PERFORMANCE ANALYSIS AND DESIGN OF SAMPLED DATA NETWORK CONTROL SYSTEM

THESIS

Submitted in fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

to

J.C. BOSE UNIVERSITY OF SCIENCE & TECHNOLOGY, YMCA

by

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To

My Parents

Shri Shiv Prasad Bansal
Mrs. Krishna Bansal

Who has always been my source of Love and inspiration

DECLARATION

I hereby declare that this thesis entitled **"Performance Analysis and Design of Sampled data Network Control System"** by **SACHI BANSAL** being submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in **ELECTRONICS ENGINEERING** under faculty of Engineering & Technology of J.C. Bose University of Science and Technology, YMCA Faridabad, during the academic year 2020-2021, is a bona fide record of my original work carried out under guidance and supervision of Dr. S. K. Agarwal, Department of Electronics Engineering, J.C. Bose University of Science and Technology, YMCA Faridabad and Dr. Anwar Shahzad Siddiqui, Faculty of Engineering & Technology, Jamia Millia Islamia, New Delhi and has not been presented elsewhere.

I further declare that the thesis does not contain part of any work which has been submitted for the award of any degree either in this university or in any other university.

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CERTIFICATE

This is to certify that this Thesis entitled "**Performance Analysis and Design of Sampled data Network Control System**" by **SACHI BANSAL**, being submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in **ELECTRONICS ENGINEERING** under faculty of Engineering & Technology J.C. Bose University of Science & Technology, YMCA Faridabad, during the academic year 2020-2021, is a bona fide record of work carried out under my guidance and supervision. I further declare to the best of my knowledge, that the thesis does not contain part of any work which has been submitted for the award of any degree either in this university or in any other university.

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ABSTRACT

Networked Control Systems (NCSs) are distributed control systems which use communication networks like WAN, CAN, LAN, Internet to interconnect actuators, sensors, and controllers. Digital networks are used because of added benefits like lowered cost, easier installation and more readily available solutions. The industrial area where these networks are installed include automobiles, aircrafts, manufacturing plants, spacecrafts, smart grids and robotics. The drawback of this system is that, because of the usage of network, the performance of the closed-loop system may get demeaned because of introduction of packet losses and network delays. Due to the introduction of delays in NCS, predictor based compensators are used to somehow upgrade the degraded performance of these systems. In addition to that, digital compensators should be implemented for digital communication network.

Firstly an elaborative study on NCS and also analysis on modeling of Network Control System using delay compensation method and controlling method for two tank and petroleum tank system is done.

Further research is done on two tank system, petroleum tank system and Network control system and different parameters, which impacts the characteristics and stability of two tank and petroleum tank system. Besides this, detailed study is done on how through research and use of controllers, stability is ameliorated despite the system having packet losses, time delays etc.

Then detailed analysis is provided on how various protocols are incorporated in the wireless network specifically in the ad hoc network. Further research is done on calculation of time delays using software like QualNet and other simulation software and implementation of various protocols. Following this, using QualNet simulation is done to calculate the effectiveness of various protocols taking into account various parameters like jitter, delay etc.

Furthermore, description on the use of frequency controlling method in two tank and petroleum tank system with various protocols in Network Control System taking into account packet loss, delay in forward and feedback channel is laid out. Further, for verification, through simulation in MATLAB 7.0 for both the systems, estimation of efficiency of the suggested controller is done.

Finally an elaborative study is shown for Network Control System with various protocols. The difference between the two systems with various protocols is elaborated. The designing of the controller is done with the main objective of characteristic of system reaching unity and every parameter providing optimum values. The impact of NIW jitter is retrenched in such a way that dynamics of the system are least affected because of random variations. The verification of the efficiency of the protocol is done through analysis.

To conclude with, focus is laid on highlighting the thesis offerings and also the future scope of research that can be done with other adhoc network protocols which have not been used in this thesis, and try to achieve optimum performance and efficiency of the NCS used in two tank and petroleum tank system.

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LIST OF ABBREVIATIONS

ACK	Acknowledgment Packet
ACQUIRE	Active Query forwarding in the WSNs
ADC	Analogue to Digital Converter
AODV	Ad hoc On-demand Distance Vector
APTEEN	Adaptive Threshold sensitive Energy Efficient sensor Network
BW	Bandwidth
CBR	Constant Bit Rate
CCA	Clear Channel Assessment
CH	Cluster-Head
CID	Cluster ID
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance
DSR	Dynamic Source Routing
DYMO	Dynamic MANET On Demand Protocol
DD	Designated Device
E2E Delay	End to End Delay
ED	Energy Detection
EMV	Energy Mean Value
FFD	Full-Function Device
FIFO	First in First out
GAF	Geographic Adaptive Fidelity
GEAR	Geographic and Energy-Aware
GPS	Global Positioning System
GTS	Guaranteed Time Slot
HPAR	Hierarchical Power-Active Routing
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IOS	International Organization for Standardization
ITM	Irregular Terrain Model
LAR	Location Aided Routing Protocol
LAN	Local Area Network
LANMAR	LandMark Ad-Hoc routing Protocol
LEACH	Low Energy Adaptive Clustering Hierarchy
LLC	Logical Link Control
LNCA	Local Negotiated Clustering Algorithm
LQI	Link Quality Indication
LR-WPAN	Low Rate-Wireless Personal Area Network
MAC	Medium Access Control
MAN	Metropolitan Area Network
MWNs	Multi Hop Wireless Networks
MLDE	MAC Layer Data Entity
NLDE	Network Layer Data Entity
NLME	Network Layer Management Entity
MECN	Minimum energy communication network
NCS	Networked Control System

NS-2	:	Network Simulator-2
OLSR	:	Optimised Link State Routing Protocol
OSPFV2	:	Open Shortest Path First Version2
OSI	:	Open Systems Interconnection
OLSR	:	Optimized Link State Routing Protocol
PAN	:	Personal Area Network
PDA	:	Personal Digital Assistants
PEGASIS	:	Power Efficient Gathering in Sensor Information Systems
PHY	:	Physical Layer
QoS	:	Quality of Service
RIP	:	Routing Information Protocol
REQ	:	Requesting the data Packet in SPIN
RERR	:	Route Error Packet
RFD	:	Reduce-Function Device
RREP	:	Route Reply Packet
RREQ	:	Route Request
SAP	:	Service Access Point
SPIN	:	Sensor Protocol for Information via Negotiation
TDMA	:	Time Division Multiple Access
TEEN	:	Threshold sensitive Energy Efficient sensor Network
WAN	:	Wide Area Network
WLAN	:	Wireless Local Area Network
WN	:	Wireless Network
WPAN	:	Wireless Personal Area Network
WSN	:	Wireless Sensor Network
ZRP	:	Zone Routing Protocols

CHAPTER I

INTRODUCTION

1.1 NETWORK CONTROL SYSTEM

Sensors, Actuators and Controllers are the components of the Control System. These are traditionally connected through wires and are known as point- to - point control architecture (Fig1.1). This configuration is achieved with the help of a large number of wires between these components but it becomes difficult to maintain so many wires and reconfigure them. In present times it is important that the installation and maintenance cost must be low, wiring is less and it is easy to reconfigure.

Network Control System helps in achieving the present requirements. In NCS[12] the components are spatially distributed[89] and connected wide LAN, WAN, CAN and the Internet. These are mainly used in process industries, space crafts etc.

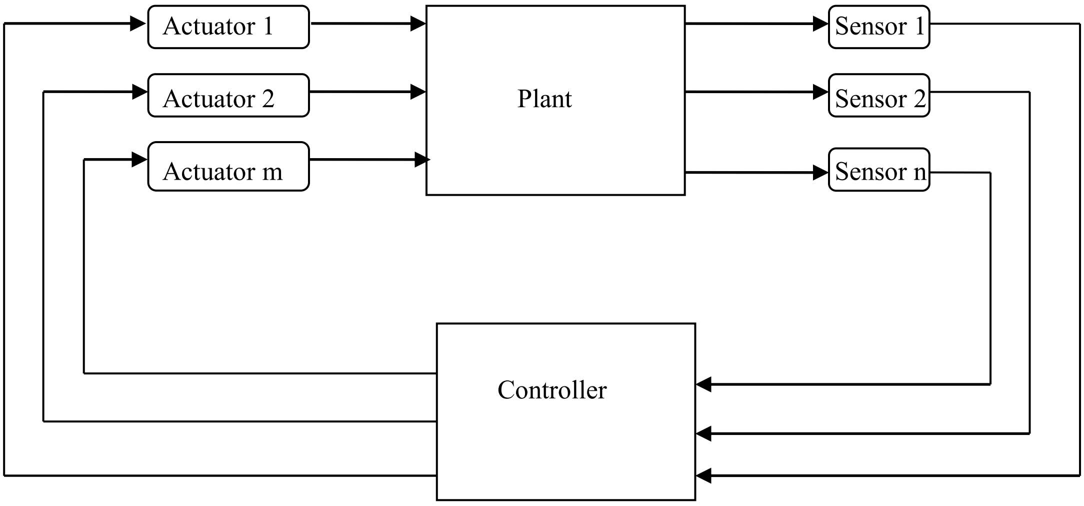


Fig. 1.1: Point to Point configuration using Network Control System

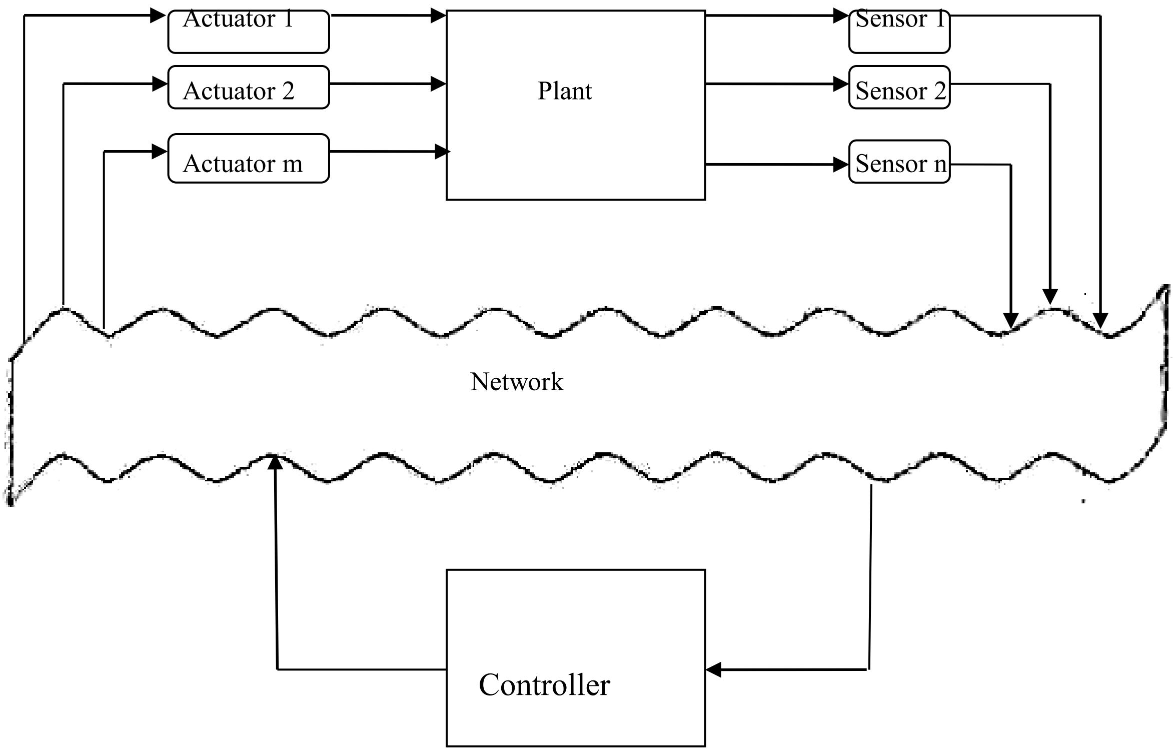


Fig. 1.2: General Configuration Using a Network Control System

1.1.1 Network Technologies for NCS

The system components communicate with each other in the computer network. Computer Networks are of two types Dedicated Networks (Control Networks) and Non- Dedicated Networks (Data Networks).

Dedicated Networks

In this network there is a constant and frequent flow of data between the high numbers of nodes ex. CAN etc.

Non- Dedicated Networks

In this network there is a flow of a large amount of data but the relatively frequency of transmission is low for ex LAN, MAN etc.

- **Local Area Networks (LANs)**

This network connects the components in a limited area such as office, building, house etc. This can be used for large data's for a distance of few Kilometers for ex Ethernet, Token Bus, etc.

- **Metropolitan Area Networks (MANs)**

MAN covers an area larger than LAN. It provides internet connectivity to LAN's and connects them to bigger area networks. MAN can be used up to 50 km for ex Cable TV networks etc.

- **Wide Area Networks (WANs)**

WAN covers a very large area spanning from several miles to across the globe. The speed of the data transferred is lower than LAN for ex BORANET, KORNET etc. The above networks can be connected to each other with the help of routers, bridges, switches etc.

1.1.2 NCS Configuration

NCS Configuration is of two types i.e.

1. Level One Communication (L1C)
2. Level Two Communication (L2C).

- **Level One Communication**

Level one Communication (L1C)[131] can be divided into two parts i.e. direct structure and indirect (hierarchical)[81] structure.

In direct structure, the controller, sensors and actuator are placed at different points and are connected by a common network to perform remote closed-loop control systems[15]. For example in the case of a DC Motor, the information of the output signal i.e. speed is sent to the input of the motor through the controller via a network is described in Fig. 1.3.

In Indirect (hierarchical)[82,84] structure shown in Fig. 1.4 the main controller and the remote controller are placed at different locations and are indirectly connected by a common network to work as a remote closed-loop control system. Here there are two controllers i.e. main controller and remote controller. The main controller calculates and transmits a reference message via network to the remote system. The remote system computes the reference message and returns to the main controller for closed-loop control. As the message is transmitted directly to the components, the overall output is increased.

- **Level Two Communication**

In Level two communication (L2C) shown in fig. 1.5 there are two channels of communication. In the first stage the real-time control network is used to connect the macro controller to the plant. As describe in fig. 1.5 the second stage micro controllers connect with a high-level controller through another communication network. In the first stage dedicated network is used and in the second stage non-dedicated network is used.

