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A CLUSTERING APPROACH TO ADAPTIVELY IMPROVE ENERGY EFFICIENCY AND LOAD BALANCING IN WSNs

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By

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DEDICATION

To soul of my mother and my father.

To my sister, and my family

ABSTRACT

Clustering has been widely used in Wireless Sensor Networks (WSN) to solve problems associated with large nodes and effectively conserve energy, while load balancing has equally been used to effectively optimize network resources such as bandwidth.

In this research, we propose a routing protocol, the Hierarchical Energy-Balancing Multipath routing protocol (HEBM) for Wireless Sensor Networks, which combines load balancing and clustering to significantly improve WSN services, e.g. information routing. In our approach, load traffic is shared amongst nodes in the same cluster with the aim of minimizing dropping probability resulting from queue overflow at some nodes.

The benefits of our proposed work include: attain an improved balanced in cluster size which could guarantee minimal energy dissipation in the entire network, balancing the energy dissipation among the sensor nodes, which in turn extends the lifetime of the network. The cluster heads are optimally selected and properly distributed over the entire network thus allowing member nodes to reach them without expending much energy, while adequately balancing the load. Additionally, member nodes are turned off periodically based on set sleeping control rules in order to optimize their energy consumption.

The methodology to be used for this work is simulation on NS2 discrete event simulator. We intend to use two scenarios in our simulations. In the first scenario, 100 nodes are uniformly and randomly distributed in a 200 square

meters area. To study the effect of scale on the performance of HEBM, 200 nodes are uniformly and randomly dispersed in a field of size 200 square meters in the second scenario. In both instances, we assume that the BS is at the center of the field. Performance metrics include: Energy consumption, Network lifetime, latency, and residual energy.

ABSTRAK

Pengklusteran telah digunakan secara meluas dalam Rangkaian Sensor Tanpa Wayar (WSN) untuk menyelesaikan masalah yang berkaitan dengan nod besar dan menjimatkan tenaga secara berkesan, manakala pengimbangan beban turut digunakan untuk mengoptimumkan sumber rangkaian seperti berkesan jalur lebar.

Dalam penyelidikan ini, kami mencadangkan satu protokol penghalaan, iaitu Protokol penghalaan Multipath Rantaian Hierarki (HEBM) untuk Rangkaian Sensor Tanpa Wayar, yang menggabungkan pengimbangan beban dan pengklustersan untuk meningkatkan perkhidmatan WSN dengan ketara, misalnya penghalaan maklumat. Dalam pendekatan kami, beban lalu lintas dikongsi di antara nod dalam kluster yang sama dengan tujuan meminimumkan kebarangkalian menjatuhkan paket hasil daripada limpahan aturan di sesetengah nod.

Manfaat kerja yang dicadangkan kami termasuk: mencapai peningkatan seimbang dalam saiz kluster yang dapat menjamin pelesapan tenaga minimum di seluruh rangkaian, menyeimbangkan pelesapan tenaga di antara nod sensor, yang seterusnya memanjangkan jangka hayat rangkaian. Kepala kluster dipilih secara optimum dan diedarkan dengan betul ke seluruh rangkaian, dengan itu membolehkan capaian dari nod anggota tanpa menghabiskan banyak tenaga, sambil mengimbangi beban secukupnya. Selain itu, nod anggota dimatikan secara berkala berdasarkan peraturan kawalan tidur yang ditetapkan untuk mengoptimumkan penggunaan tenaga mereka.

Metodologi yang digunakan untuk kerja ini adalah simulasi pada simulator peristiwa diskret NS2. Kami berhasrat untuk menggunakan dua senario dalam simulasi kami. Dalam senario pertama, 100 nod diedarkan secara seragam dan sekata di dalam kawasan seluas 200 meter persegi. Untuk mengkaji kesan skala pada prestasi HEBM, 200 nod diedarkan secara seragam dan sekata di dalam kawasan seluas 200 meter persegi bagi senario kedua. Dalam kedua-dua keadaan, kami mengandaikan bahawa BS berada di tengah-tengah lapangan. Metrik prestasi termasuk: Penggunaan tenaga, Hayat rangkaian, kependaman, dan tenaga sisa.

