DYNAMIC TIMESLOT ALLOCATION TECHNIQUE FOR WIRELESS SENSOR NETWORK

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Dedicated to my beloved parents

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ABSTRACT

Wireless Sensor Network (WSN) technology has been implemented in many data collection applications. Typically, these applications have a multi to one uplink traffic over multi-hop transmission in high traffic and these characteristics will introduce funnelling in WSN. Fixed traffic scheduling has been used to minimize the funnelling in these applications. However, this scheduling cannot adapt to the variation of traffic intensity and changes of topology. This research proposed a dynamic traffic scheduling using a technique named Dynamic Time slot Allocation (DTsA). The technique provided a mechanism for setting up and updating traffic scheduling dynamically according to the change of traffic intensity and topology. To evaluate the performance of DTsA, extensive experiments were performed to measure and evaluate throughput and packet loss over a variety of traffic intensities. The performance is benchmarked against MT-XLP, a cross layer protocol that applies fixed traffic scheduling. The results showed that the throughput of DTsA outperformed the throughput of MT-XLP for low and high level funnelling topologies. In the low level funnelling topology, the DTsA achieved a maximum throughput of 113 pps whereas the MT-XLP only reached 73 pps. In the high level funnelling topology, the maximum throughput of DTsA was 107 pps as compared to a drop to 28 pps for MT-XLP. These results showed that DTsA performed better than MT-XLP during the adaptation to the dynamic changes of topology. The technique maintained its throughput ratio even though there were some nodes that were disconnected and reconnected to the network. This connectivity issue cannot be handled by fixed traffic scheduling. On the contrary, the DTsA packet losses were a maximum of 2.43% in the low level funnelling topology and 4.06% in the high level funnelling topology in comparison to MT-XLP which had 2.44 % packet loss in the low level funnelling and 2.97 % in the high level funnelling. From the analysis, the high packet loss in DTsA is due to the issue of imprecision of timing for synchronizing communication between nodes. Due to this characteristic, DTsA is more suitable for connectionless application of data collection such as streaming and broadcasting.

ABSTRAK

Teknologi *Wireless Sensor Network* (WSN) telah banyak digunakan dalam aplikasi pengumpulan data. Biasanya, aplikasi ini mempunyai trafik *uplink* berbilang kepada satu bagi penghantaran *multi-hop* dalam trafik yang tinggi dan ciri ini akan memperkenalkan corong dalam WSN. Penjadualan trafik tetap telah digunakan untuk mengurangkan corong dalam aplikasi ini. Walaubagaimanapun, penjadualan ini tidak dapat diadaptasi dengan perubahan keamatan trafik dan perubahan topologi. Kajian ini mencadangkan penjadualan trafik dinamik menggunakan teknik yang dinamakan *Dynamic Time slot Allocation* (DTsA). Teknik ini menyediakan satu mekanisme untuk menubuh dan mengemaskini penjadualan trafik secara dinamik mengikut perubahan keamatan trafik dan topologi. Untuk menilai prestasi DTsA, eksperimen secara menyeluruh telah dijalankan untuk mengukur dan menilai kadar purata keberkesanan penghantaran dan kehilangan paket ke atas pelbagai keamatan trafik. Prestasi ditanda aras terhadap MT-XLP, protokol lapisan silang yang menggunakan penjadualan trafik tetap. Keputusan menunjukkan bahawa kadar purata keberkesanan penghantaran DTsA mengatasi kadar purata keberkesanan penghantaran MT-XLP untuk tahap rendah dan tinggi bagi topologi corong. Pada paras rendah topologi corong, DTsA mencapai kadar purata keberkesanan penghantaran maksimum 113 paket sesaat (pps) sedangkan MT-XLP hanya mencapai 73 pps. Pada tahap tinggi topologi corong, kadar purata keberkesanan penghantaran maksimum DTsA adalah 107 pps jika dibandingkan dengan penurunan kepada 28 pps untuk MT-XLP. Keputusan ini menunjukkan bahawa prestasi DTsA adalah lebih baik daripada MT-XLP semasa adaptasi kepada perubahan topologi dinamik. Teknik tersebut mengekalkan nisbah kadar purata keberkesanan penghantaran walaupun terdapat beberapa nod yang telah diputus dan disambung semula kepada rangkaian. Isu penyambungan ini tidak boleh dikendalikan oleh penjadualan trafik tetap. Sebaliknya, kehilangan paket DTsA mencapai tahap maksimum 2.43% pada paras rendah topologi corong dan 4.06% ditahap yang tinggi untuk topologi corong berbanding dengan MT-XLP yang mempunyai kehilangan paket sebanyak 2.44% dalam corong pada peringkat rendah dan 2.97% dalam corong pada tahap tinggi. Dari analisis, kehilangan paket yang tinggi di DTsA adalah disebabkan oleh isu ketepatan masa untuk penyegeraan komunikasi antara nod. Disebabkan oleh ciri-ciri ini, DTsA adalah lebih sesuai untuk aplikasi pengumpulan data tanpa sambungan seperti penstriman dan penyiaran.

