INVESTIGATION ON RELAY NODE PLACEMENT IN WIRELESS SENSOR NETWORK FOR 5G MANUFACTURING INDUSTRY

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DECLARATION

I declare that this thesis entitled "INVESTIGATION ON RELAY NODE PLACEMENT IN WIRELESS SENSOR NETWORK FOR 5G MANUFACTURING INDUSTRY" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Name : ....

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APPROVAL

I hereby declare that I have checked this report entitled "INVESTIGATION ON RELAY NODE PLACEMENT IN WIRELESS SENSOR NETWORK FOR 5G MANUFACTURING INDUSTRY" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my parents, the backbone of my life, Safiee and Robiah.

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ABSTRACT

The wireless sensor network has been increasingly studied as an effective means of achieving smart manufacturing in the industrial world. Various types of sensors with varying communication speeds and radii can be used in the manufacturing sector, resulting in a heterogeneous wireless sensor network. However, there are certain unforeseeable incidents that may trigger wireless devices to malfunction. Factors such as battery exhaustion or harsh environmental conditions can result in node failure of the sensor. For this purpose, the architecture of a wireless sensor network must take into account the feasibility and energy consumption of a longer existence. A temporary lack of contact can result in substantial costs. As a consequence, fault tolerance in the wireless sensor network has been a critical concern for the reliability of the wireless sensor network. One approach to achieve fault tolerance in the wireless sensor network is to deploy a limited number of additional relay nodes to establish paths for each pair of operating devices so that the network can survive failure. As the heterogeneous wireless sensor network is commonly utilised in the manufacturing sector, this design has two types of paths – one-way and two-way. In this project, we will concentrate on achieving partial fault tolerance in the heterogeneous wireless sensor network using the relay node location process. The purpose of this project is to examine and evaluate the effective location of the relay node using the approximation algorithm method, and then the effects of the simulation will be evaluated using the heuristic implementation approach. As a preliminary results, the predicted behaviours of the listed algorithms are far better than the findings according to the output ratio, suggesting that these algorithms operate well in actual sensor networking deployments where the target nodes are usually densely deployed.

ABSTRAK

Rangkaian sensor tanpa wayar telah dikaji sebagai kaedah berkesan untuk mencapai pembuatan pintar di dunia industri. Berbagai jenis sensor dengan kecepatan komunikasi dan radius yang bervariasi dapat digunakan di sektor pembuatan, menghasilkan jaringan sensor tanpa wayar yang heterogen. Walau bagaimanapun, terdapat beberapa kejadian yang tidak dijangka yang boleh menyebabkan kerosakan pada peranti tanpa wayar. Faktor seperti kehabisan bateri atau keadaan persekitaran yang teruk boleh mengakibatkan kegagalan sensor pada nod. Untuk tujuan ini, rangkaian sensor tanpa wayar mesti mengambil kira kemungkinan dan penggunaan tenaga yang lebih lama adalah satu keperluan dalam dunia industri. Kekurangan hubungan sementara boleh mengakibatkan kos yang besar. Akibatnya, toleransi kesalahan dalam rangkaian sensor tanpa wayar telah menjadi perhatian penting terhadap kebolehpercayaan rangkaian sensor tanpa wayar. Salah satu pendekatan untuk mencapai toleransi kesalahan dalam rangkaian sensor tanpa wayar adalah menggunakan sejumlah nod relai tambahan untuk menetapkan jalur bagi setiap pasangan peranti operasi sehingga rangkaian dapat bertahan dari kegagalan. Oleh kerana rangkaian sensor tanpa wayar heterogen biasanya digunakan dalam sektor pembuatan, reka bentuk ini mempunyai dua jenis jalur - satu arah dan dua arah. Dalam projek ini, kami akan berfokus untuk mencapai toleransi kesalahan separa dalam rangkaian sensor tanpa wayar heterogen menggunakan proses lokasi nod relay. Tujuan projek ini adalah untuk mengkaji dan menilai lokasi efektif nod relai menggunakan kaedah algoritma penghampiran (*approximation algorithms*), dan kemudian kesan simulasi akan dinilai menggunakan pendekatan pelaksanaan heuristik. Sebagai hasil awal, tingkah laku yang diramalkan dari algoritma yang disenaraikan jauh lebih baik daripada penemuan mengikut nisbah output, menunjukkan bahawa algoritma ini beroperasi dengan baik dalam penyebaran rangkaian sensor sebenar di mana nod sasaran biasanya digunakan dengan padat.