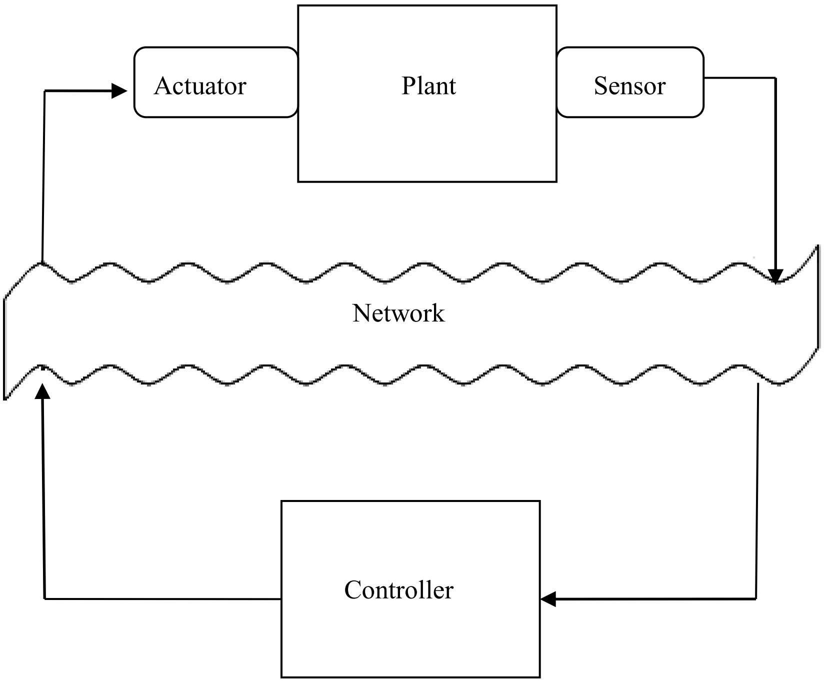


Fig. 1.3: Level One Direct Configuration Using NCS

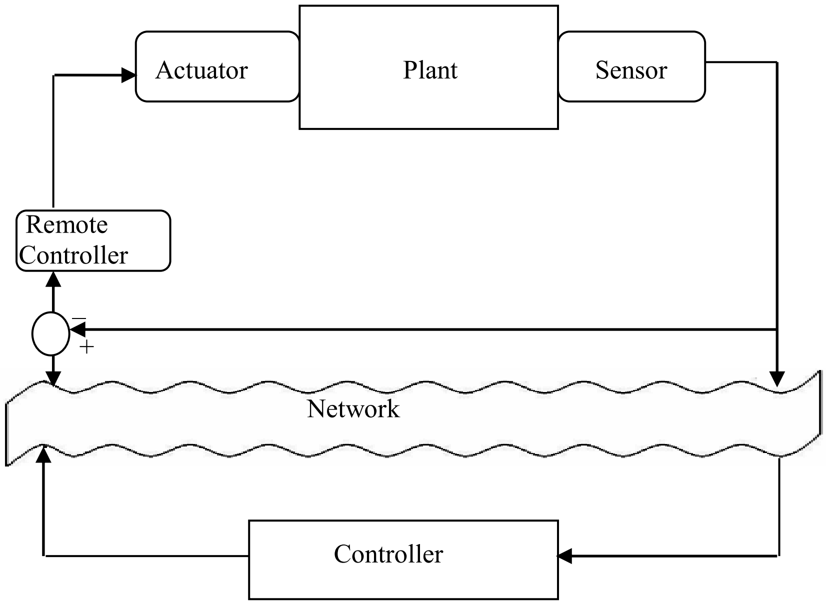


Fig. 1.4: Level One Hierarchical Configuration Using NCS

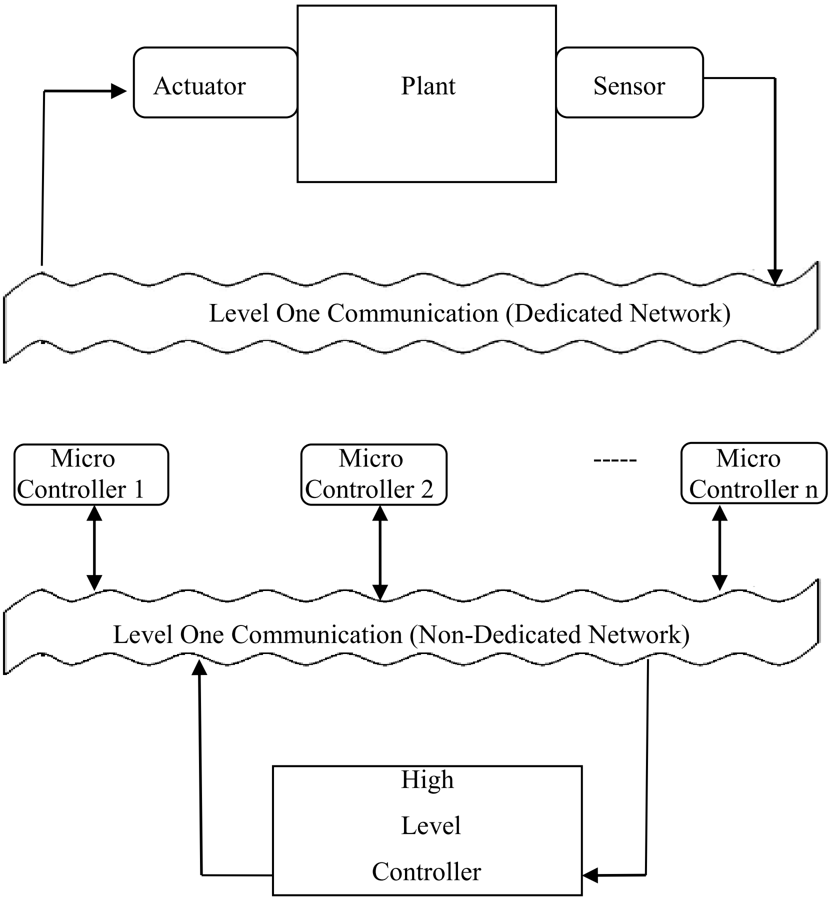


Fig. 1.5: Level Two Model using NCS

1.2 NETWORK FEATURES IN NCS

The basic issues in Network control systems non-dedicated networks are delays and loss of information. These take place in the nodes which affect the network stability[28] and performance. Understanding of controllers for these NCS becomes necessary due to their benefits and applications.

1.2.1 Time Delay

Time delay (End to End Delay) occurs in a system to an input. Whenever the input in the form of energy[95] moves from one place to another it gets delayed [1]. This delay depends on the distance that it has to travel and the speed with which it moves. The presence of long delays affects the system and it becomes necessary to do the designing properly. In NCS Configuration consisting of components delay occurs due to network [39] characteristics. These could be topologies, routing[49,50] schemes[91] etc. The delays are defined as:

Waiting Delay [$d^{w}k(t)$] = This delay[27] is the period for which the source has to wait for the availability of the network for sending the package.

Frame Delay [$d^{f}k\ (t)$] = This delay is the period taken by the source to put the package on the network.

Propagation delay ($d^{p}k(t)$) = This delay is the time taken by the package to travel from the source to the destination. The delay depends on the distance between the source and the destination and the speed with which it travels.

Delays in a feedback control system are:

Senor to Controller Delay [$d^{sc}k(t)$] = This delay takes place when a sensor sends a signal to the controller. The time between sensors to the controller at time index k is measured as

$d^{sc}k(t) = t^{cs}{}_{k} - t^{ss}{}_{k}$

$t^{cs}{}_{k}$ = time taken by the controller to measure the signal

And

$t^{ss}{}_{k}$ = time taken by the sensor to measure the output

Computational delay: $d^{c}k(t)$==This delay is the time taken by the controller to analyse the control signal after receipt. It is defined as

$$d^{c}{}_{k}(t) = t^{cf}{}_{k} - t^{cs}{}_{k}$$

where $t^{cf}k$ is defined as the instant when computing of control signal is finished by controller.

Controller to Actuator delay:[$d^{ca}k(t)$] =This delay is the time taken by the signal to travel from controller to actuator. It is defined as $d^{ca}k(t) = t^{as}k - t^{cf}k$

$t^{as}\ k$ is defined as time instant when actuator starts operating and receives the control signal.

1.2 Network Features in NCS

$d^{ca}{}_{k}(t) = t^{as}{}_{k} - t^{cf}{}_{k}$

$t^{as}{}_{k}$ is defined as the time instant when the actuator receives the control signal and starts to operate.

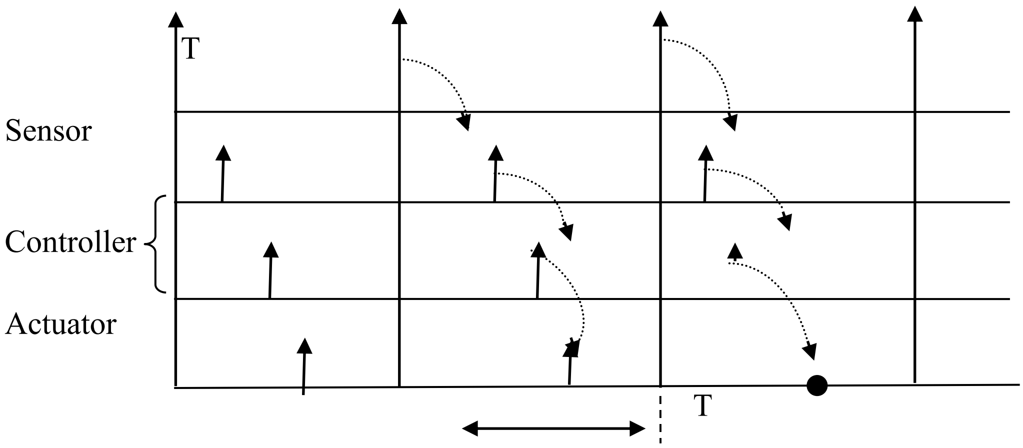


Fig. 1.6: Timing Diagrams of Delays and Packet Losses in Network Control System

The total delay in NCS is shown as $d_k(t) = d^{sc}{}_k(t) + d^c{}_k(t) + d^{ca}{}_k(t)$. The time taken by the controller to process the package is very small and can be neglected. Delays are also affected by bandwidths[114] and quantum of packets. There are additional delays such as queuing [16] delay and propagation delay when the sensor and control data goes via the network.

1.2.2 Packet Loss

Packet loss occurs when the data is sent through unauthorized networks. The properties of the network make the time signal from the plant to be sampled first. Packets get lost, when they travel, due to noise and uncertainty in the communication network. Packet loss can also happen at the source when it is delivered without any planning.

A graphical representation between time delay and packet loss is given in figure 1.6. As, per this figure, the message which is sent is considered to be time-dependent. i.e. packets are sent at regular intervals $k - 1$, k, $k + 1$ and $k + 2$, etc. The data received at $s^{th}{}_{k-1}$ and $s^{th}{}_k$ instants reach at receiving end with delays of $d_{k-1}(t)$ and $d_k(t)$ respectively. The $s^{th}{}_{k+1}$ data packet $y((k+1)h)$ is not received at the receiving end and it is shown as loss of the packet.

1.2.3 Power Consumed in Transmit mode

It is defined as the consumption of power[97,98] when data is sent from the transmitter node to the receiver node via a network. Transmission energy is defined as one type of energy in which nodes need sufficient power or energy to transfer the data packet.

1.2.4 Throughput

This is calculated in a channel that linked the communication between the nodes. It can be defined as the rate of data packet sent from the sender and successfully received at the sender node. It is calculated in terms of bits per second and many times in successful data packets received per second.

1.2.5 Packet Loss Considered As Delay

In addition to delays that take place due to network properties, loss of a packet is a major cause of worry. As shown in the graph the data is received at the receiving end with a delay. When the data packet is lost then no packet is received at the next sampling intervals. In this scenario when we continue to work the delay increases to one sampling period. The packet loss is considered as a delay.

1.2.6 Time- Driven Versus Event-Driven Communication.

Time driven communication is a conventional process in which the information is transmitted at regular periods. As this is easy to be used, NCS with time-driven communication is extensively used in practical cases. It is implemented based on the following sampling processes i.e. periodic sampling, non-uniform sampling and stochastic sampling.

Event-driven communication helps to reduce the number of samplings and avoid waste of communication. There are two types of sampling [131], event-triggered sampling and self- triggered sampling.

1.3 NCS MODELLING

The effects of delays and packet loss make it mandatory for NCS to be modeled with the help of different methods. These methods are 1) Sampled data system approach and 2) Switched system approach. The first method is used when small delays are there and the second method is used when all the nodes are time-dependent. As the delays due to time and packet losses are unpredictable [16], NCS[8] are modeled with the help of different methods leading to analysis. They are divided into two groups. A- Sampled-Data system Approach and B-Switched system approach. In the Sampled

Data approach delays take place due to nodes which are event-drivenr. In Switched system approach the nodes are the ones that are time- driven.

1.3.1 Sampled Data System Approach

In this method, NCS is shown as a system which consists of continuous- time plant and components which are time-dependent. The time input is studied periodically for communicating with the network. The study of sampled data of NCS will indicate the presence of hybrid[45] signals in the system. Delays and loss of packet occurring due to characteristics of the network can also be included in the model. The design of controllers is done with the help of lifting techniques. This method considers the change in sampling frequency.

In the given fig.1.7 of NCS consisting of sensors, controllers and actuators, sensors are time-dependent and the balance is event dependent.

In this method NCS is shown as a sampled data system. It consists of a time plant which is continuous and components like a controller, sampler, etc which are event-driven or time driven. The time signal which is continuous in nature has to be properly integrated with the network. It can possess all the signals present in the system. Features of networks like delays, packet losses can also be inbuilt in the model. Digital controllers are designed with the help of lifting techniques. This technique gives the data system with delay. This takes into account the behavior of the sample which are interrelated and frequency which is variable.

A Network Control system is shown below where the sensor is shown as driven by time and the controller and actuator are driven by an event. The sampling interval is assumed to be h If k^{th} is the sampling interval then s_k , kh.

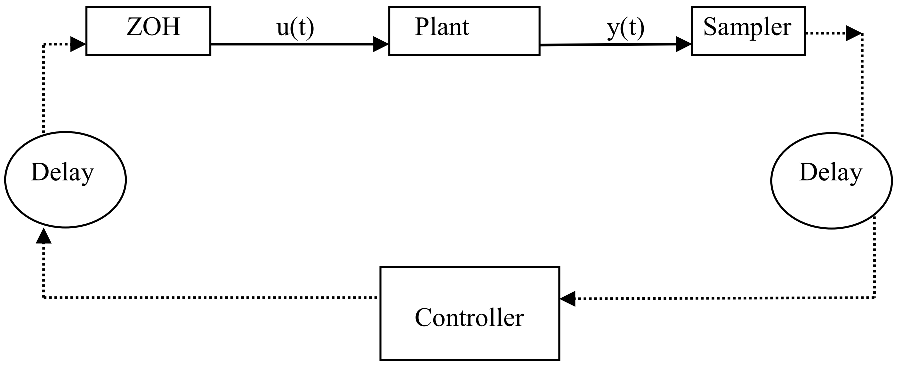


Fig. 1.7: Sampled-data system representation for an NCS

The plant factors are shown as

$x(t) = Ax(t) + Bu(t)$

$y(t) = Cx(t)$

Here $x(t)$ €R^n, $u(t)$ € R^m and $y(t)$ € R^p are the input and output vectors of the plant. The values of A, B and C are constant. The delays due to network are sensor to controller delay $d^{sc}(t)$ and delay from controller to actuator $d^{ca}(t)$. Therefore, $d_k(t)= d^{sc}(t) + d^{ca}(t)$ and $0\leq d_k(t)<h$.

In a state feedback controller of the form

$U(t) = Ky [t–d_k(t)] = KC_X [t–d_k (t)]$

Where K € $R^{1\times n}$ is a static matrix. To get feedback of the system, the flow process needs to be exploited. The below figure gives the flow diagram at the plant input with an interval of s_k and s_{k+1}. There are two control information namely x_{k-1} and x_k. This is based on the input x_k at $s_k + d_k(t)$. If delay bound is $0\leq d_k (t) \leq nh$, the active control information will be (n +1). The active control information will be

(n + 1) when the delay is nh.

