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A PROACTIVE ENERGY AWARENESS TRAFFIC ROUTING FOR WIRELESS SENSOR NETWORKS AGAINST ENERGY SINK-HOLES

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By

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Tree topology-based traffic routing in WSNs imposes a heavy burden on its root nodes which quickly results in energy hole formation and eventually sink isolation and network partitioning, which are undesirable. In the literature, proactive approaches that avoid such a formation, particularly with random node distribution, has not been extensively explored. In this thesis, cooperative communication based on tree topology construction is proposed to address energy and routing decision challenges in WSNs with single and multiple sinks. This is adopted in the proposed balanced energy-hole prevention method in tree topology (EBEHA-T) with a single sink. Next, the problem of large variations in energy consumptions with multiple sinks in merging tree-based multiple energy hole alleviation algorithm (MEHA-MT) is addressed. This is a topology construction-based cooperative routing in which alternate routes are found that avoid data delivery to heavily loaded sinks which subsequently precludes sink isolation and network partitioning. Finally, this thesis proposes a collaborative approach among multiple static sinks to achieve balanced energy among the nodes in the network resulting in improved reliability. Here, a centralized controlled multiple sink-rooted tree coordinates traffic delivery to the sink with respect to a reference energy balance pattern; this is referred to as COMEHA for centralised control-based multiple-energy hole alleviation. OMNeT++ simulator has been used to conduct performance evaluations of the above algorithms. Results show an increase in network energy balance and reduction in average energy consumption for EBEHA-T, in the range of 78% and 51%, respectively, against reactive approaches. For MEHA-MT, energy balance achieved were 46% and 60% of two sinks, compared against multiple topology-based traffic routing cooperation. Finally, COMEHA enhances work efficiency to 0.54 and increases energy balance to 21% compared with conventional schemes.

Overall results show immunization against energy hole formation during transmission, which results in extended lifetime in WSN.

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PENGHALAAN TRAFIK PROAKTIF BERKESEDARAN TENAGA UNTUK RANGKAIAN PENDERIAAN TANPA WAYAR, MENGATASI KELOMPONGAN TENAGA

Oleh

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Fakulti : Kejuruteraan

Penghalaan berasaskan pohon dalam WSN meletakkan beban yang berat kepada nod sinki yang akan dengan cepat menghasilkan pembentukan kelompongan tenaga dan akhirnya pengasingan sinki tersebut dan pembahagian rangkaian, sesuatu yang tidak diingini. Dari sorotan literatur pendekatan proaktif yang mengelakkan pembentukan sedemikian, khususnya dalam taburan nod rawak, belum lagi diterokai dengan meluas. Dalam tesis ini, pendekatan komunikasi bekerjasama berasaskan pembinaan topologi pohon, adalah dicadangkan untuk menangani cabaran tenaga dan keputusan penghalaan dalam WSN dengan satu atau pelbagai sinki. Ini digunapakai dalam kaedah cadangan pengelakan kelompongan tenaga-terimbang dalam topologi pohon (EBEHA-T), dengan sinki tunggal. Seterusnya, masalah variasi penggunaan tenaga yang luas dengan berbilang sinki, dalam algoritma pengurangan kelompongan tenaga berasaskan penggabungan pohon (MEHA-MT) adalah ditangani. Ia adalah penghalaan trafik bekerjasama berasaskan pembinaan topologi yang mana laluan alternatif dicari yang mengelak penghantaran data kepada sinki yang telah dibebankan dengan berat dan menghalang pengasingan sinki serta pembahagian rangkaian. Akhir sekali, tesis ini mencadangkan pendekatan bekerjasama di kalangan sinki statik berbilang untuk mencapai penggunaan tenaga seimbang di kalangan nod-nod dalam rangkaian, menghasilkan kebolehpercayaan yang lebih baik. Di sini, suatu kawalan berpusat pohon bertunjangkan-akar berbilang mengkoordinasi penghantaran trafik kepada sinki merujuk kepada corak keseimbangan tenaga rujukan. Simulator OMNet++ telah digunakan untuk menjalanai penilaian prestasi kepada algoritma di atas. Hasil-keputusan menunjukkan peningkatan keseimbangan tenaga rangkaian dan pengurangan dalam penggunaan tenaga purata untuk EBEHA-T, dalam renj 78% dan 51%, masing-masing, berbanding dengan pendekatan reaktif. Untuk

MEHA-MT, keseimbangan tenaga yang dicapai adalah 46% dan 60% kepada dua sinki, berbanding dengan skim-skim kerjasama penghalaan trafik berasaskan berbilang topologi. Akhir sekali, COMEHA meningkatkan keberkesanan kerja kepada 0.54 dan menambah keseimbangan tenaga kepada 21% berbanding dengan skim-skim lazim. Hasil-keputusan keseluruhan menunjukkan imunisasi ke atas pembentukan kelompongan sinki tenaga yang menatijahkan pelanjutan jangkahayat dalam WSN.

