

# **ENHANCED DELAY-AWARE AND RELIABLE ROUTING PROTOCOL FOR WIRELESS SENSOR NETWORK**

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ENHANCED DELAY-AWARE AND RELIABLE ROUTING PROTOCOL FOR  
WIRELESS SENSOR NETWORK

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Dedicated to my Father Muhammad Haleem, Mother Khan Faroza, Brother Inayat Ullah, Wife and my Children, Munaima, Romaisa, Rabiha and Hadia without their support this thesis would have never been completed

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## **ABSTRACT**

Wireless Sensor Networks (WSN) are distributed low-rate data networks, consist of small sensing nodes equipped with memory, processors and short range wireless communication. The performance of WSN is always measured by the Quality of Service (QoS) parameters that are time delay, reliability and throughput. These networks are dynamic in nature and affect the QoS parameters, especially when real time data delivery is needed. Additionally, in achieving end-to-end delay and reliability, link failures are the major causes that have not been given much attention. So, there is a demanding need of an efficient routing protocol to be developed in order to minimize the delay and provide on time delivery of data in real time WSN applications. An efficient Delay-Aware Path Selection Algorithm (DAPSA) is proposed to minimize the access end-to-end delay based on hop count, link quality and residual energy metrics considering the on time packets delivery. Furthermore, an Intelligent Service Classifier Queuing Model (ISCQM) is proposed to distinguish the real time and non-real time traffic by applying service discriminating theory to ensure delivery of real time data with acceptable delay. Moreover, an Efficient Data Delivery and Recovery Scheme (EDDRS) is proposed to achieve improved packet delivery ratio and control link failures in transmission. This will then improve the overall throughput. Based on the above mentioned approaches, an Enhanced Delay-Aware and Reliable Routing Protocol (EDARRP) is developed. Simulation experiments have been performed using NS2 simulator and multiple scenarios are considered in order to examine the performance parameters. The results are compared with the state-of-the-art routing protocols Stateless Protocol for Real-Time Communication (SPEED) and Distributed Adaptive Cooperative Routing Protocol (DACR) and found that on average the proposed protocol has improved the performance in terms of end-to-end delay (30.10%), packet delivery ratio (9.26%) and throughput (5.42%). The proposed EDARRP protocol has improved the performance of WSN.

## ABSTRAK

Rangkaian Pengesan Tanpa Wayar (WSN) merupakan rangkaian data teragih berkadar rendah yang terdiri daripada nod-nod pengesan kecil yang dilengkapi dengan ingatan, pemproses dan komunikasi jarak dekat tanpa wayar. Prestasi WSN sentiasa diukur berdasarkan parameter Kualiti Perkhidmatan (QoS) iaitu masa lengahan, kebolehpercayaan dan truput. Rangkaian ini bersifat dinamik dan mempengaruhi parameter QoS, terutamanya ketika penghantaran data masa nyata diperlukan. Tambahan pula, untuk mencapai lengahan hujung-ke-hujung dan kebolehpercayaan, kegagalan penyambungan adalah penyebab utama yang tidak banyak diberi perhatian. Oleh itu, terdapat permintaan untuk membangunkan suatu protokol penghalaan yang cekap bagi meminimumkan lengahan dan menyediakan penghantaran data aplikasi tepat pada masa dalam WSN. Algoritma Pilihan Laluan Sedar Langkah (DAPSA) yang cekap dicadangkan untuk meminimumkan akses lengahan hujung-ke-hujung berdasarkan kiraan lompatan, kualiti penyambungan dan baki tenaga metrik dengan mengambil kira penghantaran paket tepat pada masanya. Tambahan pula, Model Giliran Pengelasan Perkhidmatan Pintar (ISCQM) dicadangkan untuk membezakan trafik masa nyata dan bukan masa nyata dengan mengaplikasikan teori servis diskriminasi untuk memastikan penghantaran data pada masa nyata dengan lengahan yang boleh diterima. Selain itu, Skema Mendapatkan Semula dan Penghantaran Data Efisien (EDDRS) juga dicadangkan untuk meningkatkan nisbah penghantaran paket dan mengawal kegagalan penyambungan dalam transmisi. Ini akan menambahbaik truput keseluruhan. Berdasarkan pendekatan yang dibincangkan, Protokol Penghalaan Boleh Percaya dan Sedar Kesedaran Langkah Dipertingkatkan dan Cekap (EDARRP) juga dibangunkan. Eksperimen simulasi telah dijalankan menggunakan simulator NS2 dengan pelbagai jenis senario untuk menilai parameter prestasi. Keputusan kemudiannya dibandingkan dengan protokol penghalaan terkini Protokol Tanpa Keadaan bagi Komunikasi Masa Sebenar (SPEED) dan Protokol Pengedaran Laluan Kerjasama Yang Bersesuaian (DACR), dan didapati bahawa secara purata prestasi protokol yang dicadangkan telah memperbaiki pencapaian lengahan hujung-ke-hujung (30.10%), nisbah penghantaran paket (9.26%) dan truput (5.42%). Protokol EDARRP yang dicadangkan telah meningkatkan prestasi WSN.