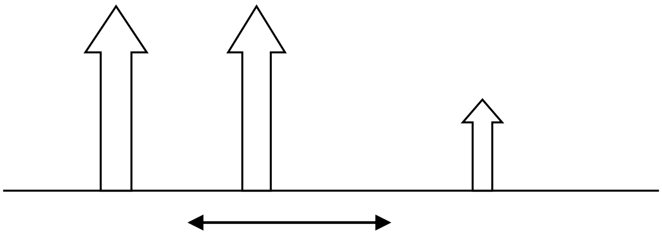


Fig. 1.8: Information flow within a sampling interval for *$0 \leq d_k (t) < h$.*

The mentioned model can be studied for analysis or design of the controller. Due to the uncertainty of the parameter d_k the model also is uncertain. For analysis and design of the controller the model is not a direct working model.

The variations in time delay lead to uncertainties [6] which can be tabled as a polymorphic framework.

1.3.2. Switched System Approach

In this method the system is shown as a merger of subsystems, one of which gets activated immediately. The switching between the systems takes place due to delay induced by the network and the packet losses which results in the generation of signals. The controller is made with the use of state-feedback approach.

The same model as considered in the previous article is used except that the actuator and controller are time-driven [7]. Time delay d^{sc} (t) and d^{ca}(t) are integer multiples of h.

The minimum and maximum integers are $n_{d=}d_k$ (t) /h and $n_d = d_k(t)$ /h. The value of n_d is a variable parameter due to delays in the network.

The control input becomes u (t)=K_y (t – d_k (t))= KC_x (t – d_k (t))

The facts move towards the nodes in NCS. The below figure shows the fact flow details at the input of the plant with an interval (s_k, s_{k+1}). Here there is an information x_{k-1}, which depends on x_{k-1} received at s_k. This information depends on delay bound which is maximum. If the delay is $0 \leq d_k$ (t)≤nh, then the information will be within an interval of n. The information will be n when the delay is nh.

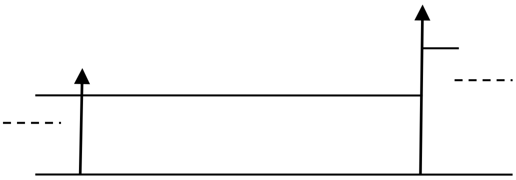


Fig. 1.9: Information flow within a sampling interval for $0 \leq d_k(t) < h$.

If $0 \leq d_k(t) < h$ (n_d=1), the control input in a sampling period (s_k, s_{k+1}) is shown as

u(t)=KCx_{k-1}, when tƐ (s_k, s_{k+1})

Therefore $x_{k+1}=A_dx_k + B_dKCx_{k-1}$

$A_d = e^{Ah}$

1.4 REVIEWS ON CONTROL SYSTEM USED NCS

Halevi and Ray constituted a plant and a controller and studied the ICCS through a distinct time approach. The plant and the controller were synchronized and studied. The system is designated by a vector which is made up of past input and output values of the plant. It also includes the present values of the plant and the controller. This gives rise to a discrete-time model which varies with the time. This model also considers packets that get rejected and samples which are empty.

In his study of NCS, Nilsson considers delays as constant and random which are controlled by Markov Chain. This helps in finding a solution to the LQG control problems. Messages which are time-stamping help to know the past data of the system.

Walsh builds a system of plant and controller which are continuous. He added the network between nodes of sensor and controller MATI was introduced (P). It indicates that the distance between messages of the sensor is P seconds. It is required to know the value of P which will make the system stable.

It is considered that

$x(t)=A_{11}x(t)$, $x(t) = [x_p(t), x_c(t)]$

xp and xc show the plant and controller state. The value P is

$A_{11}^T P + PA_{11} = -I$

Effect of Network is indicated by error e(t), which is in between the input from the controller and the plant output. State vector is $z(t)= [x^T, e^T(t)]^T$ where

$A = [A_{11} \quad A_{12}]$

$\quad [A_{21} \quad A_{22}]$

Assuming that the numbers of nodes connected to NCS are p, it shows that the node sends packets once every p seconds in a fixed order. In MATI the controller gets a signal from the sensor every p seconds.

1.5 TIME DELAY COMPENSATION FOR NCS

1.5.1 Smith Predictor

An easier system of compensation of time was introduced by O.J.M.Smith in 1957 known as Smith Predictor. It finds applications in various systems like NCS, Process Control, etc. A simple Smith Predictor control is shown in the figure. It consists of two loops. The outer loop gives the real picture of the total system and it is always affected by system delays. The inner loop is made up of a process model and generates the required delay of time. The output of both the loops neutralizes the delay which occurs in the loop.

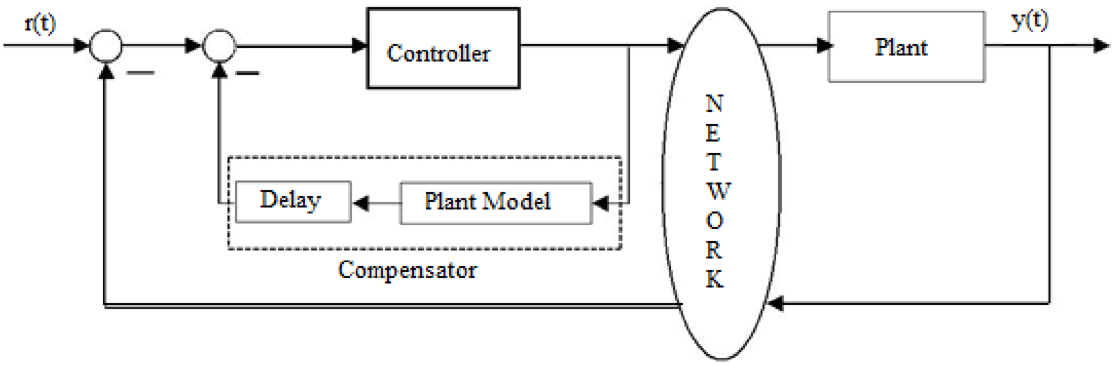


Fig. 1.10: Classical Smith Predictor

With the passage of time many modified versions of SP have been introduced for the purpose of compensation. For the betterment of the response of set point improved version of SP is suggested and it is shown that fast response of set point and good rejection of unnecessary load is achieved. In this the controller isolates the response of set time from the response of load with the help of an additional filter.

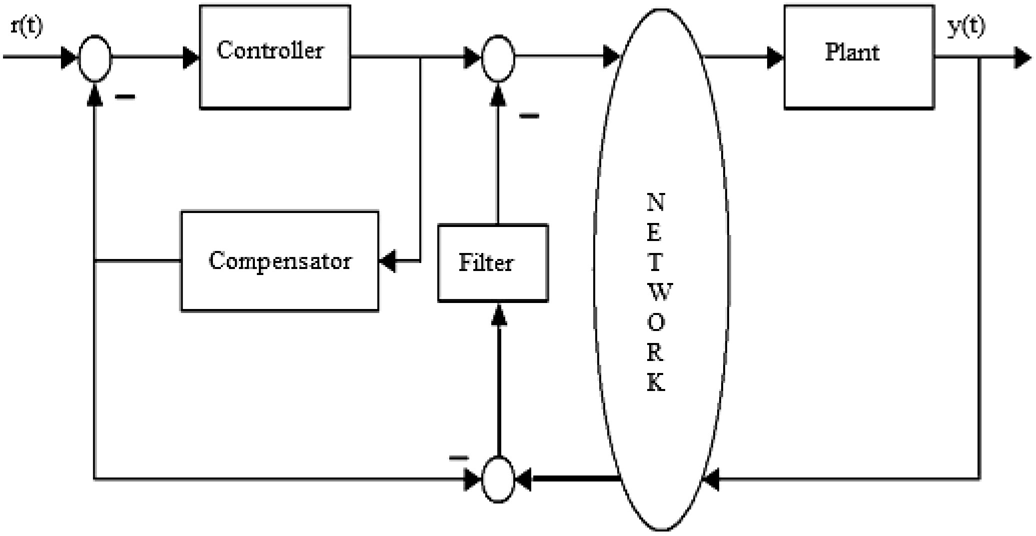


Fig. 1.11: Astrom et al.’s Smith Predictors

Adaptive Smith Predictor is useful for introducing required compensation for the changes that take place in the parameters of the plant. An Adaptive[14] SP is shown in the figure in which delay estimation of time is present. The delay of time is judged from round trip time which is measured.

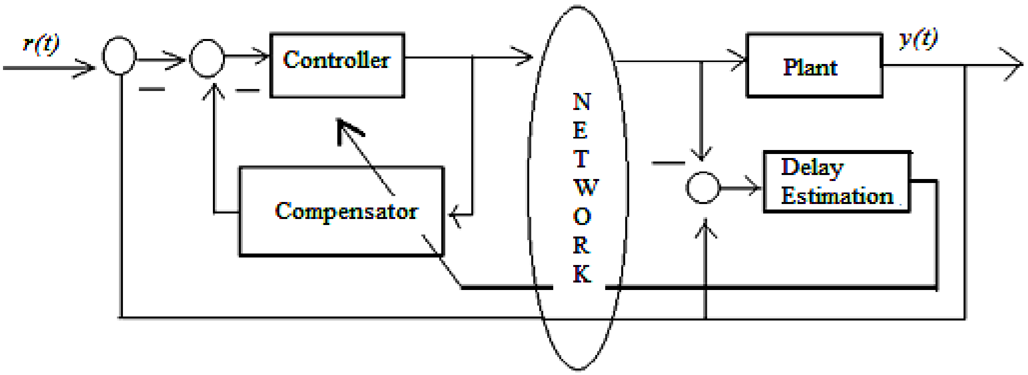


Fig. 1.12: Lai and HSU Smith Predictor

1.5.2 Predictive Control

In a Network Control system the delay due to network and packet losses has led to the introduction of Predictive[4] Control methods. It consists of two parts, Prediction control generator and Network delay compensator. Prediction Control generator initiates the control predictions of the future with the help of PID, LQG, etc. Compensator initiates the compensation for the delays introduced by the system and which are not known. It is done by selecting the control values available on the plant side. This system is shown in the below figure.

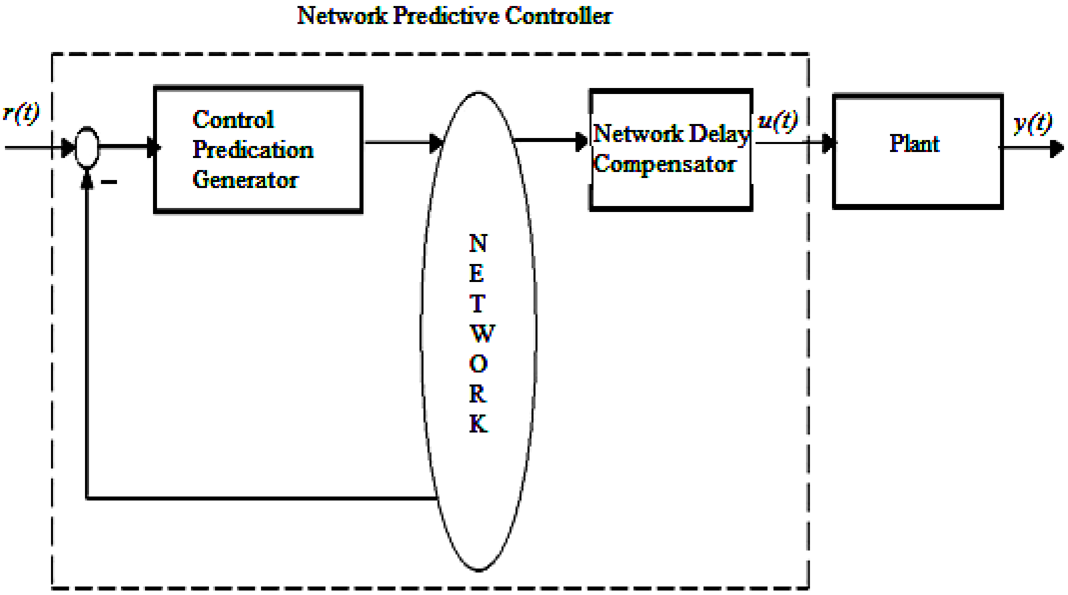


Fig. 1.13: Networked Predictive Control Systems

In reality, it is tough to get control input due to the presence of delays. To nullify this issue an improved version of the Predictive Control system is introduced in the existence of channel delays and loss of the packet. Further improvement is done in the design by compiling the present control input signal with the previous predictive signals of input. Through this the plant input of the coming times is estimated. Subsequently, the predictor is designed in such a way that its output and reliability are not disturbed by the input of the plant in the future. Another form of the Predictive Control system [31] is introduced with the help of the switching signal. The average dwell time method helps in sourcing the switching signal with the help of the Lyapunov function [3,31].

1.6 MOTIVATIONS

The study of the literature of NCS set out a plan to undertake a comprehensive review of all the conceal methods and protocols of ad-hoc networks and compensator design of NCS. It could take the opportunity offered by this comprehensive review to consider the amendments and updates made necessary by the observations made in the literature. These matters are not well understood and founded. Doubts should be acknowledged.

Use of networks [9] to control the petroleum tank is advantageous because of

1. Reduce complexity in the wiring.
2. Reduce cost.
3. Easy maintenance
4. Easy reconfiguration.
5. Remote data exchange.

The end to end delays and packet losses can be modeled as network parameters. With different protocols such modeling further requires to represent the system that is petroleum tank and two tanks [32,33] systems are analyzed. A detailed comparison of many protocols in these two modeling is to be investigated.

Network control systems involving communication networks require the implementation of delay compensators on how to design and implement Smith Predictor for NCS with delays and losses due to different protocols of Network used is not well addressed in the literature.

How to enhance quality to make a better system of NCS with minimum delays and packet losses using Smith Predictor.

How to curtail the jitter. (Jitter is a parameter related to time which is the sudden and false change in a specified time span).

How to develop an NCS experimental setup.

1.7 AIM AND OBJECTIVES

1.7.1 Aim of Thesis

Growth is a step of trial and error and doing experimentation. The experiments which fail are also a part of the step for growth as the experiment that finally works. Research is about helping us to make the journey comfortable with human life through comprehensive as well as efficient learning. By using power and influences the big amount of technical knowledge is available to us. We then familiarize ourselves with the technical detail and then present a wide variety of content to encourage growth in research and solve big problems.

With the above aspects and motivations this work strives to explain many such related issues mainly the design of delay compensators. In the preview of improving stability[11] and characteristic of control system it will further improve parameters like Delay time, Settling time, Rising time, and percentage overshoot, etc of NCS. It is attempted to design the experimental set up for different protocols used in the communication network using QualNet[26] and thus involve the real-time network to find out delays, jitter, etc.

1.7.2. Objectives of the Thesis

The objective of the thesis is as follows:-

1. To study NCS modeling using frequency method of controlling system for Petroleum tank and Two tank system with respect to involvement of Time delays.
2. To design and implement Smith Predictor for network controlled system with all type of delays, packet losses.
3. To improve the performance of network control system with different protocols used with delays and packet losses using Smith predictor with and without filters.
4. To curtail the jitter effect on the Network control system with delays and packet losses using Smith Predictor.
5. To develop a Network Control system for the different protocols used and find out the end to end delay for all protocol and experimental set up has been done in Qual-Net5.0 to find out delays, jitter, etc and also implement and simulate the overall system in MATLAB 7.0.