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APPROVAL

This thesis report is submitted to the Department of Communication Technology and Network, Faculty of Computer Science and Information Technology, Universiti Putra Malaysia, and has been accepted as partial fulfillment of the requirements for the Master's Degree of Computer Science/ Distributed Computing.

The members of the Examination Committee are as follows:

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Universiti Putra Malaysia

DECLARATION

I hereby declare that this thesis, submitted to the Department of Communication Technology and Network as a fulfillment of the requirements for the master's degree in Computer Science has not been previously, and is not concurrently, submitted for any other degree at university Putra Malaysia and other universities. I also certify that the work described here is entirely my own except for citations, which have been duly acknowledged.

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Date: / 2019

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CHAPTER 1

INTRODUCTION

1.1. Wireless Sensor Networks

Recent advances in technology encourage the wide deployment of Wireless Sensor Networks (WSNs). WSNs have been first considered for military applications where battlefields information is gathered at sensor nodes, collected via wireless links, and interpreted at a Base Station (BS). With the development of low-cost and smaller sensor nodes, WSNs have been recently considered for various civilian applications. Thus, more interest is directed towards improving different aspects of WSNs to provide better services for the public [1]. One of the most important aspects in WSNs is the routing techniques that are used to relay data among the nodes in a WSN. Routing has a major effect on the performance and efficiency of WSNs. Energy efficiency is one of the main challenges in developing routing techniques since sensor nodes have limited amount of energy. A popular technique in saving energy and extending network lifetime is clustering, which has the advantage of being able to configure the network based on the nodes energy requirements.

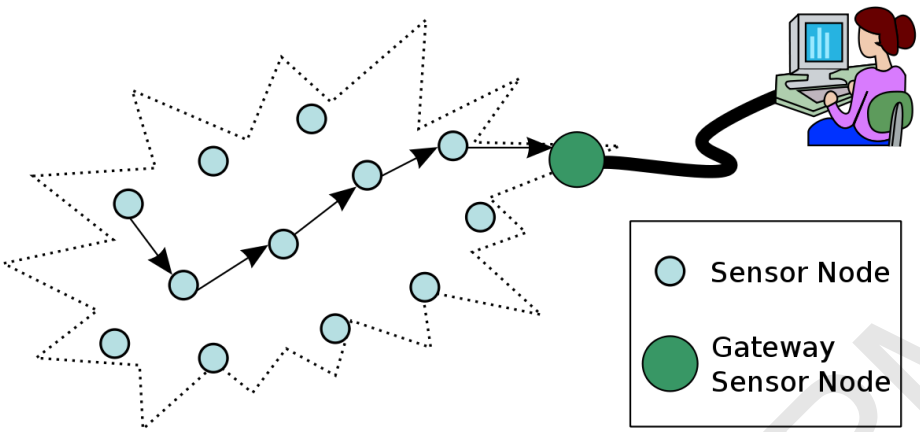

Figure 1.1: A WSN and system components of a sensor node

1.1.1. Home Applications

The demand for smart homes has increased with the need of enhancing life quality at homes and their surrounding area. A smart home is equipped with smart objects that interact with each other as part of a home network. The home network is connected to the outside world through a gateway that processes the collected data from the smart objects [4]. Since the scale of such networks is not large, there is less concern about scalability issues in these networks.

The smart objects deployed at a home and its surrounding area are associated with smart sensors. The sensors, for instance, can be used to measure temperature, Carbon IV Oxide (CO_2) level, water level, humidity or light as well as motion detectors or smoke detectors [4]. In order to establish a home network, a WSN, which consists of a number of sensor nodes and a BS as a gateway, can be used. The most important types of smart home applications can be classified into safety and security, monitoring and healthcare.

1.1.1.1. Safety and Security

A WSN is capable of providing the technology to improve home safety. This can be done through home monitoring and alarm systems which are deployed at homes and their surrounding area. It can provide information about different dangerous situations, such as gas leakage, thief intrusion, water leakage and the presence of fire [5] [6].

