LOW LATENCY ROUTING IN MOBILE WIRELESS SENSOR NETWORKS FOR MOBILE SINK CONDITIONS

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PREFACE

Welcome to "Low Latency Routing in Mobile Wireless Sensor Networks for Mobile Sink Conditions." This book explores the intricate landscape of wireless sensor networks (WSNs) with a focus on addressing two critical challenges: network lifetime limitation and latency minimization in the presence of mobile sink conditions.

As our world embraces large-scale automation, the deployment of WSNs becomes increasingly vital in applications where human intervention is impractical or hazardous. However, the effectiveness of these networks is often hindered by energy constraints and latency issues.

In this book, we delve into innovative routing algorithms designed to mitigate energy consumption while optimizing latency. Our approach leverages particle swarm optimization (PSO) to dynamically adjust inter and intra-cluster distances, thus minimizing energy expenditure and enhancing system sensitivity to environmental changes. Additionally, we explore methods to reduce data redundancy and transmission overhead by implementing threshold-based data sensing and transmission strategies.

The proposed methodologies are rigorously evaluated based on network parameters such as energy consumption, one-hop delay, and overall network delay. Through comparative analysis, we demonstrate the superior performance of our approach over existing techniques, highlighting its efficacy in prolonging network lifetime and ensuring timely data delivery in time-critical applications.

I invite you, dear reader, to embark on a journey through the pages of this book as we unravel the complexities of low latency routing in mobile wireless sensor networks. May the insights gleaned from these pages inspire innovation and pave the way for advancements in the field.

Thank you for joining me on this intellectual exploration.

ACKNOWLEDGEMENTS

I am deeply grateful to everyone who contributed to the creation of this book. Your support, encouragement, and guidance have been invaluable throughout this journey.

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I like to express my special thanks to Mr. Rakesh Giri Goswami, Assistant Professor, Medicaps University, Indore for the time and efforts he provided throughout the year. Your useful advice and suggestions were really helpful to me during the book completion. In this aspect, I am eternally grateful to you.

I would like to express my gratitude to the team at CRDEEP Publications, especially Dr. Pananjay Kartikey Tiwari (Chief Editor), Dr. Akshat Uniyal (Associate Editor), Dr. Deepti (Associate Editor), Er. Anil Bist (Graphic Designer), Mr. Tanmay (Proof Reading), and Dr. Anjana Chouhan (Proof Reading and Assistant. Editor), for their professionalism and expertise in bringing this book to publication. Your dedication and hard work are truly appreciated.

Lastly, I want to thank my readers for their interest in this book. It is my sincere hope that you find it insightful and thought-provoking.

Thank you all for being a part of this journey.

Ravi Bamanke

ABSTRACT

With large scale automation, several applications have seen the use of wireless sensor networks (WSNs) being used where human intervention can be fatal or infeasible in approach. One of the major challenges which wireless sensor networks face is the limitation of the network lifetime and latency of the system. The wireless sensor networks are typically battery operated and hence are constrained in terms of energy. More energy consumption would mean lesser network lifetime and frequent stalling of the operative system to replenish the drained out power sources. Hence routing algorithms which consume less energy are always sought after. Another critical aspect of the design of wireless sensor network is the latency minimization. If this delay or latency is large, then the system becomes less sensitive to changes in the environment where the WSN is installed. This can prove to be of serious importance for time critical applications. In the proposed work, the inter and intra cluster distances are minimized by using the particle swarm optimization to decide the clustering dynamically for each iteration. The essence of the particle swarm optimization is its capability to solve complex multivariate problems with tight bound limiting conditions and no unique solution. The redundancy in the data sensed and transmitted in WSNs is also a known fact and this can be lead to redundant data transmissions and hence large energy expenditure. This is minimized by deciding and setting up of a cap or threshold of the sensed values. Till the limit or threshold is crossed, re-transmissions are not done. The evaluation of the proposed approached based on a PSO-threshold optimization is done based on the network parameters such as the energy consumption, the one hop and network delay of the system. It has been shown that the proposed system outperforms the previously existing technique in terms of the performance evaluation parameters of the designed wireless sensor network.

Keywords: *Wireless Sensor Networks, Dynamic Routing, Particle Swarm Optimization, , Latency, Energy Consumption, Network Lifetime*

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
WSN	*Network Lifetime Wireless Sensor*
N.L.	*Networks*
D.C.	*Duty Particle Swarm*
P.S.O.	*Optimization Cycle*

CHAPTER - 1

INTRODUCTION

1.1 Basic Overview of Wireless Sensor Networks

The domain of Wireless Sensor Networks is emerging with rapid advancement and has taken a very important place in wireless sensor networks. The utility of the wireless sensor technology has benefitted the vast number of industries and the economy at large. The world is steadily and gradually converting to wireless technologies [1]. The sensors help in the communication of the signals and play a very crucial role in the wireless communication through the WSN. The wireless sensor networks also comprise of wireless sensors [2]. There are certain parameters that impact the performance with respect to wireless sensor networks. The power saver parameter is another performance metric related to the WSN [31].

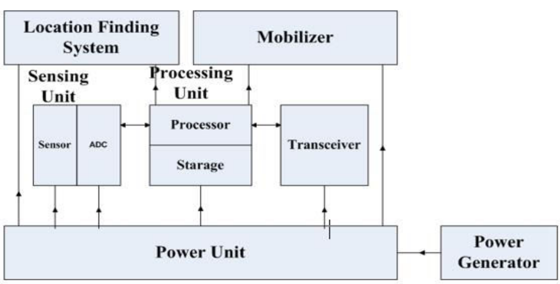

Fig. 1.1 Basic Architecture of Wireless Sensor Network

Wireless Communication plays a significant role in the day to day communication scenario. In the recent days, the majority of the communication that takes place is wireless. The wireless sensors are responsible for converting the associated signals through the wireless indicators. These sensors form an indispensable part for the wireless communication [4].