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## LIST OF ABBREVIATIONS

ACK	-	Acknowledgment
APHD	-	Adaptive Per Hop Differentiation
ARS	-	Access Request Sequence
CAW	-	Contention Access Window
CD	-	Contention Delay
CFW	-	Contenton Free Window
CHs	-	Cluster Heads
DACR	-	Distributed Adaptive Cooperative Routing Protocol
DAPSA	-	Delay-aware Path Selection Algorithm
DTWSN	-	Delay-tolerant WSN
EDARRP	-	Efficient Delay-Aware and Reliable Routing Protocol
EDCA	-	Enhanced Distributed Channel Access
EDDRS	-	Efficient Data Delivery and Recovery Scheme
ERP		Evolutionary-based Routing Protocol
E-SLR	-	Extensive Systematic Literature Review
FBP	-	Feedback
FP-MAC	-	Fast- periodic MAC Algorithm
IFS	-	Inter Frame Space
ISCQM	-	Intellegient Service Classifier Model
NRT	-	Non-real Time
NS2	-	Network Simulator 2
QoS		Quality of Service
RT	-	Real Time
TSP	-	Traveling Salesman Problem
WSN	-	Wireless Sensor Network

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## **CHAPTER 1**

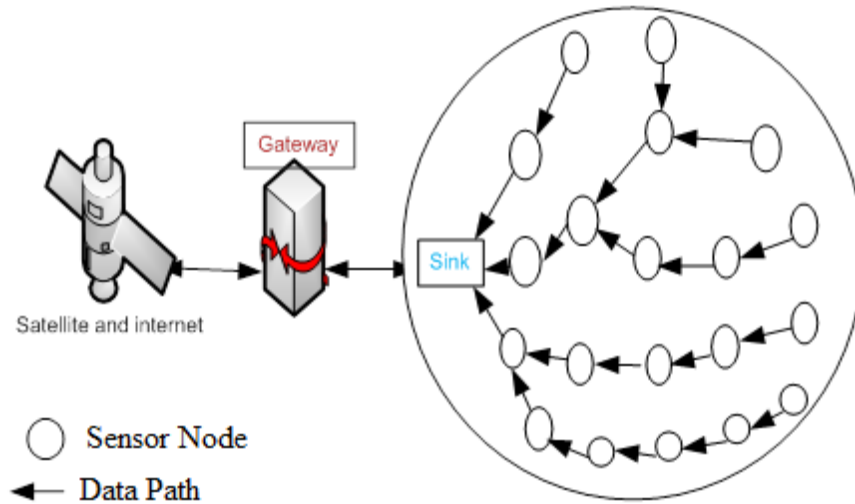
### **INTRODUCTION**

#### **1.1 Introduction**

The recent advancements and continuous increase in number of applications for Wireless Sensor Networks (WSN) have brought more and more challenges for existing systems and researchers. WSN is a kind of network which contains a large number of nodes, connected with each other, that communicate and transmit data to the sensor network (Younis *et al.*, 2014). These sensors are spread in the specific area to monitor physical or environmental conditions such as temperature, sound, pressure etc. These nodes have the capability of sensing the surrounding environment and transfer the data collected from the observed field over wireless links (Aslan *et al.*, 2012). The sensed data is forwarded through single or multi-hops transmissions to a sink node (Sumathi and Srinivas, 2012) as shown in Figure 1.1. The sink node can be the final destination or may further relay the data to other connected networks (such as Internet). The deployment of these sensor nodes can be mobile or fixed which are placed either planned or random way.

