MODIFIED RADIO MODEL FOR CLUSTERING WIRELESS SENSOR NETWORK

BY

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ABSTRACT

Wireless Sensor Network (WSN) is a new and fast advancing technology, which is opening up many opportunities in the field of remote sensing and data monitoring. In spite of the numerous applications of WSN, issues related to determining a suitable and accurate radio model that will foster energy conservation in the network limit the performance of WSN routing protocols. A number of radio models have been proposed to improve the performance of WSN routing protocols. However, the underlying assumptions and inaccurate configuration of these radio models make them inefficient and often lead to mismanagement of scarce energy and computational resources. This research addresses these challenges by proposing a modified radio model that adapts to the frequent changes in the location of the object that the sensor nodes is tracking and is robust enough to report reliable data to the base station despite fluctuations due to signal interference. The impact of incorporating stepwise energy level and specialized data transmission schemes in the proposed radio model was also investigated in this research. Key design features were identified and selected, thereafter model of proposed radio model for cluster-based routing was analyzed. Thus, proposed radio model for cluster-based routing was developed. The performance of the proposed radio model was evaluated using OMNET++ and MATLAB and the results obtained were benchmarked against Low-Energy Adaptive Clustering Hierarchy (LEACH) and Power-Efficient Gathering in Sensor Information Systems (PEGASIS). The simulation shows that the performances of the proposed Low-Energy Adaptive Clustering Hierarchy-Improved (LEACH-IMP) developed in this research are more efficient when compared to existing clustering routing protocols with respect to energy consumption, number of links faults, number of packets received, signal interference, and network lifetime. LEACH-IMP shows an improvement of 30.72% and 38.10% over LEACH in terms of energy consumption and number of link faults respectively. Moreover, LEACH-IMP shows an improvement of 29.21%, 9.28% and 53.16% over LEACH in terms of number of received packets, signal interference and network lifetime respectively. Similarly, when benchmarked against PEGASIS, LEACH-IMP shows an improvement of 17.93% and 20.24% in terms of energy consumption and number of link faults respectively. Furthermore, LEACH-IMP shows an improvement of 12.02%, 2.22% and 14.38% over PEGASIS in terms of number of received packets, signal interference and network lifetime respectively. Therefore, the LEACH-IMP developed in this research is assessed to be robust enough to report reliable data to the central monitoring system for the end user despite the fluctuations in signal strength.

خلاصة البحث

الشبكة اللاسلكي الاستشعاري (WSN) هي تقنية حديثة وسريعة النهوض، وتفتح آفاقاً كثيرة في مجال الاستشعار عن بعد، ورصد البيانات . على الرغم من الطلبات العديدة من القضايا ذات الصلة WSN لتحديد نموذج إذاعية مناسبة ودقيقة من شأنها تعزيز الحفاظ على الطاقة في شبكة الحد من أداء بروتوكولات التوجيه .WSN وقد اقترح عدد من النماذج الإذاعية لتحسين أداء بروتوكولات التوجيه .WSN ومع ذلك، فإن الافتراضات الأساسية، والتكوين الدقيق من النماذج الإذاعية جعلها غير فعالة، وغالباً ما تؤدي إلى سوء إدارة موارد الطاقة والحاسوبية إلا نادرة. هذا البحث يتناول هذه التحديات من خلال اقتراح نموذج إذاعية معززة والتي تتكيف مع التغييرات المتكررة في موقع العقد الاستشعاري، القوية بما يكفي لتقرير بيانات موثوقة إلى المحطة الأساسية، على الرغم من التقلبات بسبب التدخل. كما تم التحقق مع إدماج التأثير المتدرج في مستوى الطاقة المتخصصة في أنظمة نقل البيانات لنموذج الإذاعة المقترحة في هذا البحث. وقد تم التعرف على ملامح التصميم الرئيسية وتحديده، وتحليلها بعد ذلك لنموذج الإذاعة المقترحة لكتلة القائمة على التوجيه. وهكذا تم تطوير النموذج المقترح لإذاعة الكتلة المستندة إلى التوجيه. ومن ثم تم تقييم أداء النموذج المقترح باستخدام الإذاعة + + OMNET وكانت تقاس MATLAB والنتائج التي تم الحصول عليها ضد الطاقة المنخفضة والتسلسل الهرمي تقسيم المتكيفة (LEACH) والتجمع وتوفير الطاقة في نظم المعلومات الاستشعاري .(PEGASIS) ويظهر أن أداء المحاكاة لبرنامج تحديث الصناعة، LEACH الحديثة هي أكثر كفاءة بالمقارنة مع التكتلات القائمة بروتوكولات التوجيه فيما يتعلق باستهلاك الطاقة، وعدد من عيوب الوصلات، وعدد من الحزم الواردة، والإشارة المخففة، وعمر الشبكة. IMP LEACH - يظهر تحسناً 17،93 ٪ ، 38،10 ٪ ، 29،21 ٪ ، 9،28 ٪ ، و 53.16 ٪ في استهلاك الطاقة، وعدد من عيوب الوصلات، وعدد من الحزم الواردة ، والإشارة المخففة، وعمر الشبكة على التوالي، بالمقارنة مع LEACH وبالتساوي، عندما تقاس ضد PEGASIS، LEACH – IMP يظهر تحسناً 30،72 ٪ ، 20،24 ٪ ، 12،02 ٪ ، 2.22 ٪ ، 14.38 ٪ ، واستهلاك الطاقة، وعدد من عيوب الوصلات، وعدد من الحزم الواردة، والإشارة المخففة، وعمر الشبكة على التوالي. لذلك، هو تقييم لـ LEACH - IMP والتطور في هذه الدراسة أن تكون قوية بما فيه الكافية لتقرير البيانات الموثوقة لنظام الرصد المركزي للمستخدم الأخير على الرغم من التقلبات في قوة الإشارة.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Communication Engineering).