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Declaration by graduate student

I hereby confirm that:

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CH	Cluster Heads
CS	Case Study
DN	Deputy Nodes
FND	first node death
HC	Hop count of nodes
ID	Identification
MAC	Medium access control
QoS	Quality of service
RN	Relaying node
SHC	Short hop count
WSN	wireless sensor network

LIST OF SYMBOLS

BF_i	Broadcasted beacons
d	Distance
d_{th}	Tree depth
$E_{AvergTree}$	Average enrgy consumption by tree
E_{amp}	Energy of amplification
E_{elec}	Energy of electrical circuit of sensor
$E_{RN\ (consmed)}$	Consumed Energy of relaying node
$E_{RN(init)}$	Initial energy of sensor node
$E_{RN(res)}$	Residual energy of sensor node
$E_{Tt_{bri}}$	Energy consumed by a branch of tree topology
$E_{RNTotConsu}$	Total consumed energy by relaying nodes
$E_{\zeta-ConsRx}$	Energy consumed by joint node while packets are received
L	Number of bits in a packet
M	Entire number of sensor nodes
m	Multiple packets streams received by sensor node
n	Number of sensor node in tree branch
N	Number of sensor node in entire tree
N_{T_i}	Source node local information
$P(\zeta)$	Probability of joint node
Q	Proactive-energy routing metric
$\hat{Q}$	Hole energy status
Q_{Best}	Best of compared values
R_x	Receiving process

R	Shared nodes in R zone
R1	Data interval
S	Sink node number
$STDev_{cur}$	Current standard deviation
$STDev_{Thre}$	standard deviation threshold
$STDev_{CRT}$	Critical value standard deviation
T_i	tree topology
t_{bri}	tree topology b ranch
T_x	Transmission process
ζ	Zeta node

CHAPTER 1

INTRODUCTION

1.1 Sensors and network

A sensor is a tiny device that is reliant on a finite and non-renewable power source, which is distributed all over the area of interest based on ad-hoc communication to form a wireless sensor network (WSN). A typical topology construction of the WSN follows type hierarchical, flat, and tree topology. In practice, there are three stages in WSN implementation. First, sensors are deployed to fulfil various application and networking requirements. Next, data such as commands, monitored information, and events are disseminated to the back end via a wide area network or the Internet. Lastly, sensed data are delivered from each sensor node to the sink node which acts as the gateway to the server in the back end.

WSN has been used in many real life applications; some examples of which are in security and military surveillance, collection of environmental data from forests or other habitations, healthcare monitoring records of patients, inventory management in factory settings, hazardous chemical detection in rivers and other natural water body, pipeline monitoring, a log of a smart building control system, smart cities application, vehicle control management, and host of other applications [1][2]. The demand for excellent performance has become a necessity; however, the constraints in WSNs have resulted in numerous difficulties regarding energy resources, memory, and computational capability [3]. Apart from efficient energy implementation, researchers have been motivated to consider a variety of interesting issues, such as optimization of connectivity, scalability, data transmission, network structure, security, and data aggregation. Although no continuous power supplies for battery-powered sensors are implemented in the field of interest, the lifetime of these sensor nodes is inversely proportional to the energy consumption as well as unfair implementation. Therefore, maintaining the energy consumption of most vulnerable sensor nodes to the lowest level is a key solution to extending the life time of WSN. Such solutions that consider energy constraint are classified based on the protocol stack of WSN, such as application layer, network layer, MAC layer, and physical layer [4].

1.2 WSN challenges

Generally, replacing or recharging the battery is inconvenient or impossible because these devices are mostly deployed in harsh environments. Thus, efficient energy implementation is one of the primary WSN challenges [5]. Nodes that spend excessive energy in performing a repetitive task will rapidly lose their energy and die soon after. Thus, the inefficiency of energy consumption among sensor nodes is due to relatively high and unfair energy dissipation in a few zones or in particular nodes. Routing protocols influence the energy consumption because most energy exhaustion is attributed to data communications, passing data from one node to the other in the downstream. A few of the challenges encountered by routing protocols in WSN include the dynamic nature of WSN topology due to battery outage and node failures. This situation leads to a necessity to implement efficient and updated routing mechanism that saves and balances the energy consumption.