The WSN was initially used in the military environment for monitoring the battlefields (Pejanovi and Tafa, 2012). These networks were bi-directional which also enable control of the sensor activities. Now a day the WSN is commonly used in many other important areas such as air pollution monitoring, forest fire detection and industrial appliances.





**Figure 1.1** A typical multi-hop WSN (Mainwaring *et al.*, 2008)

WSN can be deployed in smaller areas having very less number of sensor nodes and on the other hand, it can also have larger scale deployment with thousands of sensors (Doherty *et al.*, 2012). The sensor node contains different number of units such as processing, transmission, sensing, position locator, power and mobilizer. The number of these units in a sensor can vary based on the nature of application and deployment requirements such as mobilizer is required only in the applications that have mobility factor (Dong and Dargie, 2013).

Sensor nodes communicate with the sink node directly or in hop-to-hop manner. The sink node can be a sensor inside the WSN or can be a gateway connecting the WSN to some external network. The WSN works in both distributed and centralized approaches. In a centralized approach, there always exists a base station or a cluster head (CH) that controls the working of the clusters or the network in terms of decisions regarding routing (Nikolidakis *et al.*, 2013) and resource allocation (He *et al.*, 2011). However, in distributed approach, the decisions of routing and resource allocations are made locally by the sensor nodes based on local measurements (Tunca *et al.*, 2014).

Most of the recent routing protocols are designed to satisfy the specific requirements of applications. The network designers and developers have achieved some improvements in Quality of Service (QoS) parameters; however, there is a

trade-off between the parameters due to their conflicting nature. For example, some data collection schemes reduce energy consumption but with the increasing delays. Furthermore, some routing protocols are aimed to improve one or two of the parameters and leave the rest such as energy (Yan *et al.*, 2013), delay (Cheng *et al.*, 2011) and reliability (Srinivas *et al.*, 2013). Different WSN applications enforce different kind of requirements on routing protocols and techniques in terms of QoS parameters such as reliability, delay and scalability. Therefore, further research is needed in order to improve QoS provision in routing protocols of WSN.

## **1.2 Problem Background**

WSN has gained the attention of researchers and industry in the last few years due to its practical applications in almost all walks of life (Zhu *et al.*, 2012; Conti and Giordano, 2014). WSN requires guaranteed QoS parameters, especially in real time applications. A number of techniques and models have been suggested by the researchers which solved the routing issues up to some extent. Still, it is the area of research which needs more focus for better provision of QoS parameters. A real time application must be reliable and delay-sensitive because QoS parameters are critical and have decisive effect on the performance of WSN. However, these QoS parameters have varying impact with respect to specific type of applications (Hammoudeh and Newman, 2013). For a reliable WSN, it is essential to have the guaranteed minimum end-to-end delay, high throughput for both real time and non-real time applications. However, some applications such as multimedia have additional requirement like low jitter and latency (Sumathi and Srinivas, 2012).

### **1.2.1 Routing Protocols in WSN**

There are three types of routing protocols in WSN: flat, hierarchical and location based routing (Al-karaki and Kamal, 2003). In flat routing, every sensor node in the network has the same functions and roles. Contrary to flat routing, the nodes play diverse functions in the hierarchical routing. The location based routing

uses nodes' locations to send data in the network. A routing protocol can be called adaptive when it is able to adjust according to the changes in network situations (Hammoudeh and Newman, 2013) considering specific performance parameters. A routing protocol should have the capability to establish performance metrics which are utilized to compute links/paths quality in order to minimize packet loss and to fulfil the requirements of applications. It should also be able to re-compute the paths in case of dynamic changes in the network (Carballido *et al.*, 2012).