1.8 OUTLINE OF THE THESIS

1.8.1 Chapter 1 - This chapter explains the overall description of NCS as well as the review and modeling of NCS using the controlling method and delay compensation method used in the petroleum tank system and two-tank system.

1.8.2 Chapter 2 - This chapter explains the literature review of NCS, petroleum tank system and two-tank system[41] and various parameters which affect the stability and characteristic of petroleum tank system and two-tank system. It also explains how the stability is improved with time delays, packet losses, etc by using controllers and through research.

1.8.3 Chapter 3 - This chapter explains the study of different protocols used in the wireless network[122] especially in an ad-hoc network. It talks about the study of Qual-Net, simulation software used to implement the different protocols and find out the delays, etc. and analyze the stability of the system. The effectiveness of all the protocol, taking into consideration parameters like delay, jitter, etc. is done through simulation in the QualNet.

1.8.4 Chapter 4 - This chapter explains the frequency controlling method used for the petroleum tank system with different protocols in NCS considering delay, packet losses in feedback and forward channel. The effectiveness of the proposed controller is verified via simulation using MATLAB7.0 for the Petroleum tank system. The comparison of the performance of the system with the different protocols is done here.

1.8.5 Chapter 5 -The effectiveness of the proposed controller is verified via simulation using MATLAB7.0 for Two tank system. The comparison of both the system with the different protocols is done here. The controller is designed in chapter 4 with the objective that the characteristic of the system approaches towards unity and optimum values of all the parameters are observed. The effect of N/W jitter is curtailed so that the system dynamics are very less affected by random variations.

1.8.6 Chapter 6- This chapter highlights the contribution of the thesis and future scope of work to be carried out to with all other Ad-Hoc [106] network protocol which is not analyzed in this thesis to get the optimum performance of the network control system used in petroleum tank[129] and two-tank system[130].

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

Networked control systems (NCS) [12] are continuous feedback control systems in which a real-time network is used for controlling the control loops. In the present control circle, there is a significant inclination of the researcher's interest focused on computer science, networking and integration of control. This research consists of principles, methodologies, and gears for modeling and control of complex networked distributed[112] system. There are two main domains of research i.e. control of network and control over the network. Control over the network is concerned mainly with control issues because of data networks. Control of network is a vast area of study in which control issues in the network such as routing control, data caching, congestion control and power management are studied. In the present situation computing, communication and power of sensors are increasing and are omnipresent. The more customary control loops are the ones that are linked over a communication network using devices like sensors, networking hardware and embedded processors. A classic setup of NCS is depicted in fig. 2.1 where S, A & C indicates sensor, actuator and controller respectively. The paramount benefits of NCS are minimized con volute phenomenon in wiring connections, remote data exchange and transfer among users and simplicity in maintenance. The conventional communication framework comes from 1970s when DCS (Distributed Control System) was originated in which control systems were point-to-point. The old architecture became obsolete due to exigencies like integrated diagnostics, decentralization of control, modularity, easier maintenance and lower cost. Due to these limitations shared-data network architecture came into existence. The feedback control loops are introduced to the communication network which makes the design and analysis complex due to the development of time-delay unpredictability between actuators, sensors and controllers [2]. The assumptions like non delayed sensing and actuation, synchronized control should be reassessed before being put into application in NCS's [9] as these assumptions are done according to the mainstream control theories.

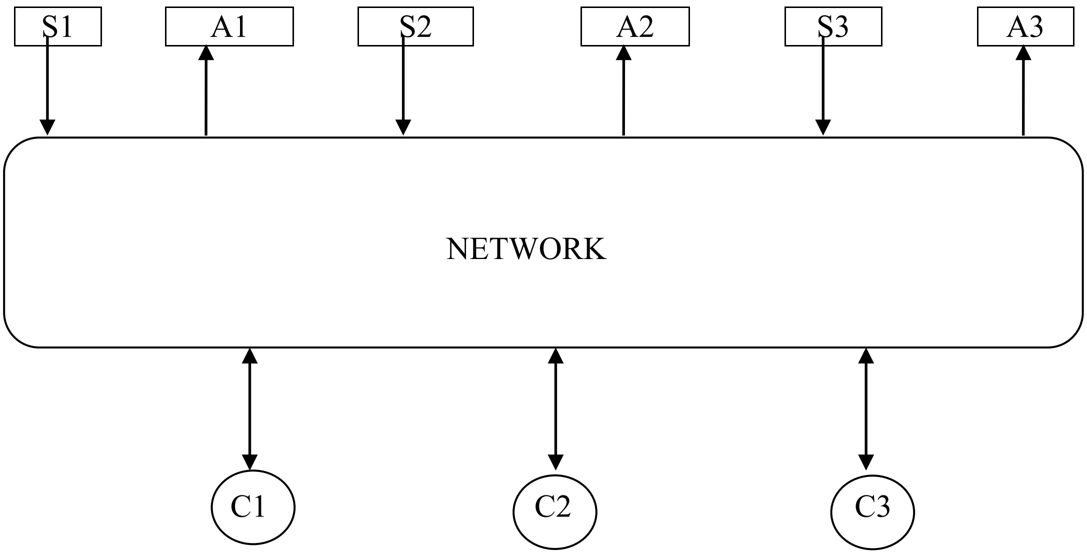


Fig. 2.1 A typical NCS setup

The Ethernet, Device Net, Profitbus, CAN [52], and FireWire are some of the networks implementing NCS. Depending on the hardware chosen and the network protocols used the characteristics of time delay can be bounded, constant or random. The processing time required for physical signal coding, computing control law, communication processing [53] and time-sharing of communication medium are the major reasons for the occurrence of time delays. Workload, packet loss, variations are some other complications that can impact NCS's. These complications have motivated the research society of control network to work in the field of NCS.

2.2 NCS and delays

Structures of NCS's

Mo-Yuem Chow and Yadyium Tipsuwan explain Hierarchical structure and direct structure are two basic structures of NCS's.

Direct Structure

It consists of various remote systems, each consisting of the physical plants, actuators and sensors and a controller. The fig. 2.2 demonstrates how the plants and the controller are connected by a data network to carry out remote closed-loop control, and also how they are physically placed at various locations.

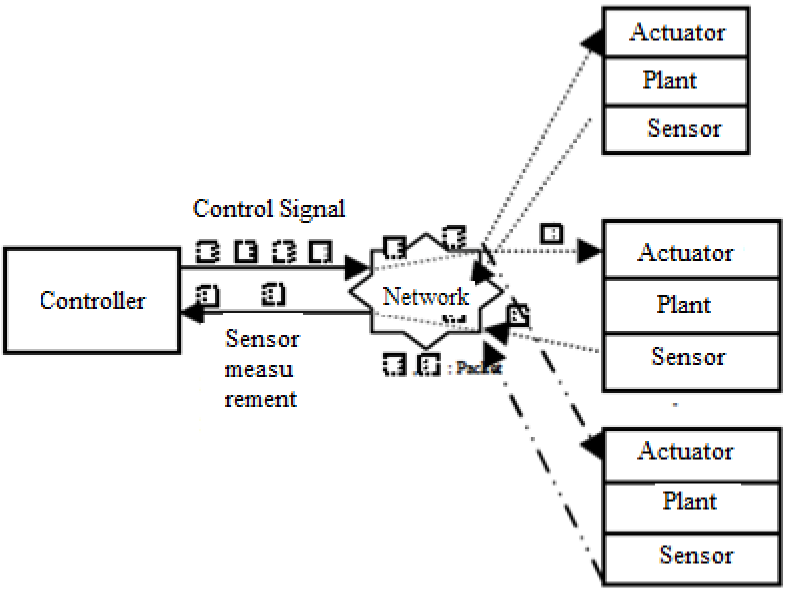


Fig. 2.2: Control system through a network under direct configuration

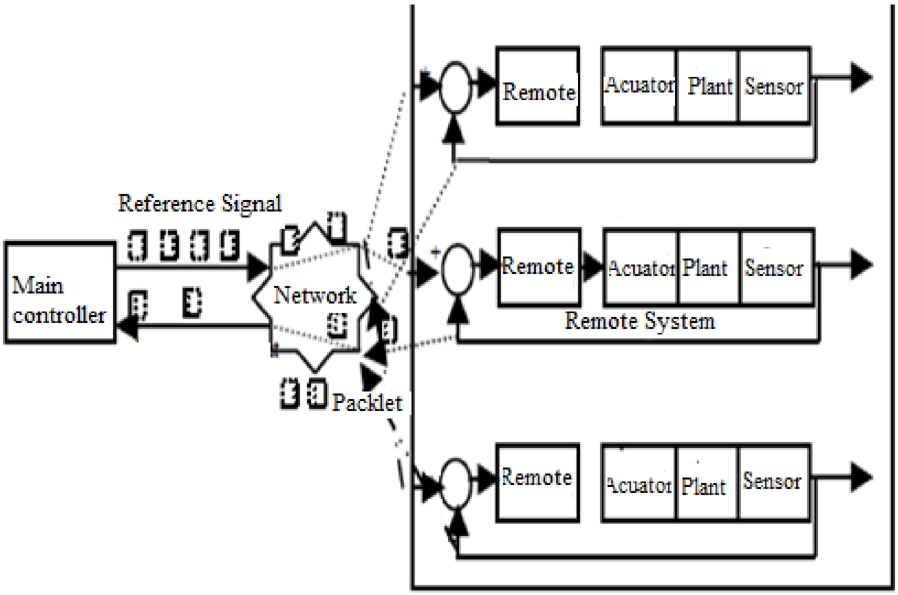


Fig. 2. 3: Control system through a network under hierarchical configuration

Hierarchical Structure

The fig. 2.3 delineates the basic hierarchical structure which consists of the main controller and some remote closed-loop subsystems. The subsystems include a set of actuators, a set of sensors and a controller [58].

All these components of the system are connected to the very same control plant. In this very particular case, the central controller is in control of transferring set points to the subsystem controller. The local closed-loop control is executed by processing the reference signal in the remote system. The sensor evaluation is sent back to the main controller in order to perform networked closed-loop control. The remote system [12] receives a reference signal in the form of a packet or frame through a network which is computed and sent by the main controller at regular intervals. The sampling period when compared for a local control loop and the networked control loop is higher for a networked control loop as before processing a new reference signal it caters to the old reference signal. Both structures showcase diverse advantages. Reconfiguration of a control loop is elementary. The interaction in the second structure is superior as the direct transmission of data to the component takes place. The second structure is even more modular when compared to the first structure. Every measurement can be observed and processed by the controller in the first structure whereas in the second structure it has to wait until the satisfaction of set point to transfer the status signals and complete measurements. Customarily the first structure is referred to as the network-based control system or simply a networked control system. Many other structures exist for NCS like two-level communication frameworks and a general framework. The figures of the framework are shown in fig 2.5 and fig 2.4. The NCS consists of two subsystems that communicate with each other using networked communication channels. The two-level communication framework and general framework for NCSs are somewhat the same as the two NCS structures but in a different manner. A typical difficulty in the field of control over network i.e. feedback internet congestion control can use figure 2.4 to research Active Queue Management (AQM) [59]. Varied techniques are used for solving various problems in the above two subsystems. In direct structure NCS, subsystem 1 depicts a plant to be managed with actuators and sensors whereas subsystem 2 depicts a digital controller equipped with controller and observer.

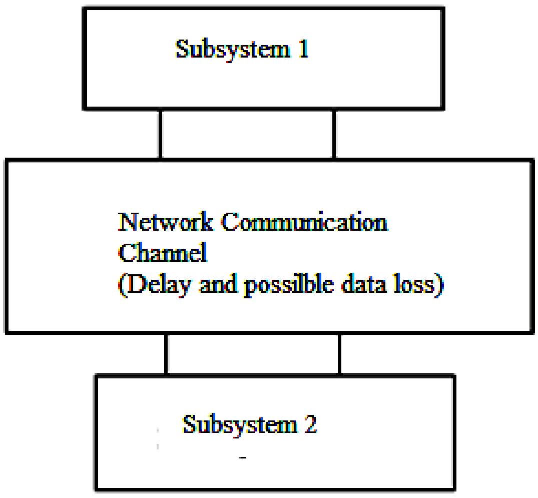


Fig. 2.4 General framework for NCS

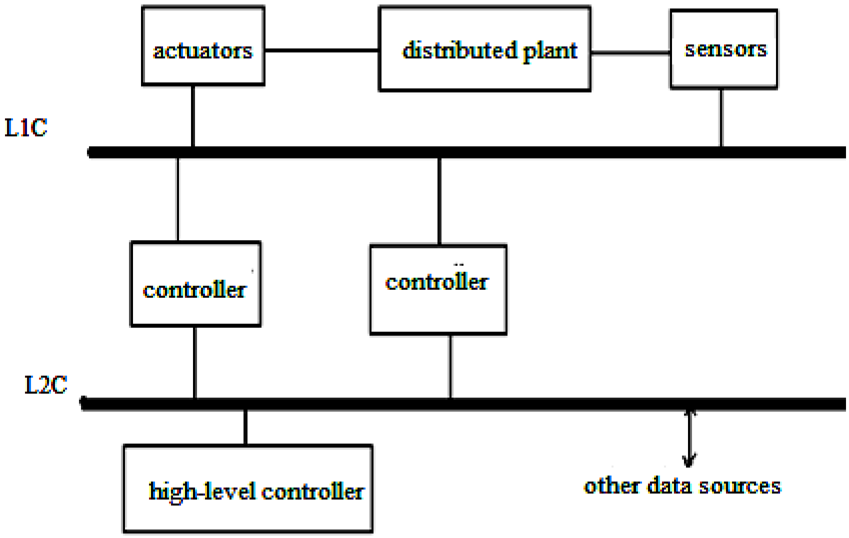


Fig. 2.5 NCS with two level communications

FUNDAMENTAL ISSUES OF NCSs

Delays in NCSs

The network delay effect is another exigent problem faced in the control of a networked-based control system. Routing schemes, typologies and sundries are the depending network characteristics which depict the amount of time required to read a measurement received from the sensor and the time to send the corresponding control signal to the actuator via a network. So as a result we can say network delays notably affect the overall performance of the networked-based control system. When at the time of transmission data loss happens, the more of the delay problem is intensified. Other than affecting the overall performance of a networked-based control system, the delays can ever again make the system more unstable [53].

Delays in the loop

Xiaoli Luan , Peng Shi , Fei Liu says Adjunctive to the controller processing delay[6], network delays occur since the operation of NCS is done via a network thereby the information transfer between the remote system and the controller induces network delays [90]. In fig. 2.3 the network delays are depicted in the control loop, where u, r, y, T, k are the control signal, reference signal, output signal, sampling period and time index respectively. The discrete-time technique is used widely in networked control methodologies which are depicted in fig. 2.6. The respective timing diagram for network delay propagation is shown in fig. 2.7.