1.2.1 Energy hole and sink isolation

A routing hole is a region in the sensor network where available nodes are incapable to participate in data routing due to their energy exhaustion. In this thesis, the battery exhaustion of sensor nodes that surrounds the sink node or base station is addressed because these nodes deplete their energy relatively faster than distant nodes with elapsed time. Consequently, either the sink node or part of the network is disconnected.

Experimental results conducted by some researchers show that 90% of the distant nodes are still available by the time the sensor nodes that surround the sink node die [6][7]. Even sparsely deployed sensor nodes that generate data at low data rates potentially create transient hole anywhere in the sensor node field, but more likely farther from the sources and near the sink. Another type of hole undergoes a few circumstances where sensor nodes that detect events will create a persistent energy hole extremely close to the sources [8]. However, the rapid energy depletion around the sink node results in sink isolation as well as network partitioning. Consequently, the sensor network loses its capability to complete data delivery to the sink regardless of whether or not there are sufficient residual energy at distant zones [9][10]. Thus, through a balanced-energy consumption specifically at zones characterized by unfair energy wasting, the resilience of routing protocols against sink holes is of vital importance. Therefore, energy consumption managing specifically at zones surrounding a sink is necessary to balance their energy consumption regardless of which topology is implemented.

The length of time a WSN survive with consistent data delivery, also known as network lifetime, is a vital issue in network performance assessment. The network lifetime has a number of definitions and is assessed by different ways, such as the time when the energy of the first node dies, when the network is partitioned, and when packet delivery rate falls below a certain threshold [3][11][12]. Hence, dramatic energy dissipation cause data delivery disruption, which consequently results in a short network lifetime [13].

1.2.2 Energy hole remedy

Circumventing or delaying the formation of energy sink-hole through efficient energy implementation is necessary to protect the sink from isolation and prolong the network lifetime [14][15]. The surrounding nodes of the sink are likely to die first compared to other distant nodes because sensor nodes are prone to drastic energy consumption as they get close to the sink node. Moreover, the functioning span is short according to the most common measure of network lifetime. Also, conventional routing protocols of WSN are susceptible to poor performance, especially under sophisticated practical assumption, such as random node distribution and various traffic density which is defined as the ratio of the number of packets to the time difference of interconnected subtrees. Thus, this gives rise to the need for cooperative efforts among nodes to achieve energy-efficient traffic routing that enhances performance in the present network.

1.3 Problem statements and motivation

During WSN network operation, network lifetime has a vital correlation with the implemented traffic routing mechanism and the drawbacks of many-to-one long-distance communications. In [1] and [16] it was argued that tree-based topology has better energy saving performance, thus adopting many-to-one tree-based topology is promising in WSN. For obtaining energy-efficient routing protocols based on tree topology construction, the following paragraphs highlight the most critical factors:

1. In [1] it was reported that sensor nodes might be cluttered because of the monitoring requirements hence they concentrate in areas where traffic frequently occurs, whereas [7] claimed that the traffic load generated at a particular area could be irrelevant to node distribution and hence linear relationship is not guaranteed. The studies in [17], [18], [19] and [20] for relaying nodes, such as maximum residual energy, maximum load, buffer, least hop count and optimum distance. However, [21] and [22] argued that the certainty of the shortest distance, as well as the high residual energy-based next-node selection decision, does not necessarily guarantee efficient energy performance, particularly for mitigating energy hole problem in WSNs with a single sink. Thus, the issue that needs to be studied is to identify the critical factors to establish relay node candidate set that proactively encourages energy balance that can preclude energy hole formation.
2. For a fully cooperative multi-dimensional tree in WSNs with multiple sinks, each sensor node is identified in all sinks, and each sink is overloaded by data traffic of multi-dimensional trees as discussed in [20],[23],[24]. In such cases, sensor nodes suffer from additional overhead control messages and redundant data transmissions,

thereby resulting in extra energy dissipation specifically around the sink node. For fully independent subnetworks as presented in [25], [26], [27],[28], each sensor node is identified to a specific sink-rooted tree, and each tree is independent and completely unaware of the performance of the remaining parts of the network. The traffic needs to be directed to the most appropriate sink that avoids relatively overloaded sink node, enhances energy balance in the energy zone, and prolonging network life span. Therefore, this gives rise to the need for a topology construction based cooperative routing that overcomes the disadvantages of constructing fully independent tree topologies-based traffic routing in WSN with multiple sinks that causes a lack of energy awareness among multiple sinks