Different routing protocols have been proposed in the last few years but the performance of these protocols varies with the nature of different type of applications and network architectures. A solution is to be sought for clustering in wireless and ad-hoc networks since these methods are mostly tempting for dense and large scale applications. In hierarchical routing, there are two or more tiers: the sensor nodes which placed in upper tier work as backbones and are known as Cluster Heads (CHs). The sensor nodes located in lower tiers are responsible for sensing and forwarding of data to base stations through CHs (Attea and Khalil, 2012). Nie *et al.* (2010) stated that multi-tier WSN networks are more scalable and provide greater benefits over single tier networks in terms of enhanced reliability, low cost and improved coverage. Numerous routing algorithms have been explored independently and also in context of clustering.

LEACH protocol suggested by Heinzelman *et al.* (2002) is a cluster based routing protocol that utilizes randomized variation of CHs role by equally dividing the energy capacity among the network nodes (Attea and Khalil, 2012). LEACH works very well for both constant and periodic monitoring applications that gathers and relays the data to a centralized station (Mendes and Rodrigues, 2011). LEACH is based on certain assumptions that limit its efficiency in different applications, such as single hop communication.

Attea and Khalil (2012) have suggested a new evolutionary based routing protocol to improve the unwanted actions of Evolutionary Algorithms in order to handle clustering routing problems in WSN. A novel fitness function is defined which integrates two clustering features: separation error and cohesion. Its main

purpose is to save energy of the network while requiring more modifications in awareness of node heterogeneity. Another research work has been done on the QoS parameters in WSN but still it is a critical problem to provide guaranteed solutions to all QoS parameters (Liu *et al.*, 2012). Therefore, it is an open issue for the researchers to propose some techniques or mechanisms. These standards do not provide any specific and satisfactory level of techniques to provide minimum end-to-end delay with high throughput. The real-time routing problem, specifically in the delay-constrained point to point network, is also discussed by Xu *et al.* (2009).

End-to-end delay has been a serious and challenging issue for the researchers in the last few years. The reasons for higher delay are heterogeneous network traffic, changing of network topology, burden on the network and the applications on demand. The situation becomes more complicated due to various causes, for example the obtainable synthesis of various changed and unusual network channels. To come up with a solution in order to handle such situations, end-to-end delay must be managed properly. Wang *et al.* (2012) presented that for heterogeneous traffic (real time and non-real time) the complexity of wireless sensor network increases while providing data delivery with lower delay. Additionally, the dynamic changes in the network can also affect different QoS parameters.

In order to achieve QoS for various types of applications, a generic system should be designed that can handle almost any kind of traffic. The performance of WSN can be measured by the QoS parameters such as achieving minimum end-to-end delay, more reliability, higher throughput, lower duty cycles and jitter (Yigitel *et al.*, 2011).

### **1.2.2 End-to-end Delay**

In wireless sensor networks, minimizing end-to-end delay from sensor nodes to the sink node is a critical issue. To come up with a solution for this issue, routing layer performance should also be taken into account (Yigitel *et al.*, 2011). Similarly, the minimization of medium access delay at MAC layer of the sensor devices can also ensure end-to-end delay requirements.

A multiple path selection technique has been suggested by Huang and Fang (2007) to provide guaranteed QoS parameters performance. The authors proposed a multi-constraint multi-path routing algorithm based on hop count metric to enhance both reliability and delay parameters. QoS provision is improved based on local information that is mapped on path links. The inaccurate approximation of link quality and estimation of path can cause the performance degradation in WSN. In this approach, to find a better solution of the problem the optimization issue is mapped into a linear programming problem by applying certain approximation approaches. However, many of the possible discoverable paths are ignored, which lacks the routing algorithm performance and can affect reliability and end-to-end delay of the network. Furthermore, the authors have not considered the data delivery schemes that can significantly reduce packet redundancy.