Traditional fire detection system has many problems. It uses cables and wires that can be easily damaged when a fire occurs, and hence leads to signal failure. Moreover, wired systems have maintenance problems and require long construction period. Therefore, wireless fire alarm systems can be employed using a WSN, since it provides reliability and stability [6] [7]. An example of a WSN used to provide a fire detection system at homes is shown in Fig. 1.2. Here, sensors are used to detect smoke and CO gas concentration as well as to measure temperature.

The information from the sensors is forwarded towards the BS for data processing [7]. If a fire is suspected, either an alarm is turned on or a message is sent to the owner on his mobile phone. Similar process can be applied to gas leakage, thief intrusion and water leakage.

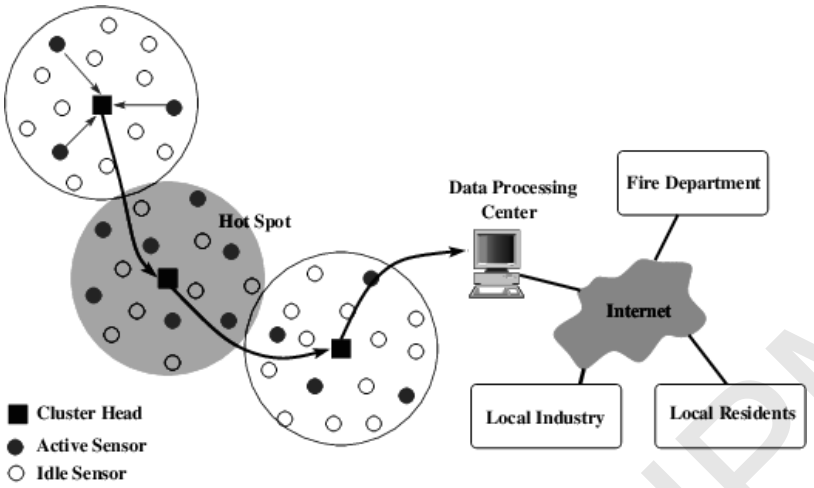

Figure 1.2: An example of fire detection using WSN [Mohamed Hefeeda]

1.1.1.2. Monitoring

The high amount of energy consumed by home appliances contributes to the negative impact on the environment. Therefore, more effort is focused on energy management at homes in order to reduce the consumption especially during peak hours. By using WSN, the amount of energy consumed by each appliance can be monitored over time and suitable actions can thus be determined.

From the collected data, an energy management system can be set according to the owner's habits. Moreover, the monitored data of energy consumption can be delivered to the energy utility to improve the efficiency of energy generation [4] [8].

In addition, the conditions of a small-scale farm associated with a home can be monitored to improve production efficiency and quality of products [9]. By monitoring crops and their requirements, farmers can identify the right amount of water, fertilizer and pesticide to

enhance yield standard. Climate and soil sensors can be used to prevent damages to crops and enhance production [9] [10]. An example of a WSN used to monitor a farm associated with a home is shown in Fig. 1.3. Data collected from the different sensors is delivered to the BS (associated with a personal computer) located inside the home of the farmer [9]. By monitoring the farm conditions, the farmer can adopt the appropriate measures that suit the requirements of the crops.