1.2 Wireless Sensor Networks History and Types

The Wireless Sensor Network's origin and existence can be tracked back to the 1950's.It was of the form of sound surveillance system. It was created by the US military for the investigation of the Russian submarines. Many other kinds of electronic equipment's were utilized for use in the Atlantic waters. Henceforth the use of the WSN's started way back in the early times when this concept of the wireless communications was relatively novel. Then with the introduction of the cordless phones and advent of cell phones just brought a paradigm shift in the communication domain and the wireless sensor networks started rising. DARPA also initiated research on WSN [33].

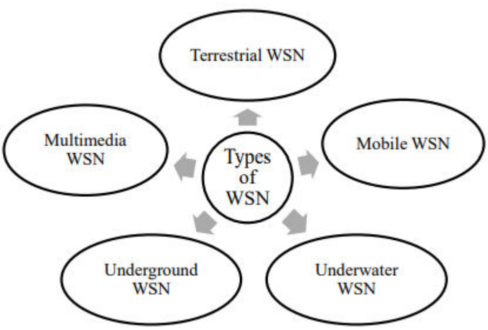

Fig. 1.2 Five Basic Types of Wireless Sensor Networks

The above diagram shows the main basic types of the wireless sensor networks. It includes the Terrestrial WSN's, Mobile WSN's, and Multimedia WSN's, Underground WSN's and Underwater WSN's. These major WSN types have got their immense applications in the every domain of wireless communications. These networks consist of multiple sensors in an arranged manner that forms clusters to yield high performances [5]-[6].

1.3 Design of WSN and Topologies

The design of the Wireless Sensor networks consists of various topologies on which the WSN is based. They include the star, mesh and tree topologies. There are some specific design metrics for WSN. These are the ideal metrics on which the Wireless Sensor Networks must be designed. These are as follows:-

1.3.1 Reliability Factor

The reliability factor is a major metric for the wireless sensor networks. The primary work of the sensors is to send the signals properly to the control station. The communication between the sensor nodes must fulfil the reliability conditions. The communication must conform totwo kinds of the metric that are with respect to packet and hop by hop.

1.3.2 Size and Density of Network

The size and density of the WSN is also of primary importance and indicative of a good design. The sensor size plays a crucial role in the performance of the communication. The thickness of the sensor nodes must be well though and designed properly. The densities of the sensor nodes that form the cluster also affect the network performance [33].

The density of the network is calculated as below:-

$$\mu(\mathrm{R}) = (\mathrm{N}\pi\mathrm{R2})/\mathrm{A} \tag{1.1}$$

Where A, and R signifies the radio signal transmission range,
N is the sensor nodes scattered in that particular area,
(R) yields number of nodes existing in the range of transmission of each node in area A.

1.3.3 Sensor Network Topology [31]

The wireless sensor network topology also is of immense importance. It has a great and profound impact on the entire design of the WSN and its network performance. Any topology that is used like the mesh, star or tree has to be properly planned and used. The routing quality also is dependent on the node clusters which are thereby dependent on the topology of the WSN.

1.3.4 Energy Consumption of WSN

A very prominent and crucial factor for any WSN set up is its energy consumption metric. The primary goal of every WSN has to be minimal consumption by the WSN network. The sensor nodes are battery operated hence the lifetime of the WSN relies on the battery lifetime and its quality. Hence forth the design must be in accordance with the routing and design protocols. All the functions must consume minimum power. The power consumption factor has to be considered diligently. Better the energy consumption metric better will be the performance.

1.3.5 Hardware Requirements

The hardware requisite is another aspect for the proper functioning of the WSN. The WSN is generally composed of various sensor nodes. It also consists of base stations and sensor nodes of the network. The network is mainly responsible for the monitoring of any physical condition like temperature change. Hence the hardware is mainly built around the sensor node. So the sensor node hardware must fulfil nest performance parameters for efficient result.

1.3.6 Quality of Connection

The connection quality of the WSN is also of great necessity. The entire routing and the WSN function greatly depend on the connection strength and quality of the WSN.The protocol of the transmission of the information is greatly dependent on the connection quality.

1.3.7 Service Quality in WSN

The service quality is also another metric that decides the performance of the WSN. The overall design must abide by the time constraints. The service must be robust and it must fulfil the necessary conditions.

1.3.8Transmission Medium

The transmission media of the WSN plays a key role in the protocol design of the WSN. Several transmission modes and methods are prevalent but the choice of the mode must be such that the performance is optimal considering all factors.

1.4 Applications and Uses of WSN [32]-[33].

Wireless Sensor Networks are the primary constituent for the wireless communication. They provide several uses and benefits for seamless wireless communication. There are diverse domains where the applications of the WSN's are prevalent. It is as follows:-

- They are used as a part of defence operations. Where it can be used to sense attacks.
- The WSN is also used in disaster management operations where it can help in sensing impending incidents of disasters.
- It is primarily used for the construction operations for building better constructions.
- It is immensely used in the health tracking systems for patients.
- One of the main uses of the WSN in day to day life is traffic monitoring and tracking.
- The wireless sensor networks are also implemented as a part of surveillance systems.

1.5 Motivation for Proposed Work

The wireless sensor networks have been a driving force in the field of wireless communications. There have been also areas of enormous research in this field to improve the network lifetime. With higher uses of the WSN's in today's world, the performance improvement factor is also a considerable area of research. The main motivation of this proposed work is to minimize the energy consumption of the WSN and reduction in delay so as to improve the performance of the wireless sensor networks.

1.6 Objective

The primary objective of the proposed work is to increase network lifetime of the wireless sensor networks by reducing the consumption of energy and optimizing it to the best of its performance. The main goal is to design such a system model that enhances the overall performance by optimizing the energy consumption. Many research works have been done before in this domain but an improved solution has to seek in order to create a robust system for the better performance of the wireless sensor networks. The network lifetime has to increase and a low latency mechanism has to be gained for the proposed system.

1.7 Outline of Thesis

Chapter-1	Introduction: This gives the basic introduction to the concept of wireless communication and the use of wireless sensor networks. It also presents the objective, motivation and uses of the wireless sensor networks.
Chapter-2	Literature Review: This chapter puts focus on the various research works done previously in this field and discusses its merits and demerits.