All the aforementioned QoS-aware routing protocols consider different parameters such as delay and reliability with the aim of achieving the increased WSN performance. These routing protocols either ignore the unique constraints of the real time delay-sensitive applications or consider only a single issue. In the available literature, Distributed Adaptive Cooperative Routing Protocol (DACR) is the latest QoS-aware protocol that considers both parameters of delay and reliability. DACR is a lightweight reinforcement method that provides the best relay node with least overhead. Comparatively, the DACR performs better than other state-of-the-art approaches (Liang *et al.*, 2009). However, DACR ignored the differentiation of real time and non-real time network traffic to avoid traffic overloading. Xue *et al.* (2011) have highlighted the fact that real time applications are more delay-sensitive and therefore needs to be prioritized in routing the data. While in Stateless Protocol for Real-Time Communication in Sensor Networks (SPEED), He *et al.* (2003) have considered this differentiation of traffic types only for low congested networks. The performance of SPEED decreases in heavily congested network. However, its performance gradually decreases due to link failure which affects the reliability and causes excessive delays in data delivery.

### 1.2.3 Data Reliability

Lack of reliability is also an open research issue and requires special attention for the betterment of QoS in WSN. For data reliability, standard CSMA/CA protocol is also used which works better in light traffic mode. However, in a heavy traffic load scenarios, the performance of CSMA/CA degrades quickly and hampers the communication in terms of low throughput and high delays (Nefzi and Song, 2012). In order to address these issues on time and to identify the packet losses, acknowledgement mechanisms can be utilized accordingly. Huang and Fang (2007) have suggested path diversity based routing mechanism to improve the reliable packet delivery.

Packet loss refers to the packets that have been transmitted by the source node but have not been received at the destination node (Dong *et al.*, 2014). These packets are usually dropped due to either high interference on the communication link or Cyclic Redundancy Check (CRC) failures at the receiving unit of the destination node (Sumathi and Srinivas, 2012). WSN can get dynamic behaviour, where the sensor nodes can be disconnected from the network and links can be changed due to battery depletion, environmental conditions and topological changes. These changes are caused by the network scalability where the sensor nodes may be increased or decreased. Similarly, connections between nodes may change due to mobility of nodes (Abbasi *et al.*, 2013). These aforementioned issues lead to packet loss and ultimately degrade the performance of the network. All of the above issues are the causes that affect QoS in WSN. Traffic load is based on the events occurred in the specific area. Therefore, in order to control the above mentioned changes, adaptive actions need to be taken by the MAC protocols according to the network dynamics. For example, for real time systems, in case of high-rate data transmission traffic, the sensor nodes must continue with a high duty cycle. However, in case of low-rate traffic streams, most of the sensor nodes could be reserved as passive to conserve energy.

The above mentioned discussion leads to the conclusion that most of the existing routing protocols are aimed to address only a single QoS parameters issue

such as end-to-end delay, reliability issue or trade-off between the both. None of these routing protocols consider the real time and non-real time network traffics, reliability and the link failure issues of WSN.

### **1.3 Problem Statement**

In WSN, QoS is affected by a number of parameters such as end-to-end delay, reliability and topology changes. The real time WSN has unique challenges and constraints of QoS parameters such as, delay-sensitivity and reliable data delivery. Different mechanisms have been suggested in literature (He *et al.*, 2003; Al-anbagi *et al.*, 2013) that consider end-to-end delay as the critical issue which needs to be enhanced in order to get efficiency. Furthermore, the issues of reliability also need to be enhanced to address the issue which occur due to dynamic network topology. Therefore, the QoS requirements of routing protocols are mainly determined by the features served in WSN applications. Most of the existing routing protocols are based on the specific application. Therefore, further enhancement is required in these protocols to make them adaptive that can satisfy the dynamic requirements of different applications. The recent advancement of WSN applications has introduced the multiplicity of nodes which increases challenges for designers to develop new protocols and improve the performance. In this research work, adaptive techniques are proposed by enhancing existing techniques for obtaining better results and improvements in terms of QoS parameters. Through an extensive literature review, it is found that no one has worked on this research theme. Hence, a protocol which alleviates the mentioned features is required.