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CHAPTER 1

INTRODUCTION

1.1 Overview

In recent years, Wireless Sensor Network (WSN) technology has been explored and implemented by many researchers. Generally, this technology is a kind of data acquisition network, controlled and monitored by a Network Operation Centre (NOC) (Lewis, 2004). It has been implemented in various applications including machine to machine communication, environmental monitoring, or data collection. Research by Khakpour and Shenassa (2008) implemented WSN for industrial control system while Rhee *et al.* (2008) implemented WSN for building protection surveillance system. Yaghmaee and Adjeroh (2009) implemented WSN for environmental monitoring system.

Applications of WSN for collecting sensor based data have some typical characteristic. The applications can employ large number of sensor nodes. The sensor nodes are spread in monitoring area, collecting information from the monitoring area and transmitting the information (sensor data) to sink node. The data collecting process forms many to one uplink traffic where high traffic intensity flows from large number of sensor nodes to a sink node. Many to one uplink traffic may suffer from funnelling since large number of data is transmitted to single destination point.

Figure 1.1 shows the funnelling issue that occurs in a network with multi-to-one uplink traffic. Suppose that A is a node that serves as data collector (also known as sink node) and nodes from B to P are sensor nodes that serve as data transmitter (also known as sensor nodes). Each of sensor nodes has different traffic intensity based on its distance from sink node. For example, a comparison between node B that is near to node A and node M that is far from node A. By assuming that every sensor node transmits a packet periodically, the node B has six packets that must be transmitted periodically. Among of them are one packet from its own packet and five packets from other nodes i.e. E, I, M, J, and N. Meanwhile, the node M only has one packet to transmit its own packet periodically.

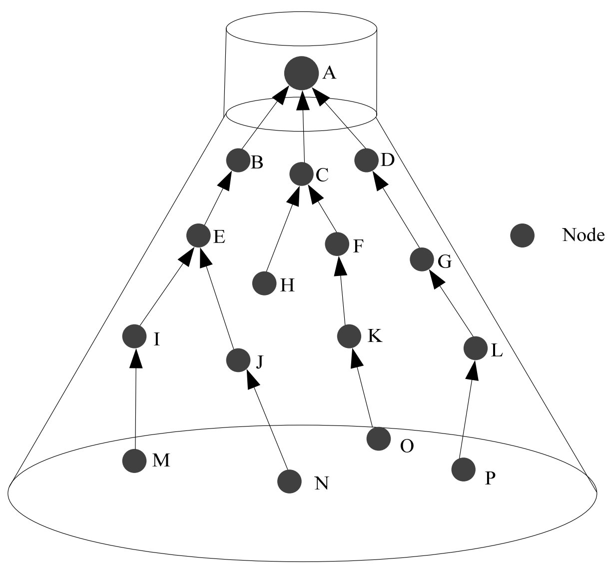

Figure 1.1 Funnelling effect

The funnelling effect is experienced by sensor nodes that are near to sink node. These sensor nodes have higher traffic intensity since they have to forward more data packets than sensor nodes that are far away from sink node. This results on incapability of the sensor nodes to forward the data as fast as flow of received data. It may cause buffer overflow that leads to degradation of overall network throughput and escalation of packet loss ratio. If this condition occurs for long time and in high traffic condition, it will cause congestion.

1.2 Background of the Problem

Figure 1.2 summarizes phenomenon of funnelling effect in WSN and existing approach to address the issue. The funnelling is usually occurred in WSN that characterized by many-to-one uplink traffic that transmits over multi hop transmission and in high traffic load. This condition causes congestion in nodes that are near to sink node. As a consequence, it may reduce throughput and increase packet loss. Many approaches have been proposed to overcome the funnelling effect. The approaches include data aggregation, funnelling-aware Medium Access Control (MAC), and congestion control.