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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LIST OF ABBREVIATIONS

3-D	Three-Dimensional
ANT	Allowed Number Of Transmissions
APTEEN	Adaptive Periodic Threshold-Sensitive Energy-Efficient Sensor Network
BS	Base Station
CH	Cluster-Head
CM	Cluster-Member
CPEQ	Cluster-based Periodic, Event-Driven And Query-Based
GAF	Geographic Adaptive Fidelity
GPS	Global Positioning System
ICE	Inter-cluster Communication based Energy-aware Protocol
LEACH	Low-Energy Adaptive Clustering Hierarchy
LEACH-IMP	Low-Energy Adaptive Clustering Hierarchy Improved
MAC	Media Access Control
MANETs	Mobile Ad Hoc Networks
MEMS	Micro-Electro-Mechanical Systems
PC	Personal Computer
PEGASIS	Power-Efficient Gathering In Sensor Information Systems
PEQ	Periodic, Event-Driven and Query-Based
QoS	Quality of Service
TDMA	Time Division Multiple Access
TEEN	Threshold-Sensitive Energy-Efficient Sensor Network
WLANs	Wireless Local Area Networks
WSN	Wireless Sensor Network
FR	Number of Transmitted Frames in a Round
TPB	Throughput Bandwidth of the Wireless Channel
RSDM	Remote Sensing and Data Monitoring
COTS	Commercial-off-the- Shelf

LIST OF SYMBOLS

A	Area of the wireless sensor network
ANT	Allowed number of transmissions
d_{th}	Threshold Distance
P_{tx}	Transmit Power
P_r	Received Signal Power
G_t	Antenna Gains of the Transmitter
G_r	Antenna Gains of the Receiver
λ	Signal Wavelength
f	Signal Frequency
d	Distance from the Transmitter
c	Speed of Light in Vacuum
h_t	Heights of the Transmitting Antennas
h_r	Heights of the Receiving Antennas
σ	Estimation of the Amount of Multiple Interferences
L	System Loss
L_t	Transmitter Loss
L_r	Receiver Loss
$L(d)$	Path Loss
β	Path Loss Exponent
$L(d_o)$	Path Loss with Respect to a Reference Distance
$F(\delta)$	Fading Effect
δ	Attenuation
$O_{s,t}$	Set of all Obstructions Intersecting the Virtual Communication Line Between Source Node (*s*) and Destination Node (*t*)
λ_s	Wavelength of the Transmitted Signal
h_{rx}	Antenna Heights of the Receiving Sensor Nodes
h_{tx}	Antenna Heights of the Transmitting Sensor Nodes
G_{rx}	Antenna Gains of the Receiving Sensor Nodes
G_{tx}	Antenna Gains of the Transmitting Sensor Nodes
E_{tx}	Transmit Energy of the Sensor Node
U	Unit by Which E_{tx} Increases
E_e	Electronics Energy
E_s	Energy Consumed for Short-Range Transmission Distance
E_l	energy consumed for long-range transmission distance
N_b	Number of Bits Contained in the Specified Frame
R	Round Duration
N_b	Number of Bits Contained in a Given Frame
S	Number of Slots Contained in the Frame
L	Packet Length
A	Active wake mode of the sensor nodes
P	Passive sleep mode of the sensor nodes

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

A brief account of the fundamental concepts and terms used in this dissertation is given in this chapter. Furthermore, a detailed explanation of the fundamental concepts of Wireless Sensor Network (WSN), a highlight of the design challenges in WSN, the differences between WSN radio model and the classical radio model are also discussed. The essential elements of this research are examined. The chapter concludes with a description of how this dissertation is logically organized.