	The various aspects of the previous works are carried out in this review.
Chapter-3	Problem Formulation: This chapter discusses the challenges faced in this context of work and possible solution methods to combats those problems.
Chapter-4	Proposed Methodology: This chapter deals with the approach used to implement the proposed system.
Chapter-5	Results and Discussions: This chapter puts forth the results of the proposed system.
Chapter-6	Conclusion and Future Scope: This chapter puts the concluding remarks regarding the work and also the possible enhancements to the present work done.

CHAPTER-2

LITERATURE SURVEY

This chapter discusses the various previous research works that were done in this domain and context. It enlists its various features and also areas of further improvisation.

In IEEE 2018, [1] Huang et al. proposed a communication system based on the low latency for mobile wireless sensor control systems.It is based on the multi hop relay transmissions that could provide better stability for the network communication. The network delay was considerably reduced.

Only the energy consumption of the system was more compared to what was anticipated. This is one area that could improve for better performance.

In IEEE 2018, [2]Ashish Pandey et al. proposed Lifetime Enhancement of Wireless Sensor Networks by using Sine Cosine optimization Algorithm. Wireless sensor networks have been the major highlight for wireless communication. In this the author used a novel approach of sine cosine optimization that worked fair. The network lifetime was increased. The optimization technology was good.

But the system faced a network delay that was major problem. The delay in network impacts the overall network performance so it needs to be reduced.

In Springer 2018, [3]Songyut Phoemphon et al. proposed An enhanced wireless sensor network localization scheme for radio irregularity models using hybrid fuzzy deep extreme learning machines. With the advent of artificial intelligence and fuzzy logic methods, it is being used for improvements and advancements. The localization method successfully enhanced the wireless network performance.

One area that could see betterment was the distribution of the cluster of nodes. The node cluster distribution has to be robust for the WSN system to work efficiently.

In IEEE 2017, [4] Padmalaya Nayak et al. proposed Energy Efficient Clustering Algorithm for Multi-Hop Wireless Sensor Network Using Type-2 Fuzzy Logic. The topology of the WSN plays a major role in deciding the network performance. The clustering could achieve better arrangement.

The topology could be used in a hybrid approach for better functioning of the cluster heads.

In Elsevier 2017, [5], Kgotlaetsile Mathews et al. put forth a technique for software defined radio (SDR) concept for wireless sensor networks. The software defined radio concept was novel for the wireless communication. The channel state information was evaluated and utilized for enhancing the network lifetime.

The cluster functioning could be more optimized to make the topology work in its favour. The clusters of nodes that perform the sensing work need to be arranged very well for seamless performance.

In IEEE 2017, [6] Cheng Zhan et al. presented the concept of UAV enabled data collection in wireless sensor networks. The primary goal of every WSN has to be minimal consumption by the WSN network. The sensor nodes are battery operated hence the lifetime of the WSN relies on the battery lifetime and its quality. As the network lifetime relies on the battery, it has to be optimally used. The consumption was greatly reduced. But the network delay increased than the ideal standards.

Minimum network delay has to be maintained for the WSN to yield better performance and perform to its optimal level.

In Springer 2016, [7]Venu Madhav Kuthadi et al. proposed An Enhanced Security Pattern for Wireless Sensor Network. The security aspect of the WSN is also of immense use. Along with the performance, the data must be safe in the communication. The author worked on a novel security pattern for protection of data.

The security was significantly enhanced but it also increased the power consumption. Measures need to be taken to reduce the power consumption in the WSN.

In IEEE 2016, [8], Ju Ren et al. analysed the lifetime and energy holes in Wireless Sensor Networks. The power consumption factor has to be considered diligently. Better the energy consumption metric better will be the performance. The congestion of data was reduced. It led to reduced delays as well.

But the consumption of power increased and also one hop delays significant. It needed further improvisation and better analysis.

In IEEE 2016, [9], Mianxiong Dong et al. proposed a novel method to increase the lifetime and also decrease the delay in wireless sensor networks. It considered improving the transport delay and implemented a joint optimization approach. The main goal was to increase the lifetime of the network.

The network lifetime was increased and improved. The cluster heads used less power due to the optimization. But there existed reliable connection issues. The quality of the transmission and connection was not upto the mark that needed further manoeuvre.

In IEEE 2015, [10]Alekha Kumar Mishra et al. proposed an enhancement of PEGASIS protocol with improved network lifetime for Wireless Sensor Networks. The better protocol and design is of the WSN, the better is the performance of the WSN. The author here proposed a novel protocol for the WSN system. The lifetime of the WSN improved drastically and it yielded very good throughput.

The one thing that hindered the performance was the high data congestion during transmission that led to more network delay and one hop delays. Delays in the WSN massively impact the performance and functioning capacity. Hence it required improvement.

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CHAPTER-3

PROBLEM FORMULATION

3.1 Identification of Challenges in WSNs

The problem formulation for wireless sensor networks (WSNs) can be categorized as:

1) Generic problems associated with the design of a particular approach for WSNs
2) Problems identified in the previous work done in the domain.

Both the problems are identified subsequently:

3.2Challenges Associated with WSN Design:

The challenges associated with the WSN design can be sue to the following inherent limitations of WSNs:

1) Energy Consumption: The key challenge is to minimize the energy consumption of the proposed routing algorithm. As the number of nodes increase in the WSN, the energy required to aggregate and transmit the data also increases resulting in the increase of energy consumption. This leads to the degradation of network lifetime of the system which is detrimental to the system performance [5]-[7].
2) Dead Nodes: This is also an associated problem which occurs due to the energy depletion or degradation of the nodes which makes them incapable to transmit or receive data [8]-[10]. This makes parts or the entire network dysfunctional.
3) Latency: This the time lag corresponding to the time the event to be captured occurs and the time the data is sent to the control

station. Larger latencies makes the system slow and less responsive to input changes [11]-[14].