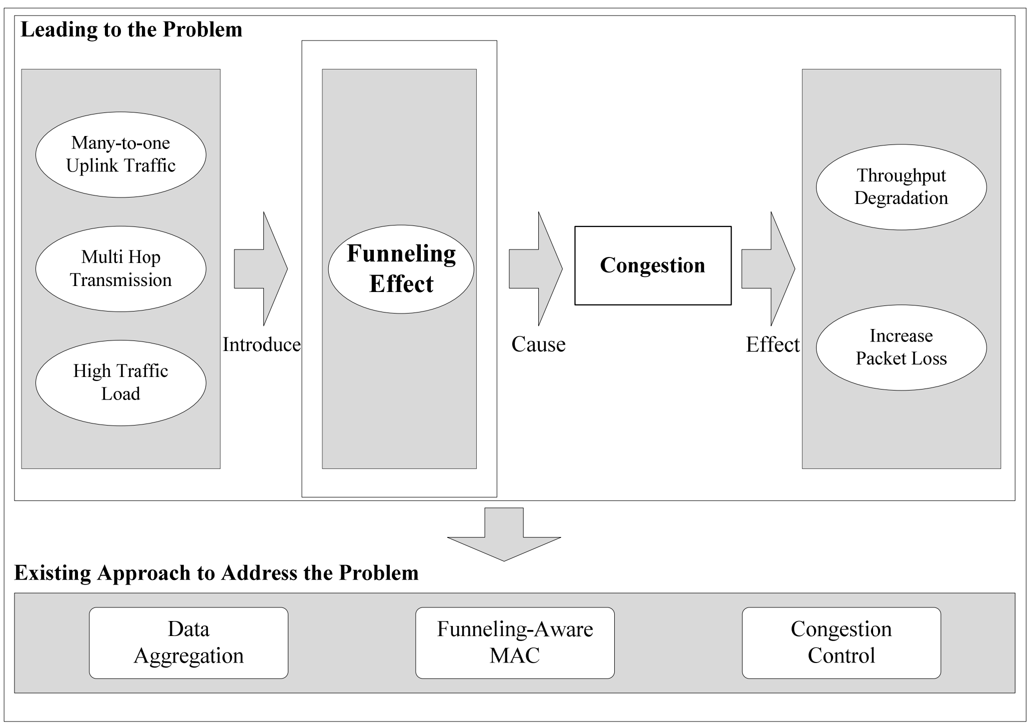

Figure 1.2 Funnelling effect in WSN

Data aggregation is mainly implemented by sensor network that using cluster-based network topology such as Low-Energy Adaptive Clustering Hierarchy (LEACH) proposed by Heinzelman *et al.* (2000). The aggregation of data can minimize funnelling effect by reducing number of packet to be transmitted (Petrovic *et al.*, 2003). The data aggregation is performed by cluster head. Despite transmitting large number of packet and processing the packets in Network Operation Centre (NOC), the cluster head pre-processes packets from its child nodes before transmitting them to sink node. The packet pre-processing summarizes information that received from child nodes. Then, only a few packets will be transmitted to sink node that represent information collected from child nodes. By this way, cluster head can reduce number of packets to be transmitted to sink node.

Other approach to address funnelling issue is by implementing funnelling-aware Medium Access Control (MAC) protocol. Z-MAC is one of funnelling aware MAC proposed by Rhee *et al.* (2008). It is a hybrid (TDMA/CSMA) protocol that acts like a schedule-based protocol under high traffic intensity and a contention-based protocol under low traffic intensity. To schedule data transmission during high traffic intensity, Z-MAC offers scheduling mechanism using DRAND (Rhee *et al.*, 2009). As drawback of Z-MAC, it cannot schedule packet transmission for high traffic intensity that is near to sink node. Therefore, it cannot fully mitigate the effects of funnelling.

The limitation of Z-MAC is addressed by Funnelling-MAC proposed by Ahn *et al.* (2006). Funnelling-MAC defines an intensity region where is near to sink node that is normally occupied by more nodes. It deploys TDMA scheduling within the intensity region, while keeping CSMA in the rest of the network to provide flexibility. The Funnelling-MAC can address the funnelling effect by scheduling more traffic in the intensity region, and enlarge the intensity region to allow more nodes to deploy TDMA scheduling.

Both Z-MAC and Funnelling-MAC assume sink node has long transmission range to cover the whole sensor field (for Z-MAC) or the intensity region (for Funnelling-MAC). This protocol can be used in some applications such as monitoring system for coastal area that employs sink nodes with long range transmission. However, it is not applicable for sink node with short range transmission. For example, WSN application for monitoring landslide that employs large number of nodes with short range transmission cannot use this approach.