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LIST OF SYMBOLS AND ABBREVIATIONS

2G	-	Second Generation
3G	-	Third Generation
4G	-	Forth Generation
5G	-	Fifth Generation
IoT	-	Internet of Things
AR	-	Argumented Reality
AI	-	Artificial Intelligence
SNs	-	Sensor Nodes
RNs	-	Relay Nodes
CHs	-	Cluster Heads
BS	-	Base Station
RNP	-	Relay Node Placement
PFRP	-	Partial Fault Tolerance Relay Node Placement
FFRP	-	Full Fault Tolerance Relay Node Placement
CFA	-	Connectivity First Algorithm
WFA	-	Weight First Algorithm
MKCSG	-	Minimum *k*-Connected Spanning Graph
HWSN	-	Heterogeneous Wireless Sensor Network

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In this chapter, the motivation, problem statement, objective and scope of this project will be discussed which it helps to give an insight about the project.

1.2 Motivation

Manufacturing industry is going through progressive changes and is now moving forward to smart manufacturing which has attracted much attention [1]. The manufacturing sector has progressively changed from conventional manufacturing systems to smart manufacturing, in which wireless connection and sensors are commonly used, in line with the transition to Industry Revolution 4.0. [2] Smart manufacturing is a large manufacturing category that uses computer-integrated manufacturing, high degrees of adaptability and frequent shifts in architecture, modern information processing, and more agile preparation for technical manpower. Massive amounts of data have been produced during the production process, along with the permeation and applications of advanced manufacturing technology [2]. Therefore, the current 3G and 4G mobile network are not feasible due to demands on higher data rate, reliability, coverage and lower latency for development and implementation of future smart manufacturing industry.

More than a few decades have passed since first-generation, voice-only device mobile wireless communication was initiated. The world has undergo a gradual yet steady transition in wireless communication networks which allow users to experience three important eras – 2G voice digitizing, 3G multimedia and 4G wireless broadband [2], [3]. By 2020, it is expected more than 50 billion devices will connect to the internet, according to Cisco IBSG’s report [4]. With increasing number of smart devices user, demand for higher data rates has steadily risen to satisfy the consumer's need for a faster, safer and smarter network which ultimately contribute to the driving forces towards 5G wireless communication network [5]. The industry expects that more spectrum resources are needed to be allocated to the fifth generation (5G) wireless communications network to accommodate more consumers at higher data rates and the new spectrum needs to be more effectively used. 5G wireless network is envisioned as the foundation to ensure steady connectivity which has a huge potential to benefit the smart manufacturing industry and it embraces various devices and applications such as the Internet of Things (IoT), augmented reality (AR), artificial intelligence (AI) and smart automation that are widely used in smart manufacturing industry

Wireless sensor network has been studied progressively as an efficient way of achieving smart manufacturing in the industrial world [2]. The wireless sensor network consists of various low-cost and low-power sensor nodes (SN) that are using wireless links in order to perform designated sensing operations and gathering information before it is send to at least one sink of the network. *Heterogeneous* wireless sensor networks consist of several wireless sensors equipped with various communication and computing capabilities. Unlike *homogenous* wireless sensor networks, all devices are having the same communication and computing capabilities [6]. In manufacturing industry, there will be various types of sensors with different transmission rate and radii will be used, which resulting to have a heterogeneous wireless sensor network. In heterogeneous wireless sensor network, the transmission radius is similar to the relay nodes being deployed while sensor nodes may use different transmission radii which it introduces asymmetric communication links between nodes [6]. Loaded with numerous functionalities, heterogeneous wireless sensor collaborate from a flexible multi-purpose sensor network and enable several sensing activities, including oceanographic data collection, emissions monitoring, offshore exploration and tactical monitoring [6].

