UNIVERSITI PUTRA MALAYSIA

TRAFFIC ADAPTIVE SCHEDULE-BASED MAC PROTOCOL FOR WIRELESSSENSOR NETWORKS

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TRAFFIC ADAPTIVE SCHEDULE-BASED MAC PROTOCOL FOR WIRELESS SENSOR NETWORKS

By

MARYAM VAHABI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

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DEDICATION

I THANK MY GOD WHOSE BLESSINGS HAVE MADE IT ALL POSSIBLE IN THE FIRST PLACE

This thesis is dedicated to:

My late father, who is greatly missed. He taught me to persevere and face the challenges with faith and humility

&

My loving mother, who has supported me through all of my educational pursuits with her strong encouragement and love

AND

My dear husband for his patience and inspiration, whose tireless support has fulfilled my dreams become true

ABSTRACT

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Faculty: Engineering

Wireless sensor networking is an emerging technology that has a wide range of potential applications including monitoring, medical systems, real-time, robotic exploration and etc. Energy is a critical resource in battery-powered sensor networks. Medium access control has an important role in minimizing energy consumption while it is responsible for successful data transferring in the network. Periodic data collection is the most comprehensive way of data gathering mechanism in wireless sensor network in which nodes report their samples in specific time intervals. It is possible to have some nodes with different update intervals in the network and therefore, finding a solution to accommodate nodes with different sampling intervals while maintaining the energy efficiency is the primary concern of this thesis.

In this work, we propose a schedule-based MAC protocol that supports periodic traffic with different sampling rates in an energy efficient manner while maintaining minimum packet loss and end-to-end delay. The schedule-based MAC design is used for eliminating the idle listening problem which leads to smaller energy consumption. We introduce a traffic adaptive technique that arranges the time schedule of each node with respect to its sampling rate. Route partitioning technique is the next step of our design to provide a collision free data transfer. By this mechanism, each route will be activated in a specific time regarding to the sampling interval of nodes that it involves. Using the enhanced time scheduling and route partitioning techniques with respect to nodes' sampling rate provides the basic design of our traffic adaptive algorithm.

In order to represent traffic adaptive capability of the proposed protocol, some nodes are considered to generate data packets with higher data generation rates than other sensor motes in the network. The most relevant existing MAC protocol which support only one generation rate is then compared with our modified version. We then analyzed the estimated energy consumption and defined the maximum number of high sampling rate nodes that can be supported by the proposed protocol. The simulation results show that our adaptive protocol provides a minimum packet delay and the least packet loss rate compared to existing MAC protocol. The energy dissipation of the proposed protocol is much less than the existing MAC protocol when its duty cycle has been adjusted with respect to high traffic node's sampling rate. The proposed traffic adaptive MAC design can achieve around 35% improvement on energy efficiency while maintaining minimum end-to-end delay and packet loss rate.

ABSTRAK

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PROTOKOL MAC BERASASKAN JADUAL TRAFIK MUDAH SUAI DALAM JARINGAN PENDERIA WAYARLES

Oleh

MARYAM VAHABI

Disember 2008

Pengerusi: Mohd Fadlee A. Rasid, Ph.D.

Fakulti: Kejuruteraan

Rangkaian penderia wayarles adalah satu teknologi yang mempunyai pelbagai potensi dalam pelbagai aplikasi termasuklah pengawasan, sistem perubatan, penerokaan robot masa nyata, dan sebagainya. Tenaga adalah satu sumber genting dalam rangkaian penderia berkuasa bateri. Kawalan capaian bahantara (MAC) mempunyai peranan penting dalam mengurangkan penggunaan tenaga disamping bertanggungjawab menjayakan pemindahan data dalam rangkaian. Pengumpulan data secara berkala adalah cara paling komprehensif bagi mekanisme pengumpulan data dalam rangkaian penderia wayarles di mana nod melaporkan sampel dalam selang waktu tertentu. Adalah mungkin untuk memiliki beberapa nod dengan selang waktu pengemaskinian yang berbeza dalam rangkaian, oleh itu, fokus utama tesis ini adalah untuk mencari satu penyelesaian untuk

menampung nod dengan selang waktu pensampelan berbeza disamping memelihara kecekapan tenaga.