3. Multiple-sink implementation optimisation in WSN has been studied from different perspectives, such as optimal placement and finding sufficient number of necessary sinks [29][30][31]. However, there is a lack of studies on the subject of multiple sinks that cooperatively organize traffic delivery for the purpose of balancing the energy at multiple energy hole zones

1.4 Aims and objectives

This thesis proposes mechanisms that enhance the performance of energy consumption to preclude sink nodes from isolation and network partitioning, thereby extending the network lifespan. Thus, the objectives of this thesis are as follows:

1. To propose an energy aware routing algorithm that proactively balances energy consumption in the most highly energy exhausted zones to avoid energy hole formation in a tree topology with a single sink.
2. To propose a topology construction based cooperative traffic routing in WSNs with multiple sinks to preclude delivery to relatively traffic overloaded sinks and thereby achieving balanced energy dissipation, hence avoiding sink node from getting isolated and network from being partitioned.
3. To develop the implementation of multiple sinks to coordinate traffic delivery across the network for optimum energy consumption balance, thus improving traffic delivery reliability, and prolonging network lifetime.

1.5 Scope of the research

The main focus of this thesis is on developing data traffic routing mechanisms that protect WSNs from energy hole formation that disrupts traffic delivery to the sink. Therefore, the thesis focuses on energy awareness strategies, robust routing decisions, and appropriate tree topology construction in WSNs; in other words, it focuses on developing a framework that provides countermeasures that manage diversity in energy dissipation in the sensor nodes, to avoid energy hole formation.

1.6 Research contributions

The main contributions of this thesis can be summarized as follows;

1. A routing algorithm that makes its routing decisions based on the awareness of the diversity in energy variations around energy hole zones instead of merely reacting to some signs indicating detection of energy hole formation in WSN with a single sink. It proactively manages traffic delivery to the sink node amongst the many nodes in the energy hole zones to achieve balanced energy consumption among sensor nodes .a hole in
2. A multidimensional topology design in WSN that overlaps multiple sinks to enhance energy awareness by source node for large variations in energy consumption. This design incorporates a cooperative traffic routing scheme among multiple trees via judicious decisions of taking alternate traffic routes to healthy paths and avoids delivery to overloaded sinks, protecting the sink nodes from isolation and improving energy consumption balance across multiple sinks.
3. A multiple-sink collaboration algorithm that coordinates the amount of traffic delivery in WSN with multiple sinks by way of a centralised-control mechanism. It coordinates the amount of traffic delivery to the sink nodes with respect to the reference energy balance pattern in the hole zones, to achieve optimum energy consumption balance, and hence an extended lifetime.

1.7 Thesis outlines

The rest of the thesis is organized as follows. Chapter 2 highlights the importance of energy efficiency and provides the background of different energy consumption balance approaches and tactics to mitigate energy hole formation in WSNs with single and multiple sinks. Chapter 3 describes the methodology used in this thesis. It provides the details of the new design of proactive-energy routing metric that the routing decision is laid on for healthy traffic routing. The chapter concludes with the results and the observations of several experiments with simulation to validate the proposed scheme in term of energy consumption balance against sink isolation. Chapter 4 describes an efficient implementation of WSNs with multiple sinks where a new topology construction approach enhances traffic routing to protect the overloaded sink hole's sensor nodes from fast energy depletion. This chapter presents the performance evaluation compared against the benchmarks. Chapter 5 presents a cooperative method of achieving optimum energy balance at hotspot zones across the entire WSN with multiple sinks. The chapter concludes with the results of the performance evaluation. Finally, Chapter 6 concludes the thesis with the description of the features and capabilities of the proposed methodologies and presents directions for future works.

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LIST OF PUBLICATIONS

M. S. A. Mustafa, B. M. Ali, S. J. B. Hashim, and M. F. B. A. Rasid, "Work in Progress: Proactive Immunization Against Multiple Sink Holes in WSN to Extend its Life Span," *Adv. Sci. Lett.*, vol. 24, no. 3, pp. 1852–1856, 2018.

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