1.2 WIRELESS SENSOR NETWORK

WSN is a fast advancing technology, which is comparatively novel and has opened up many opportunities in the field of remote sensing and data monitoring. Recent advances in digital signal processing, digital electronics, nanotechnology, micro-electro-mechanical systems (MEMS) technology, wireless communications and radio technology have tremendously led to the development of smart and miniaturized sensor devices (Oliveira and Rodrigues, 2011). Contemporary advancement in modern technology made the idea of WSN viable as it has opened up numerous possibilities in using motes (sensor nodes) for tracking, monitoring and detecting remote events. Applications of WSN includes wildlife migration tracking, wild fire monitoring, reconnaissance and tactical surveillance, weather monitoring and ubiquitous computing (Akyildiz, Su, Sankarasubramaniam, and Cayirci, 2002 and Karapistoli, Pavlidou, Graugopoulus, Tsetsinas, 2010).

1.2.1 Sensor Nodes (Motes)

A WSN consists of numerous nodes, which are deployed in a given area in little, or large proportion. In order to attain successful deployment in different geographical regions with differing environmental conditions, the sensors are usually deployed randomly. These tiny sensor nodes are manufactured with an inbuilt sensing unit, digital processing unit, transceiver and energy source. The function of the sensing unit is to monitor the desired environmental factors such as light intensity, temperature, motion, humidity, pollution content in the atmosphere, etc. The digital processing unit processes the data signals acquired from the nodes for further execution of other network operations. The transceiver is essentially used for the transmission and reception of data. The energy source is usually a battery that supplies energy to the sensor node (Chen, Gonzalez, Vasilakos, Cao, and Leung, 2010). Although the sensor nodes have limited communication range, data aggregation can be utilized to obtain accurate and reliable data by performing statistical combination of the set of correlated data collected from the nodes. After performing data aggregation, the compressed data will be conveyed to a distant base station (BS) through the nearest adjacent nodes in order to allow the end user to remotely sense the network and access the useful information. The received signal strength is used to estimate the relative distance between the nodes and their adjacent nodes (Estrin, Govindan, Heidemann, and Kumar, 1999).

WSN is mainly used to sense, gather and execute the processed data collected from a group of sensor nodes, and disseminate the aggregated data to the BS for higher-level analysis and application by the end user. Currently, researchers have proposed a number of radio models for describing the radio propagation characteristics and network dynamics of the WSN with respect to the constrained energy resources (Furht, 2008 and Karapistoli et al., 2010). These WSN-based radio models are unique and different from the well-known radio models in conventional networks because radio model in WSN is viewed as how the choice of physical layer parameters affects the energy consumption which is different from classical communication networks where radio modeling strictly deals with the characterization of physical layer parameters (Estrin, Culler, Pister, and Sukhatme, 2002). The modified radio model proposed for the novel energy-efficient cluster-based routing protocol (LEACH-IMP) in this dissertation is suitable for industrial safety control systems where tiny motes need to be strategically positioned on mobile objects and machine parts in order to ensure safety for the technicians by periodically monitoring the workspace. In such a scenario, a WSN running on the proposed modified radio model will be able to adapt to the frequent changes in the location of the motes. In addition, it will be robust enough to report reliable data to the central monitoring system for the end user despite the fluctuations in signal strength and presence of measurement errors from estimating the inter-nodal distance between motes.

1.2.2 Differences between WSN and Conventional Networks

Conventional networks are comparatively bigger in size, have higher installation cost and usually placed in a known and planned location. In addition to this, there is easy and direct accessibility to this kind of network. On the other hand, fewer sensor nodes are deployed over a geographical region, which might be hostile, harsh, remote, and inaccessible (Prasad, Dixit, Van Nee, and Ojanpera, 2010). As a result, there is need to adopt robust, fault-tolerant, maintenance-free and smart deployment techniques in order to guarantee the successful operation of the WSN. Furthermore, the use of wireless communication in WSN significantly saves the network engineer from the high cost of installing, operating and maintaining the wired infrastructures, which is inevitable in most conventional networks. In short, WSN has the following four key advantages over conventional networks (Gavrilovska, Krco, Milutinovic, Stojmenovic, and Trobec, 2010):

1. ***Accuracy***: In WSN, uncertainties and inconsistencies in sensor readings is significantly reduced due to the aggregation of data collected from sensor nodes that are closely located to each other.