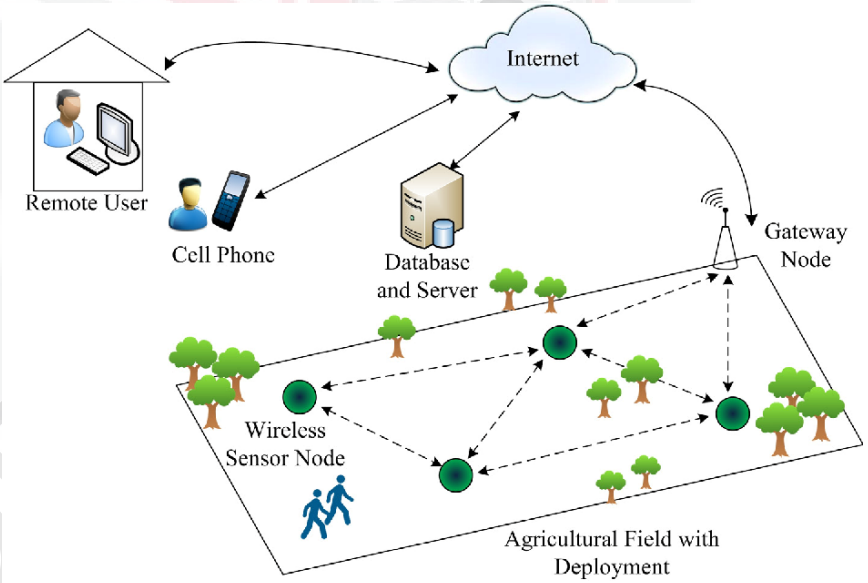

Figure 1.3: An example of a WSN monitoring a farm associated with a home [WSN applications in Agriculture]

1.1.1.3. Healthcare

WSNs have many applications related to health care. In some circumstances, deploying a home care system would be essential for living at home, especially for elderly people. Monitoring their daily activities provide information about their well-being. This can help to determine if an elderly person is at risk or if an accident has occurred. For example, appropriate sensors can indicate if the elderly person has fallen or if he is having trouble in his sleeping. An example of a home care system is shown in Fig. 1.4. These systems are preferred by customers since there is no privacy invasion caused by the usage of cameras [11].

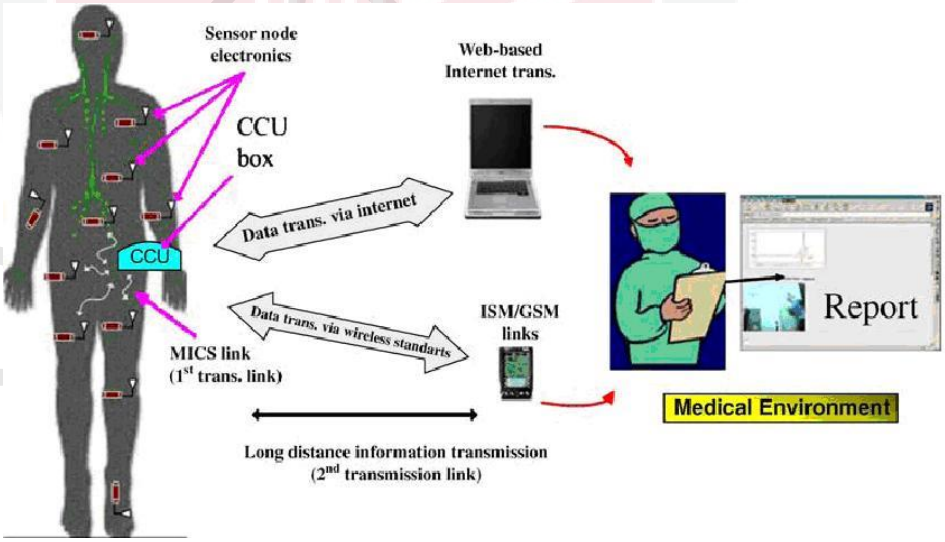

Figure 1.4: An example of a home care system [Raj Jain: Medical Applications of Wireless Networks]

1.2. Routing in WSN

In a WSN, the distances between sensor nodes and the BS can be largely different. This implies that data from a sensor node may need to traverse multiple hops to reach the BS and therefore, routing protocols are required. A routing protocol defines and determines the methods for relaying data from sensor nodes to the BS based on different requirements. Below we briefly present some of the routing challenges:

- **Energy Consumption:** Nodes have limited amount of energy and it is nearly impossible to replace their batteries in a short period of time especially in areas that cannot be easily accessed. Hence, energy efficiency is of great importance for WSNs and research has been carried out to achieve energy-efficient routing [2] [3].
- **Scalability:** The number of sensor nodes employed in a network can be very large. As a result, the routing algorithm should be able to accommodate such large number of nodes without degrading the network performance [3].
- **Transmission Media:** Since the nodes are linked wirelessly, there are wireless-associated issues such as fading and high error rate. These issues might affect the performance of the network [3].

1.3. Problem Statement

At the advent of WSN, its advantages over macro sensors were a major breakthrough in terms of increased range of sensing, better accuracy and fault tolerance. However, with increased number of nodes, major challenges have arisen in the areas of energy efficiency and management since the end devices are battery-powered and they cannot be recharged or replaced [6].