As congestion control approach, Multi-channel Time Division Multiple Access (TDMA) – based cross layer protocol (MT-XLP) proposed by Saputra (2012) uses local synchronization to eliminates the need of sink node with long transmission range. Using hierarchical cluster network topology, synchronization is performed locally within each cluster. To prevent inter-cluster collisions, this protocol uses Frequency Division Multiple Access (FDMA) scheme to assign different frequency channel to each cluster. Intra cluster collisions are avoided by applying Time Division Multiple Access (TDMA) scheme. Using TDMA scheme, MT-XLP controls congestion by scheduling the traffic. The scheduling distributes traffic over hierarchical cluster topology. Load balancing and hop-by-hop flow control are two main features of the traffic scheduling.

Although the MT-XLP offers congestion control and traffic scheduling, it cannot fully mitigate the funnelling effect. Fixed time slot allocation that used in MT-XLP cannot schedule the traffic while the network topology is dynamically changes. This condition influences amount of data packet that forwarded from node to node. MT-XLP is not flexible enough to adapt with condition and to schedule more traffic for sensor nodes that nearer to sink node.

The limitation of MT-XLP has motivated this research to design a technique for dynamic traffic scheduling that can adapt to the change of traffic intensity. By using the dynamic traffic scheduling, the funnelling effect can be minimized. A Dynamic Time Slot Allocation (DTsA) technique has been designed in this research as improvement of MT-XLP.

1.3 Statement of the Problem

Based on review on the previous works, dynamic traffic scheduling has important role in addressing funnelling effect in WSN. To minimize the funnelling effect, more traffic should be scheduled by nodes that is nearer to sink node, because nodes that are nearer to sink node has to forward more data packets than nodes that are far away from sink node. Using dynamic traffic scheduling allows nodes to dynamically scheduling their packet transmission following their traffic intensity in various network topologies.

However, designing dynamic traffic scheduling in DTsA introduces some challenges. Design of dynamic traffic scheduling in DTsA should be able to adapt with the change of traffic intensity due to the change of network topology and packet rate transmitted by sensor nodes. In addition, the dynamic traffic scheduling requires mechanism of timing and framing to synchronize communication between nodes. Moreover, minimizing the packet loss and increasing the throughput are two challenges in solving the funnelling effect. To provide such design of the DTsA, this research has to answer the following research questions:

1. How dynamic traffic scheduling can adapt variation of traffic intensity and minimizing funnelling effect?

2. How to handle child-parent node synchronization when network topology is dynamically changed using dynamic traffic scheduling?

1.4 Purpose of the Research

The purpose of this research is to design a Dynamic Time slot Allocation (DTsA) technique for WSN. The proposed technique is aimed to minimize funnelling effects in term of providing relatively high throughput and low packet loss. DTsA also allow network to adapt with the change of traffic intensity due to the change of network topology or packet rate transmitted by sensor nodes.

1.5 Objectives

The specific objectives of this research are:

1. To develop Dynamic Time slot Allocation (DTsA) technique that can adapt variation of traffic intensity in order to minimize funnelling effect.

2. To enhance synchronization in communication of child-parent node by optimizing timing and framing mechanism.

3. To evaluate performance of DTsA in various traffic intensities and dynamic change of topology.

1.6 Scope and Key Assumptions

This research is limited to the following:

1. DTsA is only designed for uplink data direction in which data comes from sensor nodes toward sink node.

2. DTsA is limited to applications with periodic data transmission.

3. Providing energy-efficient communication in DTsA is outside of research scope.

1.7 Research Contributions

The main contributions of this research are summarized as follow:

1. A design of Dynamic Timeslot Allocation (DTsA) technique for minimizing funnelling effects that can adapt various traffic intensities.

2. Management of timing and framing that enables DTsA allocate time slot dynamically

1.8 Organization of the Thesis

This thesis is organized into seven chapters. Chapter I serves as an essential introduction to the research. Chapter 2 reviews WSN, issues that are inherited with WSN including with funnelling effect, and some approaches as well as previous works to mitigate the issues. Methodology of this research will be explained in Chapter 3. Chapter 4 explains about design of dynamic time slot allocation technique. Experiment and analysis of the proposed technique is presented in Chapter 5. The whole research activities are summarized in Chapter 6. Discussion about result of the research and further works are also presented in this chapter.

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