2. ***Durability***: Due to the fact that a large group of sensor nodes is close to each other, the likelihood that the readings from these closely located nodes will be highly correlated, statistically, is relatively higher than readings from nodes that are located far away from one another. As a result, death or failure of a few of the closely located nodes would not result in significant loss of reliable data or death of the network because other nodes can be used to report data that is reliable averagely. Therefore, the entire WSN can survive the death or failure of a few nodes and still report the desired information with acceptable quality.

3. ***Affordability***: The installation, operational and maintenance cost of WSN infrastructure is comparatively cheaper and more affordable than conventional networks.

4. ***Ubiquity***: WSN makes it feasible to realize ubiquitous computing when a large number of nodes are deployed to monitor periodically real-life events in a network area spanning a wide geographical region.

1.2.3 Importance of the Radio Model in Wireless Sensor Network

The radio model in wireless sensor network is very crucial to the operation of the network. This is because one of the most energy consuming operations in wireless sensor network is the radio operation that is much energy is expended during the transmission and reception of data. The physical and data link layer are standardized in accordance to the IEEE 802.15.4 standard. This implies that most of the features in these layers are agreed upon and fixed (Robert, Reed, and Philip, 2009). The standardized features and services in the physical layer includes the data transmission service, modulation scheme, antenna characteristics, radio frequency transceiver, channel selection, channel quality, channel capacity, energy and signal management functions, choice of operation in the possible unlicensed frequency bands, etc (Robert et al., 2009). With respect to this, the focus of radio model in WSN is how the choice of physical layer parameters affects the energy consumption of the wireless sensor network. In order to conserve the scarce energy resources and limited processing and memory capacity (Robert et al., 2009)

1.3 CHALLENGES FACED IN THE DESIGN OF WSN

The implementation and enhancement of WSN has gained a lot of interest due to the previously mentioned distinctive features of WSN. In order to build energy-efficient, cost-effective, durable and reliable WSN applications, the following factors should be kept in mind when making network design decisions.

1.3.1 Ease of Deployment

The chosen techniques that must be employed for the deployment of large number of sensor nodes should be realistic and easily deployable to facilitate the placement of nodes in remote, harsh and inaccessible environments. Furthermore, the deployment should be prepared systematically and performed carefully in order to allow successful communication and strategic cooperation among sensor nodes in the absence of a preinstalled and readily available network infrastructure. In order for the WSN to operate successfully in this ad hoc scenario, the technique of self-configurability should be incorporated in the network design in order to reduce, significantly, the global control in setting up and preserving the network (Culler, Estrin, and Srivastava, 2004).

1.3.2 Prolonged Lifetime

Since the re-deployment of sensor nodes is usually costly and requires much effort and expertise, lifetime enhancement strategies should be incorporated into the design in order to derive maximum benefits from the WSN. However, merely operating for a long period is ineffective if the data reported are unreliable and of poor quality. Therefore, effective network strategies, which will ensure that sensor nodes deliver data of acceptable quality, should be employed. By incorporating these techniques, the deployed sensor nodes will successfully be able to adjust for remote locations or harsh conditions where it may be nearly impossible to recover, replace, recharge or repair the nodes and their inbuilt batteries (Mhatre, Rosenberg, Kofman, Mazumdar, and Shroff, 2005). Therefore, there is a compelling need for WSN-based radio models that will assist the network engineer in accurately measuring the amount of energy consumed for data transmission and reception and help in minimizing the energy consumed during these radio operations. This means that a modified radio model will help in enhancing the lifetime of the WSN. Therefore, network engineers are responsible for devising simple, lightweight and effective radio models for sensor nodes. This is because the sensor nodes are not built with powerful operating system that could provide energy efficient resource management due to the limited energy, storage, computational and processing resources (Trigoni, Yao, Demers, Gehrke, and Rajaramany, 2004).

1.3.3 Response and Reaction Time

In WSN, the sensed data are commonly time-sensitive and as a result, it is essential to received data in a timely fashion. Hence, long delays due to (1) data transmission and reception, (2) data storage and caching, and (3) data processing, may not be acceptable (Wu, 2006).