However, there are some unpredictable events may cause wireless devices fail to operate and disrupt the network throughout the operations. Factors such as battery depletion or harsh environment condition may result in sensor node failure. Therefore, in designing a wireless sensor network, survivability and energy efficient to prolong lifetime must take into consideration. To achieve that, a minimum number of relay node (RN) must be deployed in between SN in the wireless sensor network. This strategy is well known as relay node placement (RNP) in the literature [6]–[9]. In [10], there are two variants of RNP in which the contact ranges of SN and RN. In single-tiered relay node placement, a SN forwards packets received from other nodes [11]. In two-tiered relay node placement, the SN forwards its sensed information to an RN or a base station (BS), but does not forward packets obtained from other nodes [11]. In another word, two-tiered relay node placement is arrangement of sensor nodes that is grouped by clusters and each covered by RN (or *application node* in [10]). In order to relieve the burden on sensor nodes and have a scalable framework for the sensor nodes, a two-tiered is proposed. In smart manufacturing, with cycle times between 40-60 seconds, a temporary loss of communication may generate significant costs [12]. With that, fault tolerance in wireless sensor network has become a crucial problem for the efficiency of wireless sensor network. One solution to achieving fault tolerance in wireless sensor network is to deploy a small number of additional relay nodes to provide pathways for each pair of operating devices so that the network can withstand the failure, per described in [6].

1.3 Problem Statement

Most of the manufacturing industry that are using 5G now implemented latest technology such as automation, artificial intelligence (AI) and augmented reality (AR) to do inspection and troubleshooting. Due to the advantages such as low-cost and handy that wireless sensor networks (WSNs) offer, it is widely used in factory automation so most of production processes are carefully monitored by using large number of sensors and produced expansion of heterogeneous wireless sensor network and eventually introduce rapid growth data traffic.

Since most of the smart factories are in a large area, it is need for a reliable and high-throughput communication between sensors and base stations throughout the production area. This is to ensure that during production process, there will be a guarantee that the data transmitted will have no delay.

In factory automation, different data are obtained and transmitted which produced by different types of sensors in HWSN. However, energy constraint is one of the challenges in order to keep monitoring network available in a longer period and robust. Therefore, ways to prolong the network lifetime is the primary consideration in HWSN.

It is undeniable that production process in manufacturing might experience unpredictable events such as energy depletion or harsh environment condition. However, temporary loss of communication during the production process can led to massive loss, even it is just for a few seconds.

Not surprisingly, due to these issues such as volatile deployment environment, human interference, node hardware disruption, connectivity instability and energy depletion, HWSN can suffer from frequent failures. The consistency, accuracy and reliability of the network are also greatly impacted by these failures. Once the primary sensor nodes or the adjacent nodes malfunction at the same time, the existing network will be unavailable for work without any repair scheme.

In order to combat all the problems listed, deployment of minimum relay node placement is needed in order to improve network sensors connection and provide fault-tolerance in heterogeneous wireless sensor network.

1.4 Objective

1. To investigate the appropriate relay node placement in heterogeneous wireless sensor network.

2. To analyze the deployment of relay nodes in order to achieve fault-tolerance in heterogeneous wireless sensor network.

1.5 Scope

In this study, we are focusing on investigating the appropriate relay node placement in heterogeneous wireless sensor network. The network consists of three things – base station, relay nodes and sensor nodes. We assumed that large number of sensors that have different functionality and transmission rate will be used. Therefore, a two-tiered heterogeneous wireless sensor network has been proposed.

Since the sensor nodes have different transmission radii, it introduces network asymmetric connections can lead to two forms of pathways – one-way and two-way. With that, for this experiment, we will be focusing to find solutions to achieve optimal relay node placement for two-way connection that only can achieve partial tolerance. In order to achieve this, approximation algorithm will be used.

Approximation algorithms is used in order to compute a Minimum k-Vertex Connected Spanning Graph (MKCSG) to link all the sensor nodes and deploying relay nodes. Then, the performance ratio for approximation algorithm used will be analyzed in order to produce the best MKCSG.