4) Mobility of sinks: This is also a challenge if the sink or the control station is mobile. This makes it mandatory to re-route the data through nodes which are nearer to the sink [15]. Typically, the data to be routed through the nodes near to sink is considerably larger than the data that is routed through sinks which are far away from the sinks. There clearly exists a trade-off between the data quantity and the latency [16]-[18].

The visual representation of the mobile sink situation is depicted in the figure below:

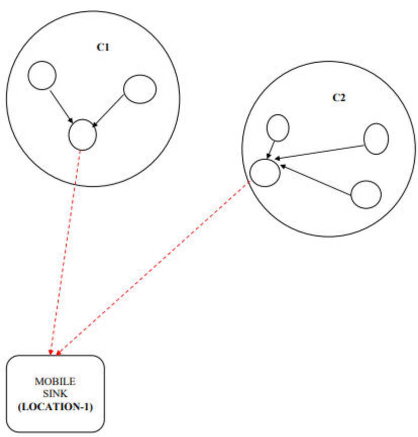

Fig. 3.1 The mobile sink situation with sink at location -1

The figure above depicts the mobile sink location for the sink at location -1 and the cluster sizes and heads chosen accordingly.

The configuration of the WSN needs to be changed when the sink changes as shown by figure 3.2

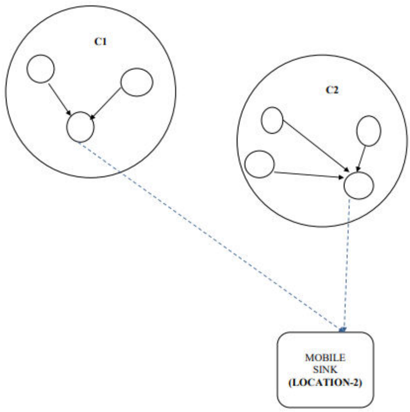

Fig.3.2 The mobile sink situation with sink at location -2

The location of mobile sink makes the routes change for the optimal transmission [19]-[20]. This helps to choose the nodes which are the nearest to the sink. Thus mobile sinks needs more adaptability compared to normal immobile sinks [21]-[23].

3.3 Research Gap with regards to previous work

The research gap with regards to previous work is cited here so as to find out the shortcomings of previously existing techniques.

In [1], only the energy consumption of the system was more compared to what was anticipated. This is one area that could improve for better performance.

In [2], the system faced a network delay that was major problem. The delay in network impacts the overall network performance so it needs to be reduced.

In [3], an area unaddressed was the distribution of the cluster of nodes. The node cluster distribution has to be robust for the WSN system to work efficiently.

In [4], fixed clustering topologies were used but the topology could be used in a hybrid approach for better functioning of the cluster heads.

In [5], the cluster functioning could be more optimized to make the topology work in its favour. The clusters of nodes that perform the sensing work need to be arranged very well for seamless performance.

In [6], no latency minimization for multi-hop network was analysed. Minimum network delay has to be maintained for the WSN to yield better performance and perform to its optimal level.

In [7], the energy consumption was not reduced. The security was significantly enhanced but it also increased the power consumption. Measures need to be taken to reduce the power consumption in the WSN, otherwise this could lead to dead noses impairing the system performance.

In [8], the inter and intra-cluster distances were not simultaneously reduced in accordance to each other thereby increasing the distance of transmission and hence the delay and energy consumption of the network.

In [9], The network lifetime was increased and improved. The cluster heads used less power due to the optimization. But there existed reliable connection issues. The quality of the transmission and connection was not up-to the mark that needed further manoeuvre.

In [10], The one thing that hindered the performance was the high data congestion during transmission that led to more network delay and one hop delays. Delays in the WSN massively impact the performance and functioning capacity. Hence it required improvement.

Thus two major facets were seen in the WSN routing protocols:

1) If the number of nodes in a cluster was increased, the energy consumption would go down but the delays would increase [24].
2) Decreasing the nodes in a cluster would increase the energy consumption of the system.
3) Thus a trade-off existed between the cluster size, energy consumption and the delay of the system which needed optimization as the key solution. This paves the path for the design of the proposed approach.

CHAPTER-4

PROPOSED METHODOLOGY

4.1 Models in Wireless Sensor Networks

Quite often, wireless sensor networks are categorized as homogenous networks and heterogeneous networks. Commonly, conditions of heterogeneity exist in WSNs [32]. Hence the impact and classification of heterogeneous networks is shown in the figure below.

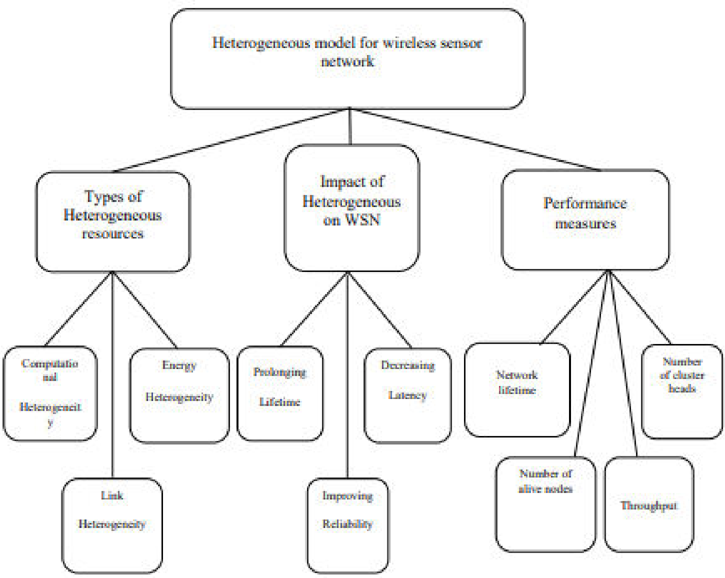

Fig. 4.1 Classification and Impact of Heterogeneity on Wireless Sensor Networks

The heterogeneity in wireless sensor networks can be in several aspects such as initial energy, computation and clustering, duty cycle etc. The variation in the parameters resulting in heterogeneity impacts the performance or output parameters of the wireless sensor networks and overall functioning. The critical aspects of