The categorization of network delays in a networked control system can be done based on the direction in which the data is being transferred i.e. from the controller to actuator delay τ^{ca} and delay from the transfer of data from sensor to controller τ^{sc}. The delays are reckoned as

$$\tau^{sc}=t^{cs}-t^{se}, \qquad \text{............(1)}$$

$$\tau^{ca}=t^{rs}-t^{ce}, \qquad \text{.............(2)}$$

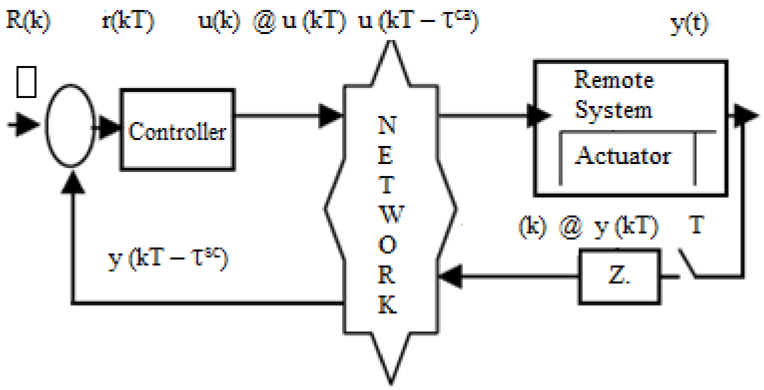


Fig. 2.6 General NCS configuration

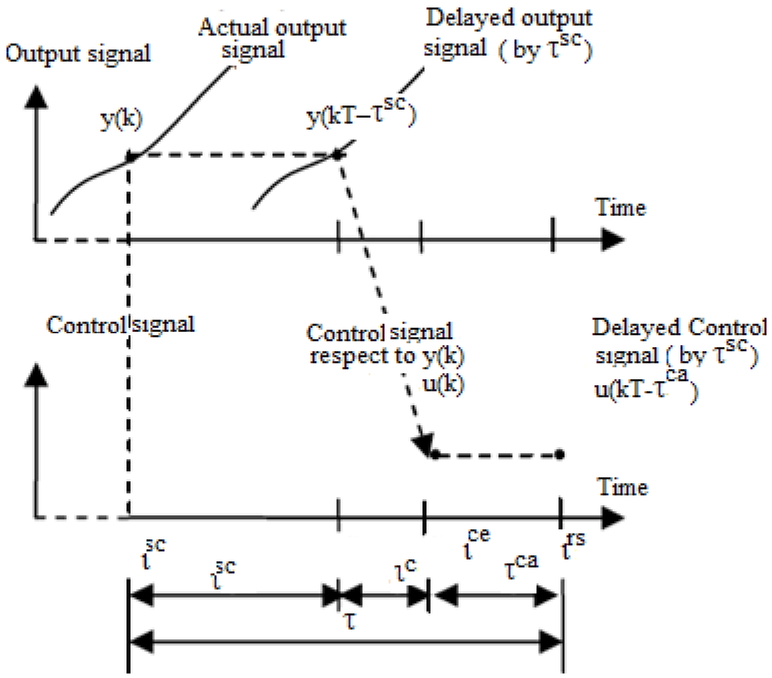


Fig. 2.7 Timing diagram of network delay propagation

where $\mathbf{t}^{cs}$ is the time instant when the measurement in the delivered packet or frame is started to process in the controller, $\mathbf{t}^{se}$ is the time instant when remote system records the measurement to be sent into a packet or frame, $\mathbf{t}^{ce}$ is the time instant when the main controller records the control signal to be sent into a packet, and $\mathbf{t}^{rs}$ is the time instant when the control signal is started to process by the remote system.

The network delays when compared to the sampling time T can be either shorter or longer. For the ease of analysis the control delay $\boldsymbol{\tau}$ can be termed as the summation of both the network delays and the delay [37] due to the controller processing $\boldsymbol{\tau}^{c}$. Some NCS have used the approach of lumping up all the delays. The delay [25] due to controller processing i.e. $\boldsymbol{\tau}^{c}$ always exists but can be neglected as it is negligible when measured against the network delays. In some scenarios the sampling time for the remote system and the main controller may also differ.

The following parts are at least present in the $\boldsymbol{\tau}^{sc}$and $\boldsymbol{\tau}^{ca}$ delays:

- Waiting Time Delay $\boldsymbol{\tau}^{w}$

This delay occurs when the source i.e. remote system or main controller has to remain stand by for queuing and availability of network before it actually sends a packet or frame out.

- Frame Time Delay $\boldsymbol{\tau}^{F}$

This is the delay that occurs during the time the packet or frame is being placed on the network by the source.

- Propagation Delay $\boldsymbol{\tau}^{P}$

This delay [24] occurs when a packet or frame is sent through physical media. The seed of signal transmission and the distance between destination and source is the governing factor for propagation delay.

In a local area network, the above-mentioned delays [35] are the three elementary delays. When the sensory or control data travels via a network, more delays can occur such as the propagation delay in the network hops, queuing delay at the router or a switch. Maximum bandwidths from packet or frame size, and protocol specifications are also governing factors for $\boldsymbol{\tau}^{sc}$and $\boldsymbol{\tau}^{ca}$ delays. If a router or a switch drops a packet, or if a fault[17] is found in a packet, retransmission may be needed for higher-layer network protocols. For NCS this is a trade-off incidence. NCS operates reasonably even though during network transmissions some sensory or control signals may be lost. In this scenario, retransmission is also not recommended as the prolonged delays may drastically affect the performance of NCS.

PACKET TRANSMISSION

Tarek K Refaat , Ramez.M.Daoud, Hassanein H. Amer , Esraa A.Maklid tells Packet transmission[5] is another basic complication in NCS's. The network can be considered as a mesh of doubtful transmission paths[126]. Other than delay during transmission, some packets can even be lost during the process of transmission. Therefore, how the NCS performs is affected highly by packet dropouts, thus this issue should be considered. Due to packet size and bandwidth constraints of the network, plant outputs are sometimes transmitted via multiple network packets thus creating another problem. Chances exist that all or part or even none of the packets arrive according to the computed time by control calculation, due to the intervention of network medium with various other nodes on the network. Multiple-packet and single-packet transmissions are utilized in the diversified networks. In a single-packet transmission the actuator or sensor data is merged into a single network packet and is made to transmit at the same time. In a multiple-packet transmission instead of sending altogether the sensor or actuator data, the data is transmitted via different network packets, due to which the data may not be received at the plant and controller at the same time. One significant reason for using multiple-packet transmission over single-packet transmission is that in a packet-switched network due to size constraints of a packet only limited information can be carried in a single packet. Therefore for transmitting data of large amounts it has to be broken down into multiple packets. Another reason for using multiple-packet transmission is that in an NCS the actuators and sensors are not located at the same location and are scattered over the big physical areas, therefore making it unfeasible to the whole data into a single network packet. For different variety of transmissions varied types of networks are suited. In Ethernet ,which was from the first day designed for information transmission, can carry data of 1500 bytes maximum in a single packet. Therefore, it can be more proficient if the whole sensor data is lumped into a single packet and transmitted together i.e. single-packet transmission. Whereas in Device Net, which has more frequent transmission but only of small size data i.e. it has a maximum capacity of carrying 8-byte data in every packet, therefore in Device Net the sensor data should be distributed in different packets. Simple communication architecture is the basis for the present control system technology wherein all the signals are transmitted in synchronous specified links, which have pre-calculated delays without any packet loss. For meeting up with the specifications of control systems, dedicated small communication networks should be configured. The behavior and influence of packet dropout on NCS's is an important field of study if the entire system is employed in a large distributed style. The occasions where message collision or node failures occur, at those times packet drops usually happen in an NCS. Even though transmission-retry mechanisms are installed in the majority of network protocols, still they are only capable of retransmitting for a bounded amount of time. The packets drop after this bounded time is over. For real-time feedback control data, it can be beneficial to toss out the non-transmitted, old message and send the newly generated packet according to the availability. Due to this the controller is able to fetch up to date data for further control calculation.

Generally, for a certain limit feedback-controlled plants can support the data loss, whereas it is advantageous to discover whether the stability of the system will be maintained if the packets are transmitted only at a definite rate and is able to calculate satisfactory lower bounds for the provided transmission rate of the packet.

JITTER

Jitter [2] is described as a time deviation between the specified start time of action and the real start time. Majorly the control systems in the present time are based on the clock, synchronous systems, therefore requiring a communication network that assures the transmission of actuator, sensor and other signals. The architecture of computer hardware, scheduling algorithms[22], clock accuracy is the governing factors to determine the value of jitter. Thereby durable controllers have to be devised, which despite having jitter can provide performance.

The time interval for sampling in the system differs both at the actuator and the sensor. Normally for every sampling interval the value of jitter varies. It is reasonable to designate the sampling intervals a system can take for a specific load condition and if the system is appropriately predictable. The jitter influence on the system can be possibly remunerated if it is known beforehand by analyzing its effects.

QUALITY OF CONTROL (QoC)

D N Tse and M.Grossglauer explain the salient aim of NCSs from the viewpoint of control is the Quality of Control (QoC) [72]. To assess the performance of closed-loop systems in mainstream feedback control theory, various properties are considered. The prime assess is interested mainly in coping up with the system response features like steady-state accuracy and transient response, and stability of the system. Other than these requisites, for certain perturbations or inputs controller designs aim to reduce system error for these inputs. The variance between the actual response and the desired response of the control system is termed as a control-loop system error.

Basic standards like ISE(Integral of Square Error) or IAE(Integral of the Absolute Error) or ITSE(Integral of Time-weighted Square Error) gives quantitative estimates for the control system response and are further utilised to evaluate controllers. Some of these criteria, evaluate errors with time, scaling down transient response errors and forbidding steady-state errors.

QoC measurement is done on the basis of closed-loop system error and criteria of IAE are used because assessing every error equally is important. The basic purpose of controllers is to reduce error(the deviation which occurs in the control system because of perturbation), therefore QoC is important as it correlates to smaller deviation (errors). Therefore we can say that the IAE index and QoC are inversely related.

Thus for the designing of periodic task systems the concept of QoC is used. Following the QoC specification of the system, the system by amplifying activation periods, can actively minimise the load. The co-design of feedback scheduling policies and adaptive[92] controllers can help in making the best use of QoC of NCSs.

Another technique with high potential that can be researched upon in NCSs is of feedback scheduling. QoC measurement is ameliorated by intelligent control theory and is further used for feedback scheduling in embedded systems.

RESEARCH DIRECTIONS OF NCS'S

Periodic vs event-based control

Nicholass , Kottenstette, Xenofon Koutsoukos,Joseph Hall, Janos Sztipanovits discuss Time-varying [7] and unknown delays are eminent difficulties faced in networked control. It is hard to obtain jitter-free transmission of control actions and measurement signals, and short latencies due to the bounded network bandwidth. As the usage becomes more frequent, this problem becomes more aggravated. To lower the frequent network utilisation, is one of the ways to deal with network delay having restricted network bandwidth, thus helping in ameliorating the overall efficiency NCSs. Huge diminution in the average utilisation of network with better performance can be promised from preliminary results derived from the event-based control theory. Therefore another course of the line that can be followed in NCS research is of event-based versus periodic control.

Till now, the research done on event-based control theory is very limited. The major reason behind this the resulting system descriptions which are both non-linear and time-varying therefore making it very complicated for analysis. Communication jitter might escalate for an event-based control, therefore making it a big drawback for such type of control. The sensitivity of event-based controllers on jitter and latency is unknown when differentiated with basic periodic controllers.

NCSs analysis and design

Michael S.Branicky, Stephen M. Philips, Wei Zhang shows that for about 60 years the feedback control systems have been researched upon. Still, even for including communication networks into an NCS showcases some un-faced new obstacles in NCS analysis, modeling and design. Ideas for modeling the structure of a plant/controller/sensor/actuator are known, whereas the idea of how to model main features of network communication in an NCS, and the interaction between the rest of the system and the network is still unknown. Therefore it is of basic significance to formulate and model the NCS problem accurately during the simulation and/or analytical study. The field of NCS still being a less explored area, the need for following pre-specified approaches does not exist. Till the problem is accurately and realistically formulated, the research of new approaches should be persisted.

In the field of NCS research, evaluation of the stability [1] of the system is a basic issue. The snag of stabilization in NCS in a discrete-time domain having erratic delays is considered in the research of NCS. The delays [8] between controller-actuator and sensor-controller are considered as Markov chains, the consequent closed-loop systems are jump linear systems consisting of two modes. For stabilizing the controllers, the needful and adequate conditions are instituted. According to the study the state-feedback gains are found to be mode-dependent. For assessing the state-feedback gains an approach of iterative linear matrix inequality is implemented. In the research on NCS the models having both data packet dropout and network-induced delay during transmission are taken into consideration.

Yodyium Tipsuwan, Mo-Yuen Chow explain Middleware [10] application to aid teleportation and NCS has been tried in recent times. This application is used to link function calls and/or applications together either via a network or locally. Middleware in some implementations was successful in handling network resource reservation and allocation linking two applications through a data network. Various network conditions like delay bound, guaranteed bandwidth or loss rate can be attained using middleware in an NCS or teleportation [63] system, by arranging resource reservations with the peer network. The process of supplanting a networked controller instead of extensively used proportional-integral (PI) for networked control capability is time-consuming and expensive. For using a non-network-based controller for teleportation and networked control, a novel methodology is introduced to middleware to do so. Other than making use of the common features of middleware, the above-mentioned methodology helps middleware in altering the output of the controller according to the present conditions of the network traffic[116]. The revision of controller output is done with gain scheduling [64] as a basis. Therefore the suggested approach results out to be conveniently applicable for existing systems and even cost-effective as there is no need to reinstall, replace or redesign the existing controller.

CO-DESIGN AND CO-SIMULATION

The designing of both interacting controlled systems and communication protocols should not be considered as unconnected, thereby steering the research interest towards NCSs. Network problems like quantization, reliability, bandwidth, message delay and survivability are proposed to be approached simultaneously in the co-design idea with the issues of the controlled systems like performance, stability, adaptability and fault tolerance. Thus, when a group of NCSs are linked to a network and searching for network bandwidth, that time study of network scheduling can be done.

Generally, the idea of network scheduling [54] is to design a schedule for transmission for each transmission unit (controller, sensor, and actuator) in the network-based system for a scheduling algorithm (set of rules, determining what messages are to be transmitted at what time).

The idea of combining network scheduling and control system design was not used in the past. The separate consideration of the problem in the past has led to the control community focusing on a particular problem and ignoring ways of how to do the scheduling. Therefore, the people ignored the fact of how much impact scheduling can have on the performance and stability of the plant. So, now when the combining of the two designs is done, many of the presumptions fail, thus impacting the performance of the system.

The field of network scheduling is an area in NCSs which is yet to be researched upon. The idea of co-design can be ameliorated by feedback schedule.

FEEDBACK SCHEDULING

Originally, a static schedule used to be used for network bandwidth, by using polling, token rings or fixed priorities. According to this, the separation between the real-time scheduling community and the control community was done. The use of this separation is that it permits bandwidth scheduling problems to be dealt by network engineers and allowing control engineers to completely focus on designing the controllers. The original idea of a static schedule, according to control engineers, was an open-loop solution. This means that, once the static schedule is initiated at system set-up, the distribution of network bandwidth cannot be altered at run time for the control loops. A static schedule for adequate bandwidth can successfully assure real-time communications. Whereas for conditions when the network resources are scant, e.g. in dynamic systems that have both workload fluctuations and bandwidth constraints, scheduling with open-loop algorithm can cause less utilization of network resources in light workload or due to unavailability of resources can provide inadmissible QoC [21] in overload conditions.