Then, a greedy heuristic is presented as an alternative to solve the MKCSG problem by analyzing the connectivity of the nodes in the spanning graph. In this case, the connectivity-first algorithm (CFA) presented in [6] will replicated and implemented in this project.

CHAPTER 2

LITERATURE REVIEW

2.1 5G Manufacturing Industry

The demands for improved wireless communication networks in terms of data speeds have been increasingly rising in recent decades in order to meet consumers' need for simpler and better wireless communication network. Based on Cisco's Visual Networking Index (VNI), by 2019, more than half of the devices connecting to the mobile network will be smart devices which resulting an exponential growth in multimedia traffic and by 2020, it is expected that more than 1 terabyte of data is downloaded by single user annually [1]. Moreover, as now many researchers actively explore in recent technologies like augmented reality (AR), Internet of Things (IoT), device-to-devices (D2D) communication and machine-to-machine (M2M) communications lead to rapid growth of data traffic.

According to International Telecommunication Union (ITU), there are three kinds of service scenarios, mobile broadband, massive machine type communication and extremely efficient low-latency communication, that need to be supported in 5G [2]. Based on the scenario, the need to have a communication network with high data rates, extremely low latency and significantly increase quality of service (QoS) have been the driving forces towards fifth generation (5G) communication network [1]. The next big evolution of wireless networking which known as 5G communication network is the cumulative result of evolving mm-wave spectrum connectivity, hyper-connected vision and modern application-specific criteria [1]. As shown in figure 1, various types of devices and application environments need a more sophisticated network that can not only sustain high throughput, but also have low data latency, an effective energy management system, high scalability to handle a vast range of devices and ubiquitous access for consumers [2].