4.2 Clustered Networks

The need for clustering in a wireless sensor network is of fundamental importance. It helps to regularize the network and decrease the energy consumption [25]-[26]. The concept of data transfer with and without clustering is shown in the figure below:

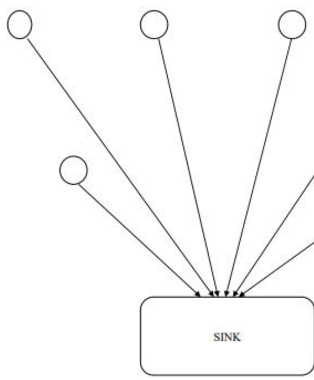

Fig. 4.2Data Transfer without clustering

The discrete transfer of data from individual nodes to the sink consumes more energy compared to clustered network in which the following operations take place [27]-[28]:

1) Nodes are grouped into clusters
2) Each cluster is allotted a cluster head (CH)
3) Cluster heads aggregate the data and transmit to the sink.

The process is depicted in the figure below:

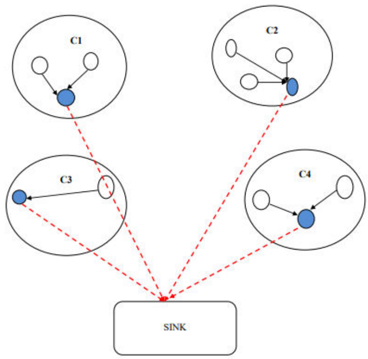

Fig. 4.3 Data Transfer in Clustered Networks

Fundamentally, there are three types of data transfer in WSNs which are:

1) Intra Cluster
2) Inter Cluster
3) Between CH and Sink

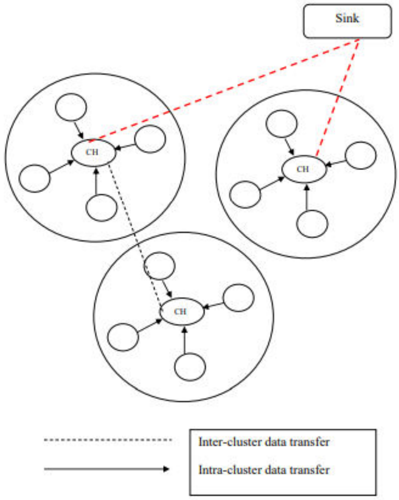

Fig. 4.4 Types of Data Transfer in Clustered Networks

The inter cluster and intra-cluster distances are critical in deciding the energy consumption and the latency of the network. Hence an algorithm that optimizes all parameters is necessary.

4.3 Proposed Algorithm

The proposed approach can be understood as the sequential implementation of the following steps:

1) Decide the cluster size dynamically so as to distributed nodes in a manner to minimize inter cluster and intra-cluster distances. The number of nodes in a cluster need not be fixed in each iteration of data transfer.
2) The cluster heads of each iteration change and is based on the average residual energy of each node in a cluster. Thus the CH of a cluster ‘n’ for an iteration ‘t’ would depend on the following mathematical condition:

$$E(CH_{n,k}) = \max[(E_1, E_2 \dots\dots\dots\dots\dots\dots E_m)_{n,k}] \quad (4.1)$$

   Here,
   m is the number of nodes in the particular cluster, which may vary from cluster to cluster
   n is the cluster index
   k is the iteration number
   E denotes the maximum energy
3) Since the inter-cluster and intra-cluster distances need to be optimized in each iteration based on a new cluster head, hence all the three parameters vary randomly in each iteration. This optimization problem becomes challengingly non-trivial for large number of nodes and clusters which is typically the case for most practical wireless sensor networks. The solution to point 3 lies in the use of a optimization technique to be adopted. The approach adopted here is the particle swarm optimization.

4) Since the data sensed is generally redundant and quasi static in nature, hence the energy can be saved by minimizing re-transmission of redundant data samples. This is done by deciding a cap or threshold percentage for the transmission to occur.
5) Compute evaluation parameters such as energy consumption and latency.

4.3.1 The Particle Swarm Optimization:

The particle swarm optimization is an extremely effective technique for multi-variate optimization problems subject to constraints in time critical situations [28]-[30]. This approach is basically based on the behaviour of groups of birds and their behavioural patterns. In this approach, the following terms are used:

Particle: The particle denotes a bird which is a probable solution to a problem at a time 't'

Swarm: This swarm is a group of possible solutions to a problem at a time 't'

The analogy of the PSO in finding a solution is as follows:

The flock of birds need to reach a certain destination collectively as a flock. The individual birds may fly in different ways but based on:

1) Individual best performance in each iteration
2) Flock's best performance in each iteration

The flocks overall position and velocity are decided. Similarly, if multiple solutions are possible for an optimization problem, each of the solutions are randomly initialized, then they are imparted their own velocities to reach an optimal value. In each iteration, each of the solution checks its individual best and the groups best and then decide and update its best solution. Thus it is an iterative approach, mathematically:

$$\mathrm{vel(k)} = \mathrm{w} \times \mathrm{vel(k-1)} + \mathrm{L1}\alpha_1[\mathrm{p_i}\text{-}\mathrm{x_i(k\text{-}1)}] + \mathrm{L2}\alpha_2[p_g\text{-}\mathrm{x_i(k\text{-}1)}] \quad (5.1)$$

$$\mathrm{x_i(k)} = \mathrm{x_i(k-1)} + \mathrm{vel(k)} \quad (5.2)$$

Here,
vel is the particle velocity
k is the iteration
L1 and L2 are learning factor values
x_i *is the particle position*
α_1 *and* α_2 *are random number values*
w represents the weights
p_i *represents particle's individual best position*
p_g *represents group's best position*

The PSO is applied at the sink controlling the clustering process. The use of the PSO is critical in setting up of the network which is followed by the steady state data sharing. The PSO optimizes the cluster size so as to minimize both the intra and inter cluster distances which as a result decrease the energy consumption and latency. This is done by minimizing the PSO cost function given mathematically as:

$$\mathrm{cost(k)} = \lambda \mathrm{g1} + (1-\lambda)\mathrm{g2} \quad (5.3)$$

Here,
g1 is the maximum mean of Euclidean distance of nodes to their CH
g2 is the ratio of total initial energy of all nodes n_i, *i=1,2,…,N in the network to the total current energy of the cluster heads candidates in the current round.*

λ *is the fitting parameter*

4.3.2 Reducing Energy Consumption by Avoiding Redundant Transmissions

Without loss of generality, it can be stated that the sensors continuously keep sensing the data. However, the data generally does NOT change very quickly.
Ex: 100, 100, 101, 101.2, 103.1, **105.8,109…….**

We can see that the data changes slowly till 103.1.