To counterattack the above-mentioned problems, the methodology of feedback scheduling is used. The methodology of feedback scheduling can be put into use for both network scheduling as well as CPU scheduling. Sending messages via a common bus is similar to accomplishing tasks in a single CPU. In both scenarios, the shared resource has to be assigned to concurrent tasks, and both the tasks have issues like real-time constraints and deadlines to be fulfilled. For NCSs, CPU time is replaced by control network bandwidth for shared resources, and data packet transmission takes place of task execution [20].

The advance feedback scheduler [36] consists of actuator, predictor, regulator and a monitor with advanced architecture. To foretell the network conditions, Elman, an online learning neural network is installed, and then according to the evaluated availability of network utilization, the control period is adjusted. For the regulation of periods, a fast algorithm is made into use. Another direction in which the control community can research is the idea of fusing feedback scheduling with an intelligent control method.

BANDWIDTH MANAGEMENT

Communication networks having a non-deterministic nature [11] cause a lot of obstacles for NCSs. For example, delay jitter, communication delays, and packet losses detrimentally affect the system's performance, and can even affect the stability of the system at times. Two different directions for research have come into existence from this advancement in NCS. Control theoretical analysis is aimed in the first direction of research keeping the network as a permanent parameter. The designing of communication network algorithms, infrastructures or protocols is targeted in the second direction of research. Designing exceptional controllers with different sampling rates comes under the example for the first approach, whereas for the second approach designing of dynamic and static message scheduling algorithms are some examples.

The basis of scheduling methods and bandwidth allocation for NCS originally, was static strategies which ensured control performance at the cost of filling up the available bandwidth permanently. Whereas, when conditions are changed at the network level or control application level, the efficiency of the static techniques reduces, because of less utilization of the pre assigned resources. If possible, for increasing the functionality or for improvising the performance of NCS, the underutilized resources can be made into use.

If distributed control is employed Omni presently over IP networks, the issue of network bandwidth comes into existence. This happens for overall every case as when various processes tussle for a limited resource, like network bandwidth [38], that too without proper coordination, congestion is obvious to occur. For determining the efficiency of the bandwidth allocation scheme, a determining factor that is usually there is fairness.

An idea to manage the dynamic bandwidth in NCSs that permits the control loops to utilize bandwidth by the dynamics of the control processes while striving to boost the performance of the NCS at an overall level is used. The above goal is attained by supplementing the space representation of the original state of every control process with a fresh state variable which pronounces network dynamics.

A scheme is put forward which methodically allots network bandwidth in various control systems. The notion used here is that the sampling periods of control systems are varied according to the congestion level supplied from the network.

Another idea of decreasing the bandwidth requirements for controllers functioning on real-time networks [56] like Controller Area Network (CAN) in reply to spells of the busier network from intermittent resources is put forward. This technique is derived from development in the research of time scales in dynamic systems.

The most favorable jitter-dependent bandwidth [62] scheduling algorithm is put forward for token-type NCSs. The jitter which is produced by scheduling [61] is only considered. Jitter is considered as joining bridge between control performance and the bandwidth occupancy in this method. The allowed range for the sampling period for every control loop is limited based on the need of the controller’s performance, by selecting the jitter [60]. Other than affecting the achievable performance of control, even the bandwidth utilization is affected by the choices for a sampling period and jitter for every control loop. Thus, a balance between the control performance and bandwidth occupancy can be determined.

INTELLIGENT CONTROL METHODOLOGIES IN NCSs

A platform for distributed learning control [57] is provided by NCSs. For PID controllers other than remote-tuning there seems no determined research activity for amalgamating learning control, adaptive control with NCSs study. The integration of NCSs and intelligent control theories (Neutral networks [38], Fuzzy logic, etc.) seems to be a research area with good potential.

To requite for network delays having fuzzy logic as the basis, Almutairi et al, suggested a modulation procedure for NCS consisting of a linear plant with an adjusted PI controller. According to this modulation methodology [44], the gains of PI controller are updated externally at the controller output according to the output error of the system created by network delays. Therefore, striking out the need to modify, redesign or interrupt PI controller for use on a network domain.

An idea is put forward to enable the already existing controllers for teleportation and networked control by middleware. The idea suggests that the external gain scheduler can use the technique of soft-computing like neural networks or fuzzy logic.

An idea suggesting designing a feedback scheduler with neural networks as the basis is put forward. For foretelling the network conditions, Elman, an online learning neural network is engaged. Then, according to the predicted unoccupied network utilization, dynamic adjustment of the control period is done.

SIMULATION OF NCSs

Simulation has a vital role to play in field of the network research. A varied set of research people who use standard framework increased their faith and started complying with the simulation results. Despite of the advantages of a common framework, specific simulations aimed at certain studies have been developed to a large extent by the network community.

Due to such simulators which are aimed at specific study, research which uses them does not often demonstrate the scope of the experience which can be seen if the researchers employ an extensive set of queuing techniques, traffic sources, and protocol models.

A significant role is played by simulation of networks in NCSs research. The research on network scheduling should be involved in the research on NCSs. NS and TrueTime are two usual simulators that can be employed for NCSs.

TrueTime is a MATLAB/MATLAB based simulator which caters to real-time control systems. TrueTime helps in simulating the multitasking real-time kernels having controller tasks, temporal behavior, and also in analyzing the impact of network scheduling and CPU on control performance. The real-time kernels are event-driven and are capable of handling external interruptions and also fine-grained details like context switches. Random scheduling policies can be expounded, and these control tasks can be executed using M functions, C functions, or MATLAB block diagrams. The block diagram obtained from TrueTime creates a possibility of researching on some fundamental scheduling problems of NCSs and the research community can also use TrueTime to expand their explicit scheduling and control methods in NCSs [118].

The most widely used simulator in network research is NS. The research has even been extended to NS-2 for simulating the transmissions of controllers and plants which are designed using ODEs. Interestingly new challenges are posed by NCSs for the mathematical design and analysis. Research is done to analyze the issues developed by these tools which amalgamate simulations at the packet-level network for communications (by expanding ns-2), and the simulations of dynamic systems for the environment and control agents (employing an ODE solver).

In some researches control trials on a physical network are investigated, which allows the involvement of real network traffic in feedback control of the plant. MATLAB is used for computing the simulation of the controller and the plant. In a plant computer, a control signal transmitted through the network is obtained by the C++ program, which further sends it for output calculation and plant state to MATLAB, which then forwards the output of the plant to the controller's computer. Plant output transmitted through the network is received in the controller's computer as a C++ program, which then computes the control signal using MATLAB, and then the plant computer receives the signal. This is the course of action followed by the control data and sensor data for communication in the network, besides having network traffic, and even undergoing delays or collisions.

2.3 PROTOCOLS

E.Royer, C.K.Toh elucidates in present times the way information is transported has been changed dramatically by changes in wireless technology and also brought about changes in the thought process of a human being. Various means of multimedia protocols [50] are available in the world which is used by individuals to communicate with each other. Mobile[100] computing makes computing possible in your space. This has become possible only due to wireless technology. The protocols used in the fixed network cannot be used in the present times because of the development of battery-operated systems. The development in computers and the way wireless transportation takes place has led to the start of the wireless sensor network[51]. These networks require all systems to be efficient due to limitations imposed by the batteries. The available battery power should ensure that the network should perform and provide information as long as possible continuously. This is defined as the maximum lifetime of the network.

Nodes use some percentage of batteries in communication during different stages of the collection of data. The route is designed in a manner so that the maximum time of the available battery[48] power can be utilized.

The routing has to look into the channel bandwidth also. There are many protocols which have been evolved in the mobile network to look into these matters.

SENSOR NETWORK MODEL

A wireless sensor network consists of a base station which takes care of transportation of information between different channels. This requires infrastructure to measure information at various locations. Wireless sensor networks are used to measure various parameters like heat, humidity, pressure, sound, etc. In present times people want the network should be more trustworthy and the information should be clearer between people and the systems. These should not be affected by different physical parameters.

Advancement of systems has led to the start of another type of communication network known As MANET. The advantage of this system is that it does not require any fixed infrastructure and can be set up at any place. This makes it possible to be used in areas where setting up of infra is not possible like rescue operations, war areas, etc.

The algorithm used for transportation of information between nodes depends upon the type of routing protocol like RIP, LAR, DSR[121], OLSR[108], etc.

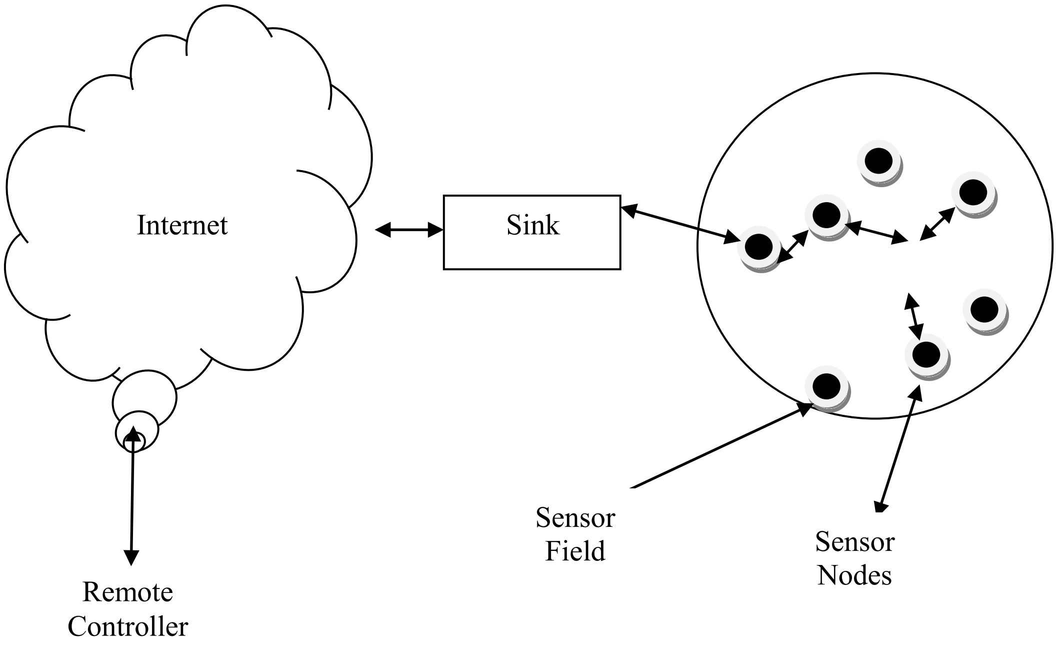


Fig. 2.8 Sensor Network Model

SENSOR NETWORK PROBLEM

POWER CONSUMPTION

Systems used in Wireless sensor networks operate on batteries and thus it necessitates that the power consumed should be less. Various methods are used to save energy and power. There are operating systems that help in the reduction of power in the hardware which is used. Power saving systems used in space applications can be used in these systems.

COMPONENTS OF SENSOR NODE.

Wireless sensor networks are classified in twp categories Structured and Un structured. In a structured category the nodes are used in a classified way which helps in reducing the cost involved in the maintenance and managing them.

Energy-efficient functions are used in the network so that the energy used is less. Components like Radio , CPU, etc use a lot of energy when they are not functioning. This requires methods to switch off the power of these components when they are idle.

2.4 Stability analysis of Networked Control System

Ray and Halevi ponder over a continuous-time and discrete-time plant controller and examine ICCS by employing discrete-time thinking. A clock-driven controller is researched upon with improper synchronization between the controller and the plant. An expanded state vector is used for representing the system having values of plant output and input from the past and even the state vectors [36] of the controller and plant from the present. The result of this is a model that is time-varying, finite-dimensional and discrete-time. Vacant sampling and message rejection are also taken into account. The network control system is also analyzed with an approach of discrete-time by Nilsson. The network delays are modeled as independently random, constant and random whereas controlled by Markov chain. Through this the most optimal LQG control problem is solved for different delay models. The significance of time-sampling messages is also pointed out, which makes us know the system's history. A continuous controller and plant are considered by Walsh. The Control network which is part of other nodes is sandwiched only between the controller and sensor nodes. Introduction of MATI i.e. Maximum Allowable Transfer Interval is introduced by them, it is denoted by, the value of this parameter tells us that the maximum time between two successive sensor messages is equal to τ seconds. The goal of the study is to find the value of this τ, which is then used as the basis for estimating the Network Control System desired performance which can be assured to be maintained. The assumption is made that, nonnetworked feedback system.

(x_c and x_p designate controller and plant state) is stable globally exponentially. Therefore, a P exists whose relation is given as

Another assumption made is that we can use error, e(t) between controller input and plant output for collectively summing up the network effects. Therefore, the state vector for the network control system is given by $z(t) = [x^T(t),e^T(t)]^T$, and therefore the network closed-loop system can be shown by where A is written as In this research two methods of scheduling have been studied i.e. token ring type static and try once discard (TOD) scheduling. With an assumption that p sensor nodes are associated with the Network Control System, then static scheduling signifies that every node transmits precisely after p transmissions that too in a predefined order. From the MATI limitation, the controller should obtain a minimum one transmission in every **τ** seconds interval from one sensor at least. Therefore in the case of static scheduling[124], after an interval of at max (**τ**) seconds all the sensor values should be updated. In the case of TOD, it being scheduled protocol, the node having the highest weighted error through the final reported value, is the one that transmits the message. Once again the MATI restrain makes sure that one transmission is received at least every **τ** seconds. Whereas, like static scheduling, in TOD it is not the same case, i.e. it is not assured that after every p transmissions node will do a transmission. For every protocol, an upper limit of MATI **τ** can be computed, which is responsible for preserving the stability of the closed-loop system.

2.5 Performance analysis of Petroleum Tank system and Two Tank System

Performance analysis of Petroleum Tank system

M.A.A. Shoukat Choudhury, N.F. Thornhill, S.L. Shah describe here are a huge amount of control loops in an ordinary chemical plant, and to ensure that the quality of the product is not compromised and production cost is also not affected, the maintenance of performance of these control loops should be of utmost importance. The benefit to the industry economically as a consequence of performance assessment is very complicated to be calculated on a loop-by-loop basis as every problem loop very complicatedly affects the overall process performance. Reduction in off-grade production, reduced cost of operation, lower variation in product property can be seen by tracking down and repairing the problem loops all over the plant. Lacs and crores of rupees can be saved in a process industry even if 1% betterment is noticed in the energy consumption or any other work involved in the industry. One of the preliminary reason which leads to poor performance in control loops is oscillatory variables, which is therefore a challenge to pin out the main reason for oscillations in the process industries. The oscillations intensify the variation in process variables, therefore leading to an increase in the rate of rejection, second class quality of products, an increase in consumption of energy, and overall leading to a reduction in the profitability of the process. The oscillations can even reduce the life of the valve and make it wear out earlier. The cost of operations is increased almost proportionally to the deviations caused because of oscillations. The need to find and diagnose the root cause of these oscillations is important because the profitability for a plant manufacturing products with desired quality is more as compared to a plant that is making products with variations in the desired quality limit. Some of the factors which lead to oscillatory control loops are friction in the control valve, bad tuning of controllers, badly designed control system, oscillatory disturbances. Approximately 30% of the oscillations in the control loops are caused by problems in control valves. Non-linearities in the control valve e.g., dead band, backlash, and friction, can in turn make the output of the valve oscillatory which can lead to oscillations in the output of the process. Out of all these nonlinearities, friction is most repeatedly faced problem in the chemical industry. It restrains in achieving good performance in control valves and even control loops. Numerous studies have been done to find and diagnose friction or static friction. Still, after so much research yet there is no particular definition and depiction of the way how friction works. In this research this issue is addressed. In physical model parameters like spring constants, the valve's moving parts mass and various forces are unknown. To fabricate the desired response from the control valve, these parameters have to adjust properly. Even the effect which will be caused by hindrance in these parameters is unknown. Therefore operating with this type of physical model consumes up a lot of time and also cumbersome for carrying out the simulation. For estimation of static and other problems in industrial practice, it is done using percentage the valve travels or the span of the input signal of the valve. The correlation between backlash, dead band or friction and the values of parameters of the physical model is complicated. In this research we focus on providing a model of friction which is based on empirical data and is used for simulating and diagnosing oscillations in process industries.