Dalam tesis ini, protokol MAC berasaskan jadual yang membolehkan trafik berkala dengan kadar pensampelan berbeza telah dicadangkan disamping mengekalkan kehilangan paket dan lengah hujung ke hujung secara minima. Reka bentuk MAC berjadual digunakan untuk menghapuskan masalah melahu dengar yang membawa kepada penggunaan tenaga yang kecil. Teknik trafik mudah suai yang menyusun jadual masa setiap nod mengikut kadar pensampelan telah diperkenalkan. Langkah seterusnya dalam rekabentuk ini adalah teknik pemetaan laluan bagi memastikan tiada perlanggaran dalam pemindahan data. Menggunakan mekanisme ini, setiap laluan akan diaktifkan dalam satu masa tertentu bergantung kepada selang masa pensampelan nod yang terlibat. Menggunakan jadual masa yang lebih baik dan teknik pemetaaan laluan terhadap kadar pensampelan nod menyediakan asas reka bentuk algoritma trafik mudah suai ini.

Untuk mewakili kebolehan protokol trafik mudah suai yang dicadangkan, sesetengah nod dianggap menjana bingkisan data dengan kadar lebih tinggi berbanding penderia lain dalam rangkaian tersebut. Protokol MAC sedia ada yang paling hampir menghasilkan satu kadar penjanaan bingkisan data kemudiannya dibandingkan dengan versi yang telah diubahsuai. Anggaran penggunaan tenaga kemudiannya dianalisis dan bilangan maksimum kadar pensampelan tinggi nod yang boleh ditampung oleh protokol yang dicadangkan ditakrifkan. Keputusan simulasi menunjukkan bahawa ptotokol mudah suai menyediakan lengah bingkisan yang minimum dan kadar kehilangan bingkisan yang paling rendah berbanding protokol MAC sedia ada apabila pusingan

tugas telah diubah bergantung kepada kadar persampelan nod bertrafik tinggi. Reka bentuk MAC trafik mudah suai yang dicadangkan boleh mencapai peningkatan kecekapan tenaga sehingga 35% disamping mengekalkan lengah hujung ke hujung dan kadar kehilangan bingkisan yang minimum.

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LIST OF ABBREVIATIONS

BEB	Binary Exponential Backoff
B-MAC	Berkeley MAC
CSMA	Carrier Sense Multiple Access
CTS	Clear To Send
DC	Duty Cycle
DFI	Data Forwarding Interruption
D-MAC	Data gathering MAC
EEDSFT-MAC	Energy Efficient Delay Sensitive Fault Tolerant MAC
HDC	High Duty Cycle
HSR	High Sampling Rate
HTR	High Traffic Route
LDC	Low Duty Cycle
LPL	Low Power Sampling
LSR	Low Sampling Rate
MAC	Medium Access Control
MTS	More To Send
NAV	Network Allocation Vector
NS-2	Network Simulator-2
PDC-MAC	Periodic Data Collection MAC
PEDAMACS	Power Efficient and Delay Aware Medium ACsesS
QoS	Quality of Service

RATE EST MAC	RATE ESTimation MAC
RI-MAC	Receiver Initiated MAC
RD	Route Discovery
RP	Route Partitioning
RTS	Request To Send
SCP-MAC	Scheduled Channel Polling MAC
SD	Schedule Dissemination
S-MAC	Sensor MAC
SM-TDMA	Sleep Mode TDMA
SR	Sampling Rate
STEM	Sparse Topology and Energy Management
TA-PDC-MAC	Traffic Adaptive PDC-MAC
TDMA	Time Division Multiple Access
T-MAC	Time out MAC
TRAMA	TRaffic Adaptive Medium Access
TS	Time to Start
TS_D	Time to Start Data collection
Wise-MAC	Wireless Sensor MAC
WSN	Wireless Sensor Network

CHAPTER 1

INTRODUCTION

Wireless sensor network has been emerged by the combination of sensing, computation, and communication into a single tiny chipset. Deployment of large number of low-cost sensor devices can compensate their extremely limited transmission range. Wireless sensor networks support wide range of applications, varies from environmental to military domains. These applications include contamination tracking, habitat monitoring, health monitoring, traffic monitoring, building surveillance and monitoring, industrial and manufacturing automation, distributed robotics, enemy tracking in the battlefield and many others.

Due to the vast variety of sensor applications, they must provide the following characteristics [1, 2]:

(a) Self-organizing: Unlike traditional networks, sensor networks do not rely on the pre-existing infrastructure. This allows random deployment in inaccessible terrains or disaster relief operations. Hence, sensor network protocols must possess self-organizing capabilities.