So sending all the values may NOT be useful but increases the number of transmissions and the energy consumption. It is better to decide a threshold (5%) here so re-transmit. So, if the limit or threshold of 5% is crosses, only then re-transmissions will occur. This saves the energy of the system. Thus a threshold or cap of 5% is set for re-transmission values. Thus re-transmission occurs as per the following condition:

Initialize transmission
If (sensed value stabilizes & Threshold ~ reached & delay ~ exceeded)
{
Do no re-transmit data
}
Else if (Value stabilizes &Threshold reached)
{
Re-Transmit Data
}

The entire concept can be summarized in the flowchart of the system given below:

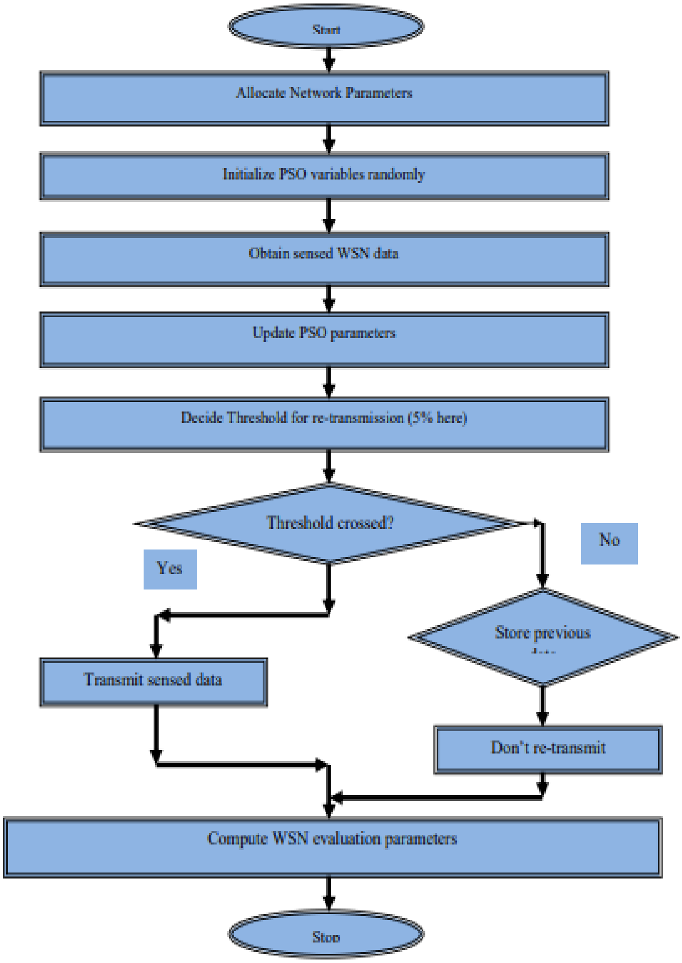

Fig. 4.5 Flowchart of Proposed System

4.4 Evaluation Parameter

Duty Cycle: This is a measure of the active to active plus idle state of a node

$$DC = \frac{T_{ON}}{T_{ON}+T_{OFF}} \tag{5.4}$$

Here,
DC is duty cycle
T_{ON} *is on-state time*
T_{OFF} *is the off-state time*
Its conspicuous that increasing duty cycle increase expenditure of energy.

Energy Consumption: It tells about the expenditure of total energy. Mathematically [1]:

$$E_{ToT} = (\int_i^f E(t)_{LPL} + \int_i^f E(t)_T + \int_i^f E(t)_R)dt \tag{5.5}$$

Here,
i is the initial time
f is the final time
E(t) is energy dependency on time
LPL is low power listening i.e. energy expenditure in sensing but no transmission
R is received energy
T is transmitted energy

Delay: The delay in computed as:

$$\delta = \sum_{i=1}^{m}[\delta_f^i + \delta_t^i] \tag{5.6}$$

Here,
δ is total delay
f is the find mode delay
t is the transmission mode delay
m is the number of hops for data to reach from source to sink

Network Latency: It is a measure of the difference in time of sensing and the time of reaching the sink which is mathematically given by:

$$L = \frac{1}{n}\sum_{i=1}^{n} T_i^S - T_i^r \tag{5.7}$$

Here,

L is the average latency

n is the number of nodes

T_i^S *represents the sensing time node 'i'*

T_i^r *represents the data reaching time of node 'i'*

The results on the implementation of the system are depicted in the next chapter.