In this research clarification is provided on the confusion in literature of control and also in the control fraternity regarding misinterpretation of words like friction and similar terms. Another definition for friction is put forward which considers parameters like the ones used in ANSI, the definition for hysteresis, dead band and backlash. These definitions display the main attribute of focusing on the input-output actions of these elements. An advanced data-driven two-parameter model for friction is invented and authorized with already functioning friction models and also from the figures acquired from control valves in industries that are affected by friction. The developed model is proficient enough to handle stochastic inputs. It can even simulate friction in MATLAB's MATLAB framework in the research of control loop glitches related to friction. After performing function analysis in the newly developed friction model, it shows valuable information on friction working. For instance backlash or dead-band never can in the existence of PI controller generate limit cycles until and unless an integrator is present in the plant under closed-loop feedback arrangement.

Performance analysis of Two Tank System

J.A. Ramos and P. Lopes dos Santos spell out Control Engineering touches human life in many ways. It is used in many applications such as automobiles, compact disc, DVD players, etc which are used by us. With time electronic components have become affordable and its availability has become easy. This will help to increase the application areas of Control Engineering which in turn will help in improving our comfort level by finding applications in areas of defense, health care, environment, etc.

A plant model helps to design a model-based controller based on first principles. The functions of the model are determined from various data that are obtained in various experiments. Experiments which help to draw functions are non-linear and are repeated. Plant models are of continuous state-space models that make the data distinct. This leads to various problems. A function estimation method is shown in this paper. Initially with the help of algorithms as CVA, N4SID, etc, a repetitive time state-space model is established. This is then changed to continuous time by using an algorithm. With the help of similarity formulae, non-linear equations are made and then changed to complement issues. The answer to this helps in getting the similarity matrix and functions of the system. The controller can be designed with the help of these functions. In this paper a case study related to control design is presented. The initially mathematical equation for a two-tank fluid system is made then functions are decided and lastly the controller is designed that will control the level of fluid in the tank. The designing of the controller is done through pole placement.

In the next chapters the mathematical equation of the two tank systems is established. This is followed by system identification and functions, in the next chapter, which is determined based on input and output data. Ultimately the controller is designed and in the last stage conclusions are made.

2.6 CONCLUSIONS

This chapter focuses on introducing and reviewing the already existing and modern research field areas for NCSs. The field of NCS is a potential research area having a wide range of applications. As the implementation of network applications is increasing widely in almost all places inclusive of places like offices, manufacturing plants, and even homes, therefore NCSs can be a promising field in the nearing future.

CHAPTER 3

WIRELESS SENSOR NETWORK AND MOBILE ADHOC NETWORK

3.1 INTRODUCTION

In today’s world Wireless technology has bought about a paradigm shift in the way of transferring information and has even changed an individual’s thinking perspective. A wide range of multimedia services exists in the world which enables people to communicate with each other using a wireless cellular network. Mobile computing [115,119] allows anytime and anywhere computing. This is possible due to advances in wireless technology. In the present computing environment the architecture and protocols used in a fixed network cannot be used due to the usage of battery-operated devices involved in computing of data. The improvement in miniature computing model and wireless transmission methods led to the creation of a wireless sensor network. Energy-efficient rules are required at all levels of protocol stack due to battery limitation and this type of sensor network. For a given battery power it is required that the sensor network continues to work and provide information as long as possible. This is known as the maximum lifetime problem in sensor networks.

Nodes use a part of the battery in transmitting, receiving and relaying packets during each phase of data collection. The routing algorithm is designed to maximize the time till the first battery expires or a part of nodes have the batteries expired.

In addition to the battery energy in the low bandwidth network, the channel bandwidth is also another issue and the routing problem has to look into it. There are many routing protocols which have been evolved for the mobile network which deal with these affairs.

Sensor Network Model

A wireless sensor network [46] is a network that comprises one main base station which deals with the handling of communication between various other nodes. The network requires a communications infrastructure for observing and noting down readings at sundry locations. Heat, illumination intensity, humidity, speed, power-line voltage, pressure, sound intensity, wind direction, chemical concentrations, pollutant levels, vibration intensity are the diverse parameters measured by a wireless sensor network. With time people foresee to have various advancements in the technology of future wireless networks like the network should be more dependable and communication should be more clear and undisturbed between people and devices irrespective of the various physical restrictions.

Another type of technology for transferring data and communication is Mobile Ad-Hoc Network [80] (MANET) which is a type of ad-hoc network. MANET has the basic advantage that communication infrastructure is not a prerequisite quantity and therefore it can change locations and can be configured anywhere. Due to its mobility its main use is where setting up the infrastructure is not viable or impractical. It is mainly used for rescue operations, and war zones, etc.

The algorithm [83] followed by routers for communicating, promulgating information between any two nodes is stipulated by the type of routing protocol selected. Some of the types of routing protocols that are available are Routing Information Protocol(RIP), Location Aided Routing(LAR), Dynamic Source Routing(DSR), Zone Routing Protocol(ZRP), Optimized Link State Routing(OLSR) protocol, etc.

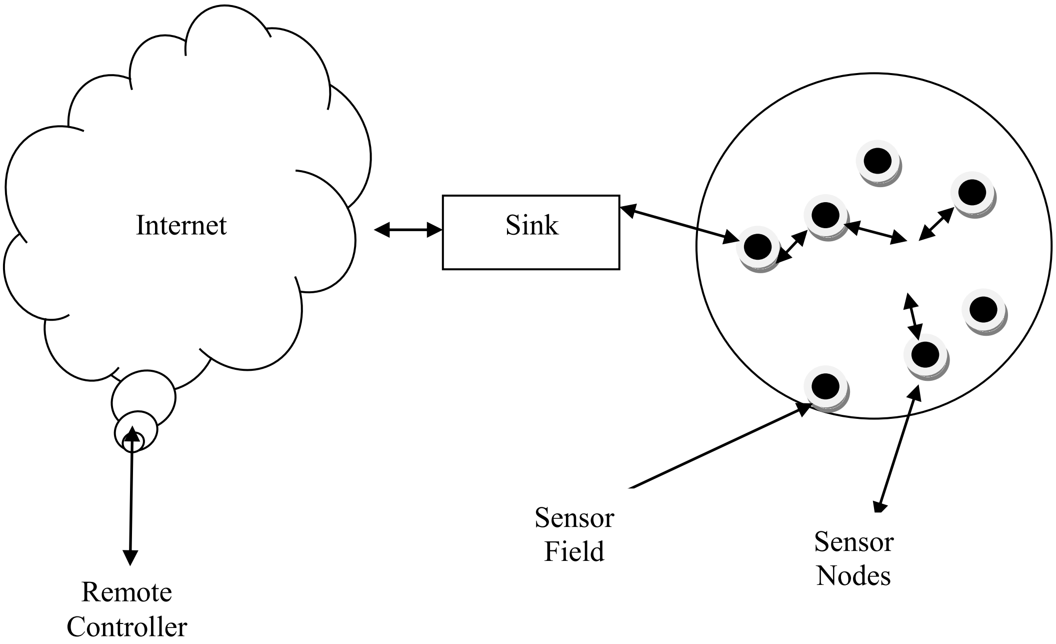


Fig. 3.1 Sensor Network Model

Power Consumption

Devices in wireless sensor networks operate on batteries [48] and thus should consume less power. Energy and power-saving methods are used at different stages of software. Operating systems have functions to limit the power consumption of the hardware used in BIOS Interface. Power consumption method used in space applications, more energy used by hardware, such conditions displays of hardware can be putting off instead of using the screen saver of the system.

Components of Sensor Node

Wireless sensor networks are of two types Structured and Unstructured. A structured network uses all or some of the sensor nodes in a preplanned manner. The advantage of this network is the usage of lesser nodes thus reducing the network maintenance and management cost.

During network activities, to minimize energy consumption some special types of protocols are used named Energy efficiency protocols. The node components such as Radio, CPU, etc. when in an idle condition also consume a large quantity of energy. This requires methods such as they manage the power to switch off the node components that are not needed temporarily.

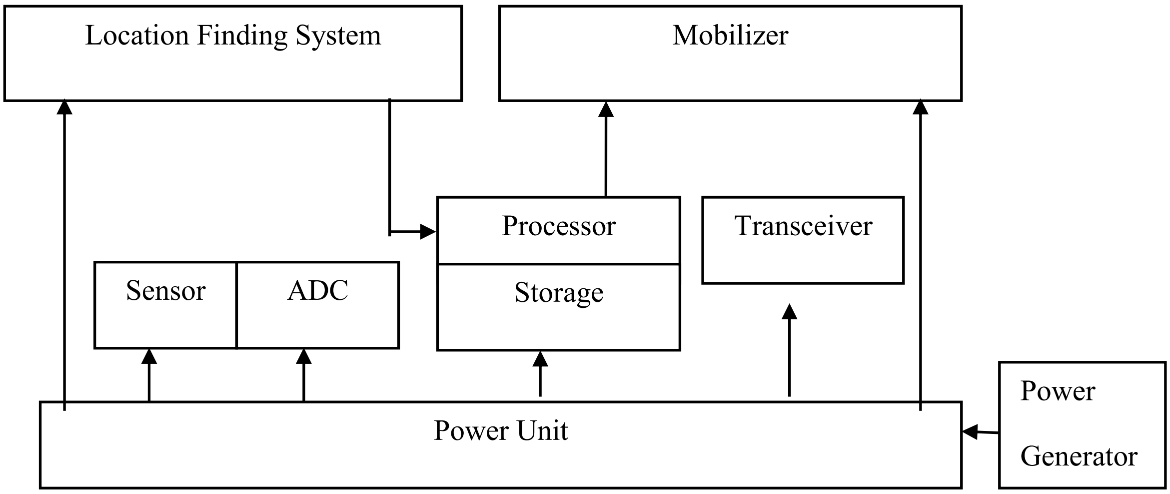


Fig. 3.2 Components of Sensor Node

3.2 WIRELESS SENSOR NETWORK

Wireless sensor network (WSN) also abbreviated as WSAN i.e. Wireless Sensor and Actuator Network consists of sensors nodes which have the work of recording environmental or physical conditions. The sensor nodes are equipped with four basic electronic components [58] i.e. transducer, microcomputer, transceiver and power source. The transducer is responsible for converting the sensed physical conditions into electrical signals which can be further processed by the following components. The role of a microcomputer is to process and store the sensed input. The transceiver is there to receive directions from the central unit and to transmit the data further. The power source supplies power for the functioning of all these equipments.

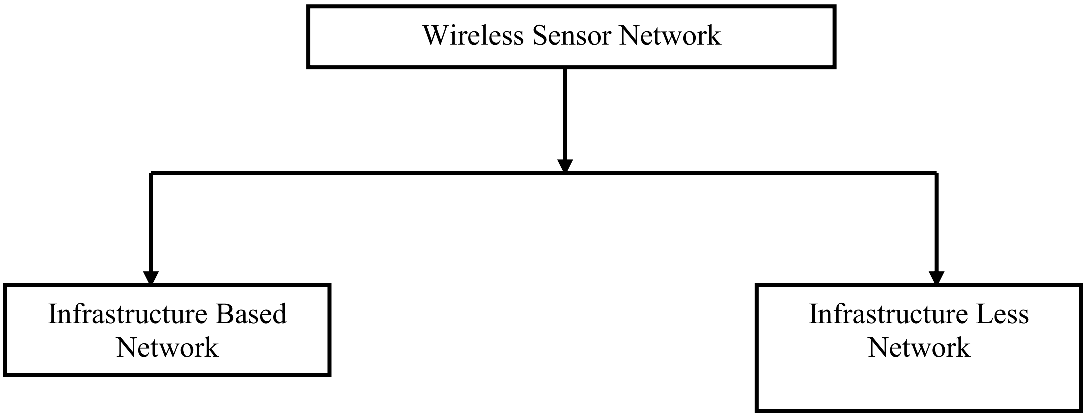


Figure.3.3 Types of Wireless Networks

3.2.1 Types of Wireless Sensor Network

There are five types of wireless sensor network which are classified based on the area where the infrastructure is set up. The classification is as follows:

1. Underground WSN’s
2. Terrestrial WSN’s
3. Multimedia WSN’s
4. Mobile WSN’s

3.2.1.1 Underground WSN’S

As the name suggests these sensor networks are used to observe underground conditions. For sensing the conditions the whole network is set up underground but to transfer the information to the base station sink nodes are bought into action which is present on the ground. Other than cost another challenging factor for these types of sensor networks is the recharging of batteries present underground and loss of signal also occurs sometimes.

3.2.1.2 Terrestrial WSN'S

These types of WSN's are present on the ground level and therefore these networks comprise more than thousands of sensor nodes. These sensor nodes can be planted in a structured or unstructured manner. As the sensor nodes are present on the ground therefore they can be recharged by solar power and therefore making the process of recharging them easy and cheap.

3.2.1.3 Multimedia WSN'S

As the name suggests these sensor networks can collect information in the form of images, audio or video. For capturing these data all the sensor nodes are equipped with a camera and microphone. This enables the sensor nodes to oversee and record different events occurring at different places. For keeping track of the collected data together, all the sensor nodes are interconnected using a wireless connection. The obstacles faced by Multimedia WSN's are that they require high power and high bandwidth [125] since deals with multimedia and it should deliver clearly without any disturbance.

3.2.1.5 Mobile WSN's

These sensor networks do not have fixed sensor nodes therefore they can move from one place to another and thereby providing enhanced coverage and better channel capacity. These sensor networks are more versatile when compared with static wireless sensor networks.

3.3 CHARACTERISTICS OF WIRELESS SENSOR NETWORK

There are numerous factors which define the efficiency of the deployed network. Some of the main judging factors are as follows:

3.3.1 Power Consumption

The energy supplied in the sensor network is mainly used for three purposes i.e. computation, transmission and storage. Maximum energy is consumed by sensor nodes for transmission of collected data. The sensor nodes being non-rechargeable in most cases, the algorithm for the working of sensor networks should be made taking into consideration the power consumption of the sensor nodes.

3.3.2 Cost Factor

The overall cost of the sensor network depends on the cost of sensor nodes being used as they are the primary equipment in the network and are installed in a large quantity.