(b) Scalability and Reliability: Sensor networks should be scaled to the size of the organisms under study, moreover, they must sample data at frequencies equivalent to physical phenomenon changes that organisms encounter, and deployed to capture the full range of the organism's exposure.

1.1 Background

Common characteristic of many Wireless Sensor Network (WSN) application scenarios is monitoring some phenomena and relaying data toward the sink or destination node. Two categories of data collection can be distinguished; event-based reporting of outliers and periodic data collection of key parameters [3]. In event-based data collection, the sensors are responsible for detecting and reporting events. Two examples of this kind of data collection are: (a) "the localization of a sniper based on analyzing the sound of a gunshot" [4], and (b) "A Line in the Sand" intrusion detection system [5]. This kind of data collection is less demanding in terms of the amount of wireless communication, since local filtering is performed at the sensor nodes, and only events are propagated to the base node [6].

In the periodic data collection, periodic updates are sent to the sink node from the sensor network, based on the most recent information sensed from the physical parameter. Example of the periodic monitoring class include the observation of nesting patterns of storm petrels at Great Duck Island [7], measuring light intensities at various heights in a redwood tree [8] and logging temperature and humidity in the canopy of potato plants for precision agriculture [9]. This data collection approach is also further classified into two; query-based data collection which also called continuous queries [10], and periodic reporting data collection. The first class is used to express user or application specific information interest and support aggregate queries, such as minimum, average, and maximum. These types of queries result in periodically generating an aggregate of the recent samples of all nodes. Similar to event-based data collection, the raw data is not

communication of nodes. Schedule-based MAC design is one of the basic solutions for energy efficiency in periodic data collection systems. In these systems, sensors report their sensing value in a specific time interval to the sink node or base station. In addition, it is a common situation to have different sensors with different sample intervals in the network. This will cause a network with different traffic rates in each part. One way of tackling this problem is to define a global sampling rate for all nodes. The global sampling rate should be chosen in such a way that achieves a reliable data transmission. Only the highest available sampling rate can provide to reach this approach. However, with this decision, all nodes must wake up frequently even when they have no data to send which is more power consuming. This fact motivated us to propose a schedule-based MAC protocol to support different sampling rates of sensor nodes while obtaining energy efficiency.

1.3 Aim and Objectives

This research introduces a schedule-based MAC protocol for sensor networks with periodic data collection. The main goal of this study is to achieve an energy efficient MAC design that can support nodes with different traffic generation rates by using schedule-based MAC protocol to overcome problems such as idle listening and packet collision. Therefore, the main energy consuming part of the sensor network protocol will be controlled.

However, due to the rigid characteristics of timing schedules, TDMA-based MAC protocols cannot provide a good adaption with different traffic rates. This thesis

proposes a MAC protocol that combines benefits of the energy efficiency capabilities of TDMA-based protocol together with a mechanism to accommodate sensor nodes with different sampling rates. The main objectives of this thesis are as follows:

- To reduce the energy consumption of existing WSN MAC protocol by using schedule-based MAC design.
- To minimize end-to-end delay and packet loss rate in the sensor networks by introducing an improved scheduling mechanism.
- To implement an existing Periodic Data Collection MAC protocol (PDC-MAC) as our benchmark.

1.4 Thesis Scope

In this thesis, we focus on the periodic reporting data collection, as it is the most common traffic pattern in wireless sensor networks and provide arbitrary data analysis at the collection centre. There are two types of MAC protocols for multi-hop wireless networks; those that are based on scheduling or resource allocation, and those that are contention based [13].

As stated earlier, the most suitable MAC design for periodic data collection is TDMA-based protocol. It can provide collision free time slots for sensor nodes to send their sensing data while minimizing idle listening problem. We consider this type of MAC classification to achieve an energy efficient protocol. As it is possible to have nodes with different reading intervals in the network [14], the selected protocol should be

compatible to different sample intervals. In this thesis, we did not focus on how sensor nodes change their sampling rates as discussed in [15-17], as each application needs its specific sampling rate regarding to the physical phenomenon that it observes. We focused on the presence of different sampling rates in the network.

Generally, redundancy of sensor readings compensates the need of acknowledging to each packet [18-22]. In this research, the MAC level acknowledgement was not considered to achieve more energy efficient protocol by allocating the time slots for data transferring and eliminate extra listen periods for receiving the acknowledge message from the receiver.