CHAPTER-5

RESULTS AND DISCUSSIONS

5.1Experimental Results

The experiment has been set up on the software package Matlab 2018a. The simulation parameters chosen are:

Table 5.1 Simulation Parameters

S.No.	Parameter	Value
1.	Length	100m
2.	Breadth	100m
3.	Maximum Distance of Mobile Sink	150m
4.	Clustering Approach	PSO
5.	Re-transmission Threshold	5%
6.	Initial Energy	0.1J
7.	Tool	Matrix Laboratory (Matlab R2018a)
8.	System RAM	8GB
9.	Operating System	Windows 10

The system parameters depict the values of the parameters which are used for the set up and subsequent execution of the system. The performance evaluation parameters are:

1) Average residual energy of nodes
2) Energy consumption
3) One hop delay
4) Network delay

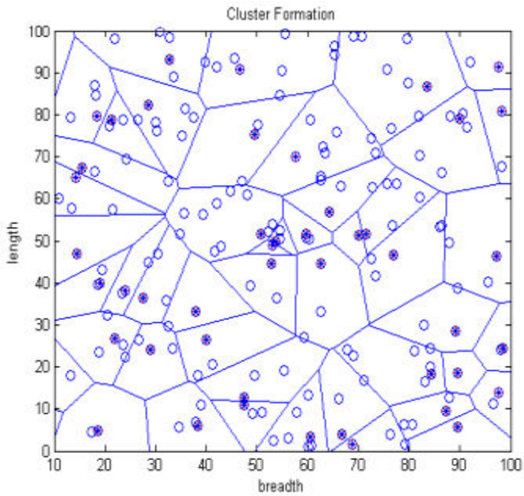

Fig 5.1 Clustering formation

The above figure depicts the final steady state of the cluster formation of the 100m x 100m field area network.

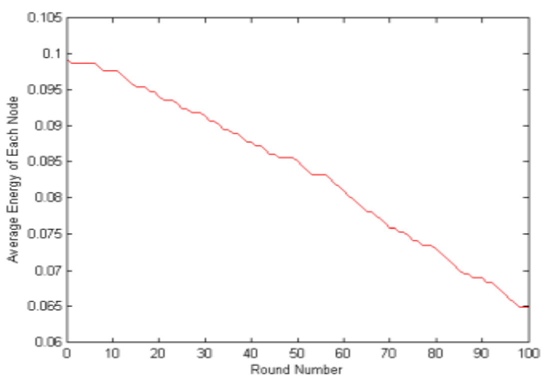

Fig. 5.2 Variation of residual energy

The figure above depicts the variation of average residual energy as a function of epochs. The following points are to be noted:

1) The initial energy is 0.1 J

2) The energy decays monotonically

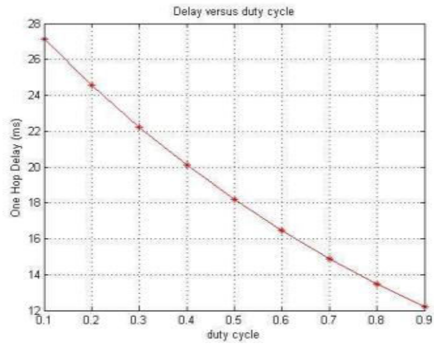

Fig. 5.3 Variation of one hop delay of network

The above figure depicts the variation of the one hop delay of the network in accordance with the duty cycle of the system.

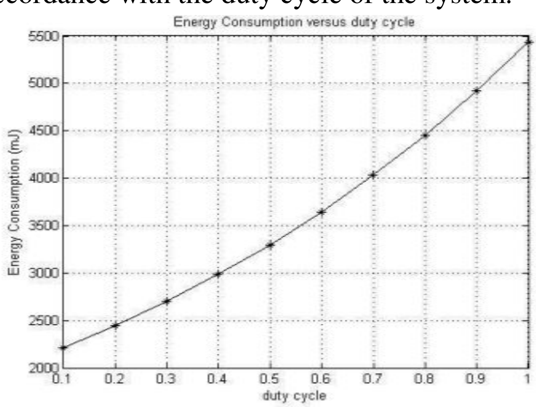

Fig. 5.4 Variation of energy consumption with a value of r=80

The above graph shows the changes in the energy consumption with respect to two variables:

1) Duty cycle
2) Distance of sink for a value of 80m.

It can be seen that the energy consumption keeps increasing with the increase in the duty cycle

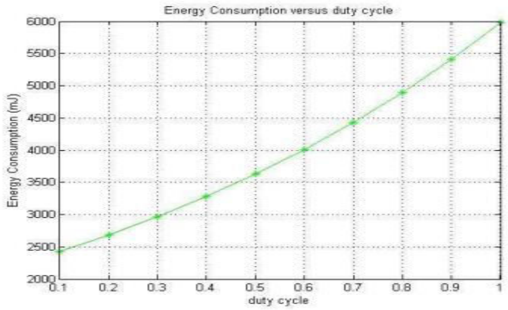

Fig. 5.5 Variation of energy consumption with a value of r=100

The above graph shows the changes in the energy consumption with respect to two variables:

1) Duty cycle
2) Distance of sink for a value of 100m.

It can be seen that the energy consumption keeps increasing with the increase in the duty cycle

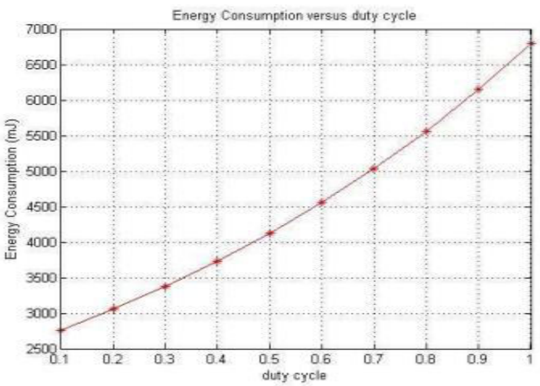

Fig. 5.6 Variation of energy consumption with a value of r=120

The above graph shows the changes in the energy consumption with respect to two variables:

1) Duty cycle
2) Distance of sink for a value of 120m.

It can be seen that the energy consumption keeps increasing with the increase in the duty cycle

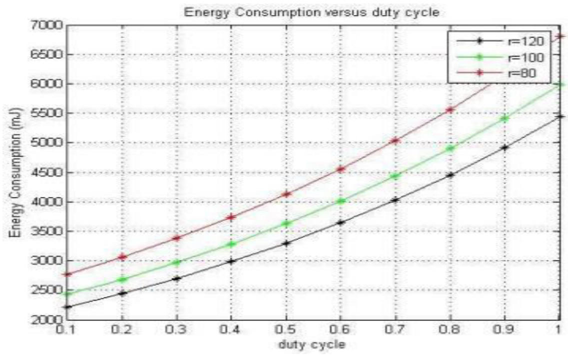

Fig. 5.7 Energy consumption as a function of duty cycle and distance

The above graph shows the variation in the energy consumption of the wireless sensor network as a function of variable distance of the sink from the plant and the duty cycle. It can be see that as the duty cycle, so does the energy consumption.