1.3.4 Suitability of Aggregated Data

Data suitability in this context is a qualitative measure that varies from one application user to another and it can be essentially defined as the degree by which the data transmitted to the base station correctly, reliably and accurately matches the real events in the WSN (Ferentinos, Tsiligiridis, and Arvanitis, 2005). In WSN, sensed data by each node is needed for further analysis and processing at the base station rather than other nearby nodes as in the case of cellular networks and wireless local area networks (WLANS). Consequently, data suitability or quality in WSN differs from that of other cellular network and (WLANS) (Madden, Franklin, Hellerstein, and Hong, 2002 and Yao and Gehrke, 2002). In WSN, the end user is not really interested in every bit of data that is sensed in the network due to the fact that: (i) the data from neighboring nodes are highly statistically correlated which makes such data redundant; and, (ii) the end user focuses on the description, forecast and interpretation of events taking place in the monitored area. Hence, suitability in this context is a user-dependent qualitative measure of the aggregated data rather than the quality of each and every data (Eskicioglu, Ahmed, and Hussain, 2005 and Younis, Munshi, and Al-Shaer, 2003).

1.4 PROBLEM STATEMENT AND ITS SIGNIFICANCE

There is an increasing demand for wireless sensor networks. However, the performance of sensor networks is limited by problems related to determining an accurate and energy-efficient radio model for the sensor nodes in the network. In addition to this, radio model issues cannot be overlooked in WSN protocol design because the most energy consuming functions are radio operations, i.e., data transmission and reception (Heinzelman, Chandrakasan, and Balakrishnan 2000, and Akyildiz et al., 2002). The first order radio model has been proposed to address the aforementioned issues. The first order radio model operates by assuming that there is only one clear line-of-sight path in the ideal propagation condition between transmitter and receiver due to the short inter-nodal distance between the sensor nodes (Ye, Heidemann, and Estrin, 2004). However, it has been shown that the assumption of short distance between sensors nodes is impractical. This is because network engineers who incorporate this model in their protocol design observe much discrepancy between the readings that protocol reports and what is actually occurring in the WSN field (Alejandro, Jose-Maria, Esteban, Javier, Leandro, and Joan, 2005). Most especially, the reported readings of energy consumed during transmission and reception have been shown by researchers to be largely different from the actual amount of energy consumed in the network. These misleading readings often lead to mismanagement of scarce energy and computational resources (Mallinson, Hussain, and Park, 2008).

In order to address the aforementioned issues in the first order radio model, the second order radio model was proposed as an integral part of the Geographic Adaptive Fidelity (GAF) routing protocol. The second order radio model, accounts for the effects of multiple signal propagation paths and fading (Sendra, Lloret, Garcia, and Toledo, 2010). This model suits the scenario where there is a long inter-nodal distance because it accounts for a single clear line-of-sight and other multiple paths as a result of signal reflection. This model yields good performance when the inter-nodal distance is constantly large and fixed but in a scenario, where the inter-nodal distance dynamically changes, the performance degrades and poor or misleading results are obtained (Zhuang, Pan, and Cai, 2010). Unfortunately, this is often the case in WSN because the inter-nodal distance and network size are not always constant and are subject to dynamic changes. Therefore, no single radio model can suit the dynamically changing network scenario (Li, Zhang, Hao, and Li, 2011).

These problems have limited the practical implementation of cluster-based routing protocol in various industrial WSN applications. Therefore, there is a need for this research which attempt to address this issue by developing a modified radio model for Clustering Wireless Sensor Network.

1.5 RESEARCH OBJECTIVES

The main objective of this research is

1. To produce a mathematical model for the signal propagation characteristics in the sensor radio.
2. To incorporate the developed model into the design of an improved cluster based routing protocol.

3. To implement the integration of specialized data transmission scheme into the proposed cluster based routing protocol.
4. To evaluate the performance of the proposed routing protocol against set of standard cluster-based routing protocols.

1.6 RESEARCH METHODOLOGY

The research methodologies adopted in achieving the stated objectives are:

1) Literature Review

A comprehensive review of relevant literature on cluster-based routing protocols and radio models in wireless sensor network was carried out in order to be aware of the recent developments in this area of research.

2) Identification and Selection of the Key Design Features

This stage of the research involves conducting a critical examination of various cluster-based routing protocols with special emphasis on their radio models. The objective of this critical examination is to identify the limitations of the existing radio models and discover the possible areas for improvement. As a result, this leads to the proper understanding, identification and selection of the key design features needed for developing the proposed radio model.

3) Modeling of the Proposed Modified Radio Model for Cluster-Based Routing

This stage of the research entails the modeling of the proposed modified radio model for cluster-based routing. Factors that could help in enhancing the radio model in terms of practical energy conservation and better overall network performance were incorporated to develop the modified radio model for energy efficient cluster-based routing for sensor network.

4) Implementation of the Proposed Radio Model for Cluster-Based Routing