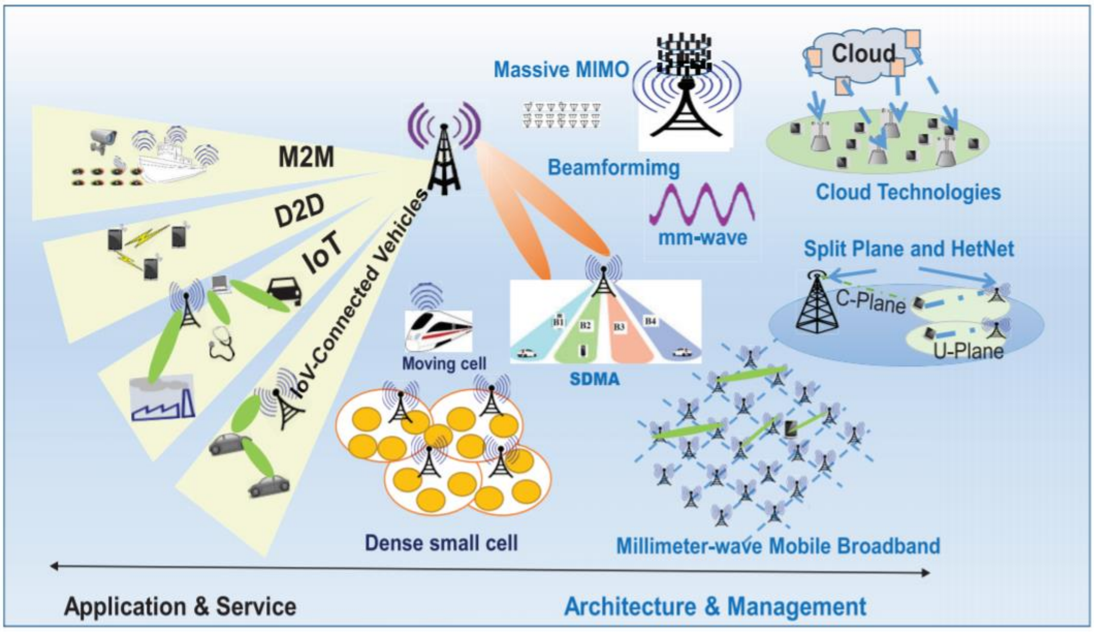

Figure 2.1.1: Schematic Diagram of Next Next Generation of 5G Wireless Networks

Wireless communication systems are increasingly used in industrial automation, especially in the field of process automation and factory automation. The fourth industrial revolution needs a high degree of automation, enhanced performance, machine stability, better reliability, optimised output, machine protection and protection for productive optimised and greener industries. Connection between broad industrial blocks is of the utmost importance to ensure better efficiency and to turn large industrial infrastructures into a single optimised unit. 5G provides scalable infrastructure blocks to ensure optimal results by integrating Ultra-Reliable and Low-Latency Connectivity (URLLC) within the enterprise to provide better process management and automation [13]. In the initial release of 5G, it focuses on generic services such as Massive Machine-Type Connectivity (mMTC) seeks to benefit tens of billions of wireless network-enabled computers. Scalability and wide-area coverage was prioritised over peak speeds relative to intense cell broadband. Ultra-reliable Machine-Type Contact (uMTC) aim to provide ultra-reliable low latency communications in order to deliver modern technologies with severe availability, latency and efficiency specifications [14].

2.2 Wireless Sensor Network

Wireless Sensor Network is well-known as one of the best options that implemented Machine Type Communication (mMTC) which widely used in manufacturing industry [15]. This option usually focused on basic tasks in factory automation such as monitoring and sensing which it is one of the crucial tasks in the industry. It is normal for HWSN to suffer from frequent failures because of erratic deployment, human reaction, node hardware disruption, connection instability and energy depletion. These failures often influence the efficiency, accuracy and durability of the network significantly. When the primary sensor nodes or the adjacent nodes are failing concurrently, the existing network is unavailable without any repair scheme [16].

In these recent years, wireless sensor network has become a research interest in most studies. Some researches have been done regarding the wireless sensor network in various scope such as topology control, node placement strategy and energy efficient scheme. According to [16], topology control is one of the most important strategies used to minimize energy consumption and to expand the network's overall survival under the effective mechanism. In order to combat problems that commonly happen in HWSN such as energy depletion, study in [17] is focusing on using geometrical and location approach in order to prolong the lifetime of cluster heads (known as Application Node (ANs) in [17]). When deciding the node lifespan, a variety of considerations are concerned, such as an energy-conscious MAC that prevents energy lost by consistent channel sensing and regular collisions and the energy-favoured flow and error scheme, like most BS's power overheads, asymmetrical architectures that are not energy-constrained.

Per discussed in [17], they are focusing on topology control for ANs and base station, which they prioritizing maximize topological network lifetime by arranging base station locations so ANs can relay on it optimally. In recent work by [15], they believed that routing protocols can help to increase the energy efficiency of wireless sensor network. With that, they conducted sink node analysis in order to determine the best network model in WSN. Then, they made a comparison of using base stations and high-altitude platforms on which has better performance in ability to deliver information quickly and serve number of users using fewer terrestrial transmission device contact facilities. Node placement strategy has become one of the most highly studied topic when it comes to wireless sensor network with the same agenda – to find the best solution in order to avoid wireless nodes tail and partition the network. However, there are variety of approaches and algorithm used in this method. As for [18] and [19], the two different algorithms used to determine the position of homogeneous relay nodes for the optimal K-connectivity in wireless sensor networks consisted of a small number of heterogeneous sensor nodes. With that, they used an approach on deploying additional relay nodes in order to provide multi-path connectivity (k-connectivity) between all nodes.

Table 2.2-1: Summary of researches related to Wireless Sensor Network

Scope	**System Model**	**Contributions**	**Reference**
Topology Control	Heterogeneous	• Focus on the topology control process for application node and base stations • They propose approaches to maximize the topological network lifetime of the WSN, by arranging BS location and inter-AN relaying optimally • Develop an optimal parallel relay allocation to further prolong the topological lifetime of the WSN	[17]
Sink Node Analysis	-	• Use Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. • To compare wireless sensor network using Base Stations and High-Altitude Platform as Sink Node	[15]
Node Placement Strategy	Heterogeneous	• Minimizing Network cost with constraints on lifetime and connectivity • Propose scheme in two phases.	[20]