of them based on SNR, such as (Aguero *et al.*, 2009) that showed an innovative quality aware metric, based on link SNR, to boost multi-hop routing. But; it substantiates that its method has outclassed not just the favored antecedent Dynamic Source Routing (DSR), but also the Expected Transmission count (ETX) metric; it possesses imprecise constraint since an assumed bit error rate is caused by SNR, and overall studies prove that SNR cannot be taken as an impartial approximate, rather it can aid in improving the accuracy of PRR approximate.

Moreover, when connections are within the transitional area, they suggested avoiding SNR as a link quality estimation (Baccour *et al.*, 2012).

An integration of different link quality metrics into one value was also researched by learned persons. (Zhou *et al.*, 2009) showed a novel link-quality aware routing metric for multi-hop wireless networks. This routing metric averts comprising very poor connections while at the same takes into account hop count metric and link-quality. The total of the average Smoothed SNR (SSNR) value and the smallest SSNR value in the path determines its choosing of the path. Notwithstanding the fact, compared to hop count metric, it has been shown to give a 12% higher throughput. While lengthier paths take in more energy, it contributes a slight increase in end-to-end delay and a slightly lengthier path.

Furthermore Al-Jemeli *et al.*, (2012) showed a routing metric which is based on the information from the immediate nodes. This information comprises the received signal strength indicator (RSSI) and remaining energy of the immediate nodes; the major drawback of its method is that this method is able to deliver good approximation whether a connection is of excellent quality (connected area) (Baccour *et al.*, 2012); or else (Mottola *et al.*, 2010) stated that the categorization of intermediate links should not be done by RSSI.

Some works have been employed by PRR-based methods while earlier works have explored Mobile Ad-hoc Networks (MANET), in mobile wireless sensor networks. For example Zamalloa *et al.*, (2008) a greatly conducive metric for geographic forwarding in true situations is the discovery of the product of the packet reception rate and the distance enhancement towards destination (PRR x d). They explained that the (PRR x d) metric itself is uncertain to how the packet reception rate is calculated, and also their process may not be conducive; for example, in greatly active situations where link qualities vary quickly ,it isn’t likely to attain constant and usable PRR approximations. But, where a huge group of sensor networks in which the sensors are inert and the situation is generally stable to obtain approximations of PRR, their work is appropriate (Zamalloa *et al.*, 2008).

Lastly in the two analysis Rezayat *et al.*, (2010) and de Araújo and Becker, (2011), the method WMEWMA (Window Mean Exponentially Weighted Moving Average) was utilized. Nevertheless; the accuracy was very poor even though this method was easy and memory effective (Zhou, 2010). Furthermore as one of the strength of the filter based WMEWMA estimator is storing the whole history of the channel in their old values in this static scenarios turns to a weakness in the mobile experiment where the channel changes often quickly, the knowledge of the history is not of much use, this limitation approved by Heinzer, (2011) as the last drawback for this technique Baccour *et al.*, (2009) revealed that WMEWMA is the most optimistic estimator, this mean it tends to over-estimate the link quality. The main reason is that it is not aware of the number of retransmitted packets.

It is clear from earlier analysis that no LQEs can give a fast link quality approximation for higher layer routing layer because of the flaws and setbacks of each metric they possess, while a routing protocol depends on single LQE metric approach or depends on LQE methods that integrate LQE metric with other routing metrics. Hence, this situation motivates this study to decrease the chances of retransmission by focusing on utilizing a suitable link quality estimator to give an accurate approximation to the higher layer. Therefore, better data trustworthiness is achieved and the lifespan of WSNs can be extended.

1.3 Problem Statement

There are many link quality estimation techniques that utilized by routing algorithms in mobile WSN as routing metric, in which most of LQEs based on a single link quality metric, PRR (Cerpa *et al.*, 2005; Couto *et al.*, 2005), LQI (Polastre *et al.*, 2005; Boano *et al.*, 2009), RSSI (Lin *et al.*, 2006; Srinivasan and Levis, 2006), due to the limitations of these metrics individually that they have in estimating link quality (mentioned in sections 1.2.1 and 1.2.2), there is a lack of accuracy. This leads to degrade the performance of the networks in terms of reliability (end-to-end delivery), and energy efficiency because of high packet loss ratio and increased number of retransmissions. So it is required to adopt an accurate LQE technique as routing metric to overcome these problems.

The statement of the problem can be stated as follows:

*“**How to enhance a routing algorithm in mobile wireless sensor networks which uses a combination of LQE parameters in order to extend the WSN lifetime and improve network throughput in term of delivery ratio and loss ratio**?”*

1.4 Objectives

Key objectives of this study are:

1. To investigate existing link quality estimation methods and routing algorithms in wireless sensor networks.
2. To enhance an existing routing algorithm based on link quality estimation in mobile WSNs.
3. To evaluate the results in simulation environment in terms of packet delivery ratio, packet loss ratio and energy efficiency.

1.5 Scopes

This work will consider mobile WSNs with fixed sink, and considers deployment in clear environment (without any obstacles). Additionally as MAC layer this work will use IEEE (Institute of Electrical and Electronics Engineers) 802.15.4 with Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism. Finally; this project will implement in simulation environment by using OMNeT++ for simulating routing protocols.

1.6 Study Aim

The aim of this study is to develop a routing algorithm based on a combination of LQE parameters for mobile wireless sensor network in which the performance of a network will be improve in terms of packet delivery ratio, packet loss ratio which are enhancing the reliability of the network, and energy-efficiency which is usually encourage prolonging the networks lifetime.

1.7 Significance of Study

As the objectives of the study will be achieved, the suitable link quality estimation is able to provide an accurate information about the radio links in mobile WSNs, this is lead to perform transmission over good and reliable links and reduce the possibility of retransmission, additionally as the results will enhance existing routing algorithm to provide better performance and it also improve the lifetime of the network in mobile wireless sensor networks.

1.8 Study Organization

Chapter 2 illustrates some basic backgrounds about Wireless Sensor Networks, Link quality estimation and its impact in WSNs, and it will present investigations regarding to LQE techniques that utilized in WSNs, In the Additionally discuss about previous findings related to LQE techniques and LQE aware-routing protocols.

Chapter 3 discusses on the used methodology and detail of the operational frame work in this study. Chapter 4 presents the implementation requirements and the process of preparing the simulation to achieve the second objective of this study which is enhancement of an existing routing algorithm based on link quality estimation in mobile WSN, the comparison and analyzing of the results of simulation will explain in chapter 5. Finally chapter 6 presents and evaluates all purposes of the project in order that have been included in previous chapters. Furthermore, some future possible works are proposed to improve the network performance.

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