### **1.4 Research Questions**

The following research questions will be addressed:

- i. How to reduce end-to-end delay in order to deliver real time data in a certain time threshold.
- ii. How to distinguish real time and non-real time data packets to improve overall throughput of wireless sensor network.
- iii. How to improve packet delivery ratio, to guarantee quick recovery from link failures and to ensure reliability of data transmission with acceptable delay.

### **1.5 Research Aim**

The aim of this research is to come up with a new routing protocol which will be able to improve the medium access and to provide low end-to-end delay to get the high level efficiency in the wireless sensor networks. The aim of designing a queuing model is to distinguish the real time and non-real time traffic of the network and forward the traffic accordingly. Furthermore, an efficient data delivery and recovery scheme is also aimed at improving packet delivery and recovering the lost data packets due to links or transmission failures. So, the development of a routing protocol which will facilitate the aforementioned requirements is the main aim of this research oriented work

### **1.6 Research Objectives**

The following research objectives are to be achieved during the research work. These objectives are in the perspective of the research questions mentioned above.

- i. To design and develop an efficient delay aware routing algorithm based on hop count metric using multi-path selection to achieve minimum end-to-end delay.
- ii. To design and develop an intelligent Queuing model that identifies and distinguishes the real time and non-real time traffic and forwards the traffic efficiently.



- iii. To design and develop an efficient data delivery and recovery scheme that ensures packet delivery and recovery caused by broken links and transmissions failures during the data transmissions.

## 1.7 Research Scope

To know and understand the scope of the proposed research, one needs to know issues related to the QoS parameters in depth. The scope of this research work covers the issues related to QoS parameters in WSN. The real time data delivery and reliability are both the desired aspects of this research work. This research work enhances QoS required for both real time and non-real time applications which provides reliable and time bound data delivery to the users. The scope of this research work is as follows.

- i. In WSN, the network traffic can be of both real time and non-real time nature. These types of traffic have their own delay-constraints which need to be considered accordingly. This research work focuses on routing mechanism for both real time and non-real time communication.
- ii. The deployment of sensor networks can be planned or random which is based on the type of applications. The proposed work is applicable for both types of deployment as far as the sensors are in the communication range of each other.
- iii. The topology of WSN is sometimes affected by the movement of sensors which may have decisive effect on routing. Therefore, this research does not consider sensors' mobility. However, sometimes static topologies are also affected by node failures and lead to link failure which are considered in this research work.

## **1.8 Significance of the Study**

The use of this research work can be substantial in different real life applications such air control system, industrial applications where on time data delivery is required. The routing is a key factor which degrades or improves the overall performance of the network. In this work, the delay and reliability features of real time traffic and non-real time are quantified on the basis of hop-count, residual energy and link quality. This research provides both delay-tolerant and delay-sensitive data delivery depending upon the type of application. The proposed research provides the reliable data delivery with reduced delay in WSN. The traffic load is classified by distinguishing the type of traffic which reduces the link failure and improves the performance of WSN.

## **1.9 Organization of Thesis**

The remaining of the thesis is organized as follows: Chapter 2 provides a detailed literature review about the latest work in the field of WSN with respect to routing issues and their existing solutions. Different techniques used for improving reliability, minimizing delay and maintainability of the quality of services classes are elaborated. Chapter 3 presents the research methodology, including the operational framework for the design and development of an enhanced delay-aware and reliable routing protocol (EDARRP) for WSN. It consists of three components namely DAPSA, ISCQM and EDDRS. Chapter 4 provides discussion on the first component that is designing and development of the Delay-Aware Path Selection Algorithm (DAPSA).

Chapter 5 presents the second and third components that are designing and development of an Intelligence Service Classifier Queuing Model (ISCQM) and an Efficient Data Delivery and Recovery Scheme (EDDRS). Chapter 6 is the detailed description of the evaluation and results of the proposed routing protocol and its comparison with state-of-the-art protocols. Chapter 7 concludes and describes the contributions of this research with possible future directions.

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