1.4. Research Objective

The main objective of this research is to attain an improved balanced in cluster size which could guarantee minimal energy dissipation in the network by proposing an adaptive clustering protocol with energy efficiency that is capable of collecting data by means of intra-inter cluster multi-hop communication. This will lead to the attainment of an improved balance in cluster size which can guarantee minimal energy dissipation in the network [7]. The resultant effect will be increased network lifetime as well as an efficient hierarchical WSN clustering scheme.

1.5. Research Scope

The scope of this work is limited to a homogeneous WSN, where all nodes are arbitrarily dispersed within a square area. It is also assumed that all the nodes have enough energy to communicate with the sink as well as have different levels of power for effective communications.

Also, only stationary nodes are considered, and the sink is located at the center of the area of interest. Nodes are in clusters and can communicate with their neighbors using a communication distance of one-hop.

1.6. Motivation for the Research

Clustering has been used to effectively coordinate WSNs with huge number of nodes and achieve energy efficiency, while load balancing has been effectively deployed to optimize network resources such as channel bandwidth. With the proliferation of WSN sue to its numerous benefits in environmental monitoring, the researchers are motivated to combine these two approaches to help solve some challenges in WSN. These challenges include: coverage, information routing, and energy consumption.

Clustering is one of the important routing techniques that are able to re-configure the network based on the desired requirements. By configuring the network, all the communications and routing paths are specified among all the nodes and the BS. In clustering, the network is divided into clusters, each of which has one Cluster Head (CH) that is responsible for its Cluster Members (CMs). A CH collects information from its members, aggregates and forwards such information to the BS. Clustering is an energy efficient routing technique that can extend network lifetime [12] [13] and it will be discussed in details in Chapter 2. The beneficial characteristics of clustering motivated us to focus the research in this thesis on clustering and cluster-based routing protocols.

In order to design a cluster-based algorithm, there are three main aspects that need to be considered, namely, CH selection, cluster forming and cluster communications. These different processes should produce a network configuration that delivers data to the BS in an efficient manner. As mentioned above, reducing the network's energy dissipation is the primary concern.

Besides, fast energy depletions in some nodes might cause network partitions and shorten the lifespan of the network. Through our review of the existing cluster-based algorithms, we observed a number of issues that motivated us to do the research and address them in this thesis. These issues are mainly concerned with balancing load and energy consumption among nodes in a WSN. Selecting CHs is one of the critical decisions in configuring clustered-networks since CHs have more responsibilities and functions than CMs. To form clusters, one of the main concerns is how to balance the load generated by CMs among the different CHs. Delivering data from CHs to the BS need to take into consideration energy efficiency and load balancing. Configuring networks requires signaling messages which may increase overhead and energy consumption, which is another concern that needs to be considered.

1.7. Contributions

To overcome the issues observed in the existing cluster-based protocols, this thesis contributes to the area of routing in WSNs by designing and implementing an Energy-efficient and dynamic Load

Cluster-based (ELC) routing algorithm. The key contributions of this algorithm are summarized as follows:

- It introduces a new method to determine the neighbors of each node in the network to be used in the selection of CH.
- Load among the CHs is balanced by introducing the members of the same CH as one of the parameters in cluster forming.
- It incorporates multi-hop routing paths into the process of forwarding data from CHs to the BS to balance load and energy consumption among CHs.
- It allows only the nodes with significant changes in their status information to send updates to the BS to be used in network configuration, as opposed to all the nodes updating the BS.
- It employs only Carrier Sense Multiple Access (CSMA) in data transmission, with no Time Division Multiple Access (TDMA) or Code Division Multiple Access (CDMA).

The rest of this thesis is organized as follows. Chapter 2 presents a literature review of clustering and describes the first cluster-based routing protocol as well as the recently proposed protocols. It discusses the issues in these protocols that this thesis is exploring. Chapter 3 discusses the methodology used in this research work as well as analysis of the proposed algorithms. In Chapter 4, the results and performance evaluation are discussed in details, while Chapter 5 presents conclusion and direction for future work in this aspect.

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