Also as the distance from sink reduces (near to sink), the energy consumption increases since the nodes route more data compared to far nodes.

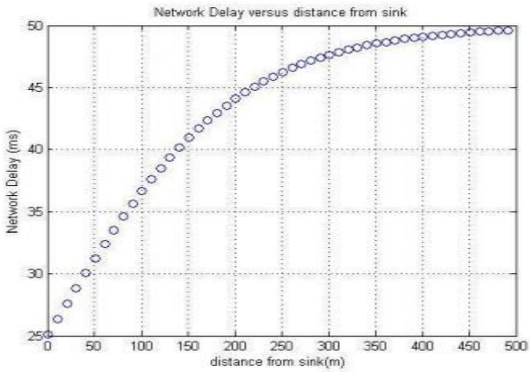

Fig. 5.8 Variation of network delay as a function of distance from sink

The figure above depicts the variation of the network delay as a function of the distance from the sink. It is clearly observed that as the sink is farther away from the plant, the delay or latency of the network also increases.

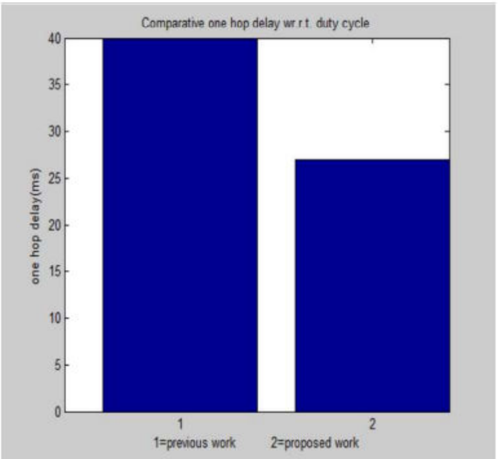

Fig.5.9 One hop delay w.r.t. previous work

It can be observed that the one hop delay of the proposed work is less than the previous work.

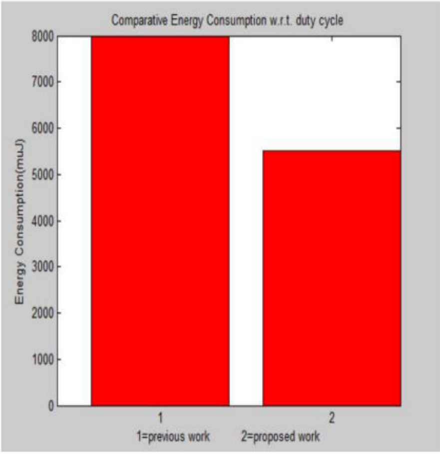

Fig. 5.10 Comparative Energy Consumption w.r.t. previous work

The figure clearly indicates that the proposed work attains lesser energy consumption compared to previous work.

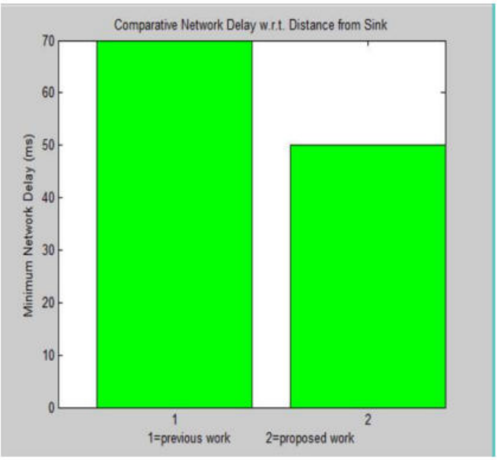

Fig. 5.11 Comparative Network delay

The figure above implies that the network delay of the proposed system is lesser compared to previously existing system.

CHAPTER- 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

With large scale automation, several applications have seen the use of wireless sensor networks (WSNs) being used where human intervention can be fatal or infeasible in approach. Several such applications can be large scale industrialization, climate monitoring, defence, healthcare etc. One of the major challenges which wireless sensor networks face is the limitation of the network lifetime and latency of the system. The wireless sensors networks are typically battery operated and hence are constrained in terms of energy. More energy consumption would mean lesser network lifetime and frequent stalling of the operative system to replenish the drained out power sources. Hence routing algorithms which consume less energy are always sought after. Another critical aspect of the design of wireless sensor network is the latency minimization. There is some finite amount of time which elapses between the moment the data is sensed by the sensing nodes and the moment the data reaches the sink. If this delay or latency is large, then the system becomes less sensitive to changes in the environment where the WSN is installed. This can prove to be of serious importance for time critical applications. The proposed approach tries to address both the issues. In the proposed work, the inter and intra cluster distances are minimized by using the particle swarm optimization to decide the clustering dynamically for each iteration. The essence of the particle swarm optimization is its capability to solve complex multivariate problems with tight bound limiting conditions and no unique solution. The redundancy in the data sensed and transmitted in WSNs is also a known fact and this can be lead to redundant data transmissions and hence large energy expenditure. This is minimized by deciding and setting up of a cap or threshold of the sensed values. Till the cap or threshold is crossed, re-transmissions are not done.

The evaluation of the proposed approached based on a PSO-threshold optimization is done based on the network parameters such as the energy consumption, the one hop and network delay of the system. The simulation or experimental results are obtained after designing and implementing the system on matlab 2018a. It has been shown that the proposed system outperforms the previously existing technique in terms of the performance evaluation parameters of the designed wireless sensor network.

6.2 Future Scope

The proposed system can see future enhancements in terms of using:

1) Machine learning based clustering and data transmission
2) Securing the data transmission mechanism in term of an effective lightweight encryption mechanism.

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