Finally, to achieve a more flexible protocol, which supports different sampling rates of nodes in the network, we introduce a traffic aware scheme together with some precise scheduling and provide a traffic adaptive schedule-based MAC protocol for periodic data collection.

1.5 Study Module

Figure 1.1 illustrates the schematic diagram of this study, where the bold lines represent the direction followed in this thesis to achieve our goals and the dotted lines represent the other directions that are already considered in previous researches.

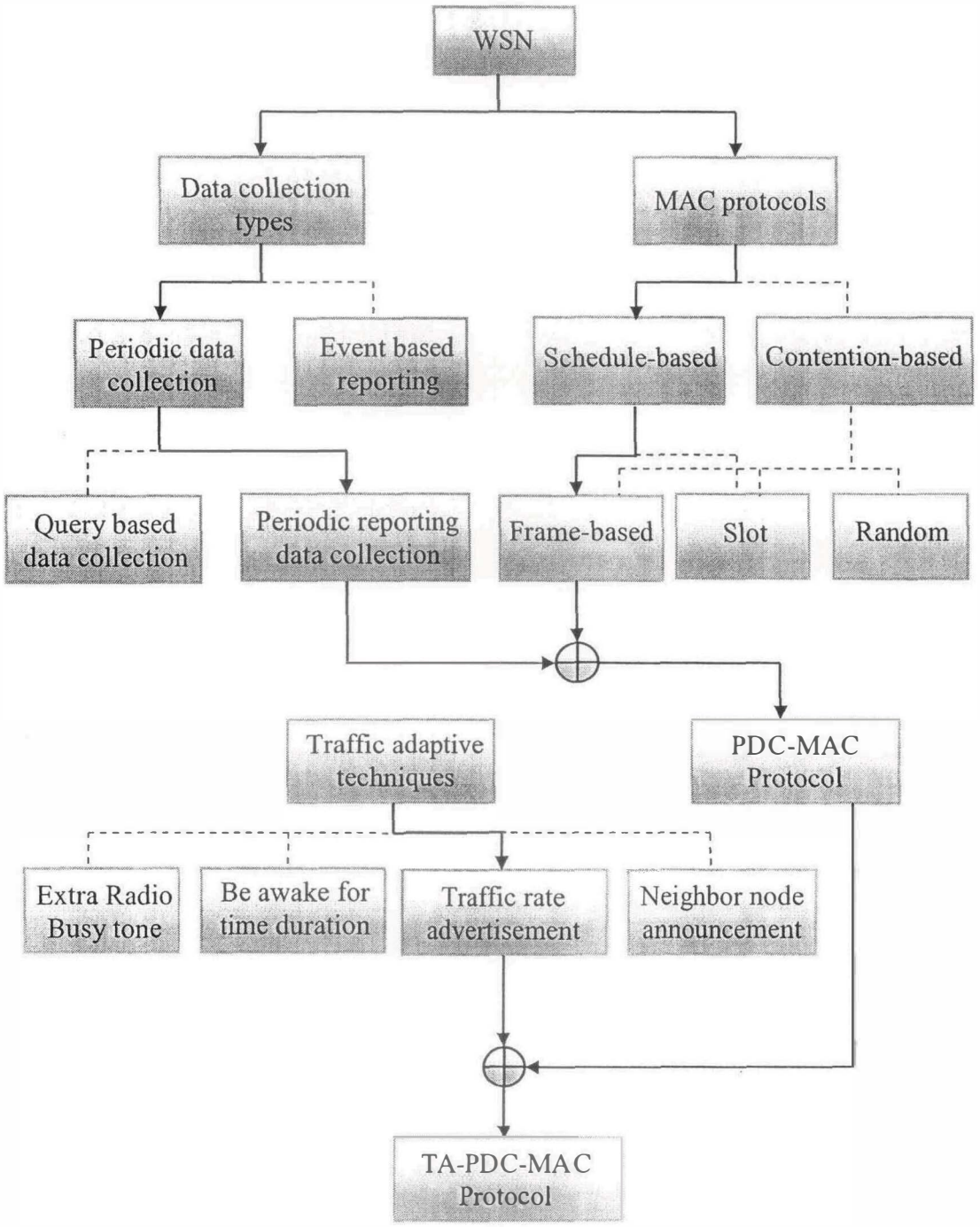

Figure 1.1: Schematic Diagram of Study