3.3.3 Multi-Hop Communication

Since a large number of nodes are stationed in WSN's therefore for communicating data between sensor nodes and the base station, the other nodes act a channel[66] for transferring data from that node to the sink. Therefore when the communication is to be done by a node beyond its radio frequency, multi-hop communication comes into play.

3.3.4 Application Oriented

The sensor nodes are stationed depending on the area where the network has to be used. The network can be used in environmental, military or any other sector. Therefore depending on this the nodes are placed and the protocol is decided accordingly.

3.3.5 Network Topology

Since the network majorly depends on the sensor nodes and the battery of the node gets exhausted after certain usage, the network should be configured in such a way that it adjusts itself to the existing network and no data loss occurs. Due to the frequent addition of nodes, the topology[85] of the network changes dynamically.

3.3.6 Secure[106] Connection

The sensor nodes should be enabled with a high performance security system to safeguard the data from illegal and unauthorized access. Additional privacy operations should also be taken into consideration.

3.3.7 Self Organization

Since the sensor nodes are stationed randomly fashion in an unattended and abandoned environment, it should have the capability of organizing itself on its own and forming a proper network according to the allotted algorithm.

3.4 DIFFERENCE BETWEEN WSN AND MOBILE AD-HOC NETWORK

Wireless sensor network and Mobile Ad-hoc [47] network can be distinguished under various categories as follows:

3.4.1. Application

The main focus of WSN is to sense environmental conditions and transmit the readings to sink via sensor nodes whereas Mobile Ad-hoc networks are responsible for one to one applications like data transfer for example.

3.4.2. Network Topology

The topology used for WSN is mostly Star-Star topology whereas in Mobile Ad-hoc network majorly mesh-star topology is used.

3.4.3. Energy Consumption

In WSN most of the energy [86] is used by sensor nodes which are powered by a small battery but still they have a longer lifetime and the batteries can even be recharged by small power suppliers like solar cells etc. In the Mobile Ad-hoc network the nodes consume high power hence the power is mostly supplied to these nodes using AC/DC charger.

3.4.4. Number of Nodes

WSN is capable of handling more number of nodes when compared to Mobile Ad-hoc network.

3.4.5. Hardware

Hardware complications are less in WSN as compared to Mobile Ad-hoc network, therefore, making it more adaptable.

3.4.6 Software

Both the networks are application-driven but the simplicity level of software usage is more in WSN nodes whereas in Mobile Ad-hoc network the complexity level is more multiple levels of software is used.

3.4.7 Mobility

The nodes in Mobile Ad-hoc network are mostly human-driven therefore making it more mobile whereas in WSN the mobility of the nodes depends mainly on the application and the area where the nodes are stationed.

3.4.8 Communication Traffic

In WSN [51] the data is transmitted in the direction of the sink through one or more sensor nodes whereas in Mobile Ad-hoc network the data can be transmitted between the nodes and no central control is required for sending commands.

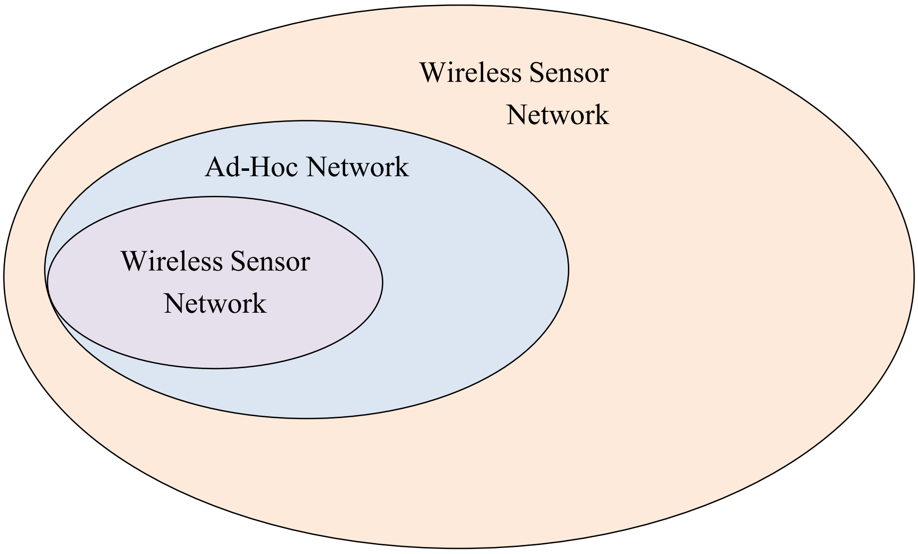


Fig. 3.4 Wireless Sensor Network as a subset of Wireless Network

3.5 ADVANTAGES OF MOBILE AD-HOC NETWORK

In today's world with the quick development of technology in the Ad-hoc network it is being vastly used in daily use gadgets like mobile phones and laptops. Due to its self-organizing nature of the network it readily reduces the cost of communication. With the introduction of 4G technology it has made the ad-hoc network better and powerful. The design is simple for installation and designing makes it better. The Ad-hoc network [67] has the following advantages:

3.5.1 Continual Re-Configuration

The network gets healed automatically because of its continual re-configuration.

3.5.2 Communication Is Quicker

The nodes in this network do not depend on any software or hardware, therefore, making the communication more quickly and better connected.

3.5.3 Flexible Nature

The setup can be done temporarily anywhere and anytime because of its flexible nature.

3.5.4 Planning

For communication from source to the destination node in a wireless ad-hoc network do not require any before in time planning.

3.5.5 Design

To design a small independent device wireless ad-hoc network, unable to do so.

3.5.6 Robustness

Robustness [69,13] means ruggedness, toughness, activeness, liveliness, strength and so on. The wireless sensor network as well as MANET's is lived in case of disaster.

3.5.7 Cost

Once we developed the infrastructure to use the wireless networks to communicate between the primary users to the way in nodes, and if required to add more user and to expand the system to use a wireless network the system do not require increasing the cost.

3.6 ROUTING PROTOCOLS

The act of transferring data from the data generating source to the final destination is known as routing. The process involves two basic steps i.e. firstly to identify the optimum path for sending information and secondly to send the data in the form of packets through the internetwork. The methods used for the calculation can be a standard measurement of the number of hops thereby deciding the algorithm for transmitting the information.

Wireless sensor networks[93,94] main job is to sense a prefixed event like vibration levels, temperatures and pressure in various environments. Many of these are not within the reach of humans. WSN's are not mandatory to be mobile. The set of a mobile node which is coupled by wireless links is termed an ad-hoc mobile network.

The arrangement of pattern thereby changes very frequently. Routing protocols that decide the path to be followed by data packets from the source node to the destination node used in wired networks cannot be used in wireless networks. This is due to the dynamic nature of network patterns and the absence of established infrastructure. A large variety of routing protocols has been introduced in recent years.

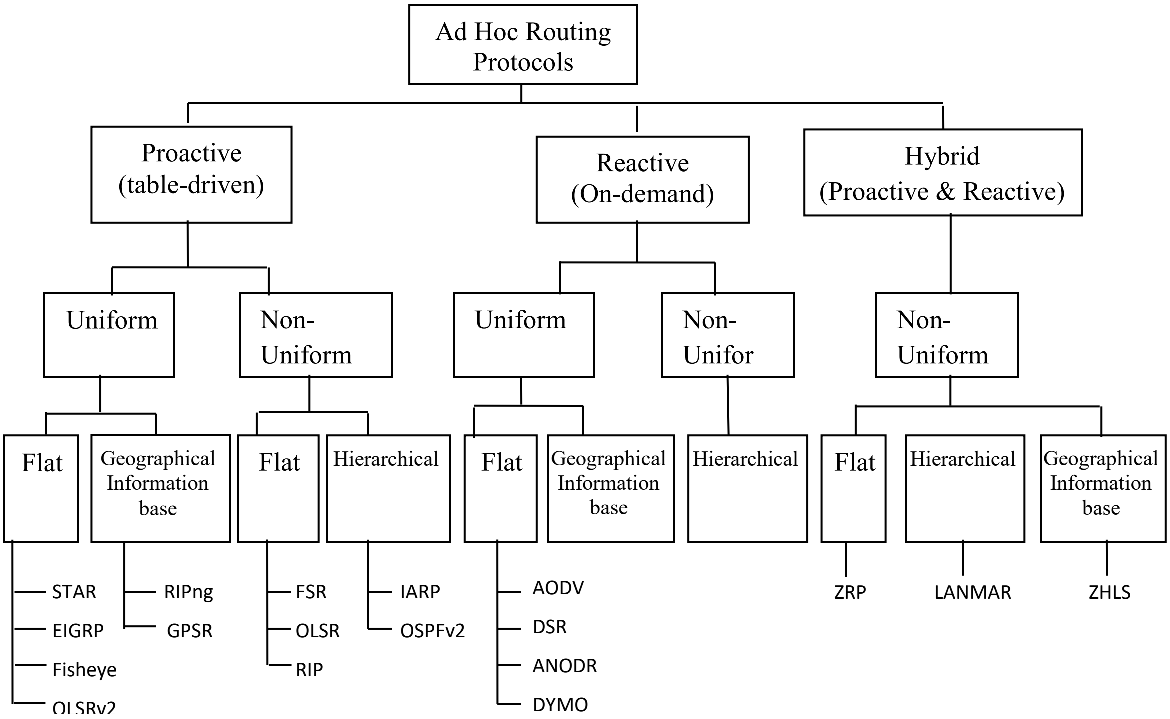


Fig. 3.5 Classification of Routing Protocols in WANET

OVERVIEW OF WSN'S ROUTING PROTOCOLS

The different varieties of routing protocols should be studied to find its utility in wireless networks. They have various requirements while the routing metrics are being worked out. This requires a proper understanding of routing protocols and its characteristics and finds out which routing metrics help the routing in wireless networks. Routing protocols are characterized in three ways on the basis of the way the packets are sent on the paths. These are on-demand routing; Proactive routing and Hybrid routing. They are also defined on the basis of the role played by the nodes.

1. Flat routing strategies. These are divided into two ways; Proactive and Reactive based on the philosophy of design.
2. Routing strategies which are Hierarchical.
3. Routing which is helped by Geographic positioning.

The first routing expects a strategy which is straight. Every node has the same role to play. The second routing gives different roles to the participating nodes. In the last case the nodes have a Global positioning system and they are helped by this Positioning system to know the location. This is required today as the cost of these devices is very competitive.

3.6.1 Routing Protocols In MANET

1. The classification of the protocol used is done mainly based on the structure of the network and the strategy being used by the network for transferring information. The classification done based on the network structure is mainly categorized into three groups i.e. flat routing, Routing strategies which are Hierarchical and Routing which is helped by Geographic positioning. The flat routing is divided into two ways; Proactive and Reactive based on the philosophy of design.

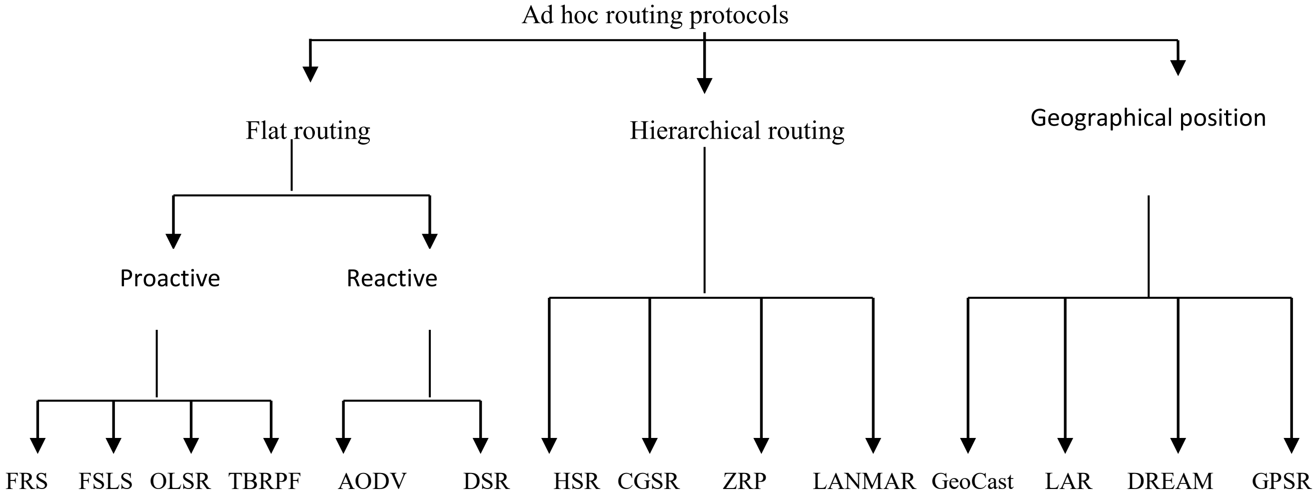


Figure 3.6 Type of Protocols

Routing protocols of mobile ad-hoc wireless networks are divided into various types on the basis of varied functions. The types are given below

REACTIVE AND PROACTIVE ROUTING PROTOCOLS

Reactive and Proactive protocols [65] help the mobile ad-hoc networks to transmit messages to the required points. Here the data is transmitted through nodes which are mobile. This network is applied in areas which are affected by certain disasters, military area or the areas where the deployment of fixed infrastructure is not possible. The nodes can be placed at any location/point. The data is transmitted through various nodes which makes it desirable to have a predetermined protocol so that the data is delivered to the correct location. Certain routing protocols are

- AODV
- DSR
- DYMO
- LAR

3.6.1.1 OLSR - Optimized Link State Routing Protocol

This routing protocol is under the category of proactive type has the routes available whenever needed. The work of OLSR over the basic link-state routing protocol is to first lessen the control packet size by not declaring all the links and just telling a subset of links. By reducing the nodes and using only selected nodes it helps in reducing the flooding of control traffic. OLSR uses hop by hop routing for transmitting the information. Therefore nodal mobility is possible in OLSR i.e. the nodes are traced using control messages.

OPTIMIZED LINK STATE ROUTING PROTOCOL (OLSR)

OLSR [78] is an IP Routing protocol that is designed for mobile Ad-hoc networks and also used in other wireless ad-hoc networks. OLSR is a proactive link-state routing protocol and use hello and topology control messages to discover and broadcast the link-state message in the whole network. Each node takes this help to determine the next hop point for all the nodes and the shortest path is chosen.

Open shortest Path First (OSPF[127]) and IS-IS determine a particular router on every link to tackle flooding of topology information. In wireless ad hoc networks, link notion is different and a different system is required to have the full benefit of the flooding process. At each node the OLSR protocol looks for 2-hop neighbors with the help of HELLO messages and then determines Multipoint relays (MPRs). Nodes select MPRs on the basis of the existence of a path to each of its 2-hop neighbors via a node which is shortlisted as MPR. These MPR nodes then source and forward TC messages that contain MPR selectors. This way MPRs make OLSR different from other link-state routing protocols. The forwarding path for TC messages is not informed to all the nodes and depends on the source. Nodes that are selected as MPR are only shared.

The topology data-base should be the same in the whole network in the link-state routing and thus OSPF and IS-IS carry out flooding with the help of a reliable algorithm. It is a very cumbersome exercise to make these algorithms for ad hoc wireless networks. In such a case OLSR does not bother with reliability and simply floods topology I a manner that the data remains stable for the required interval of time.

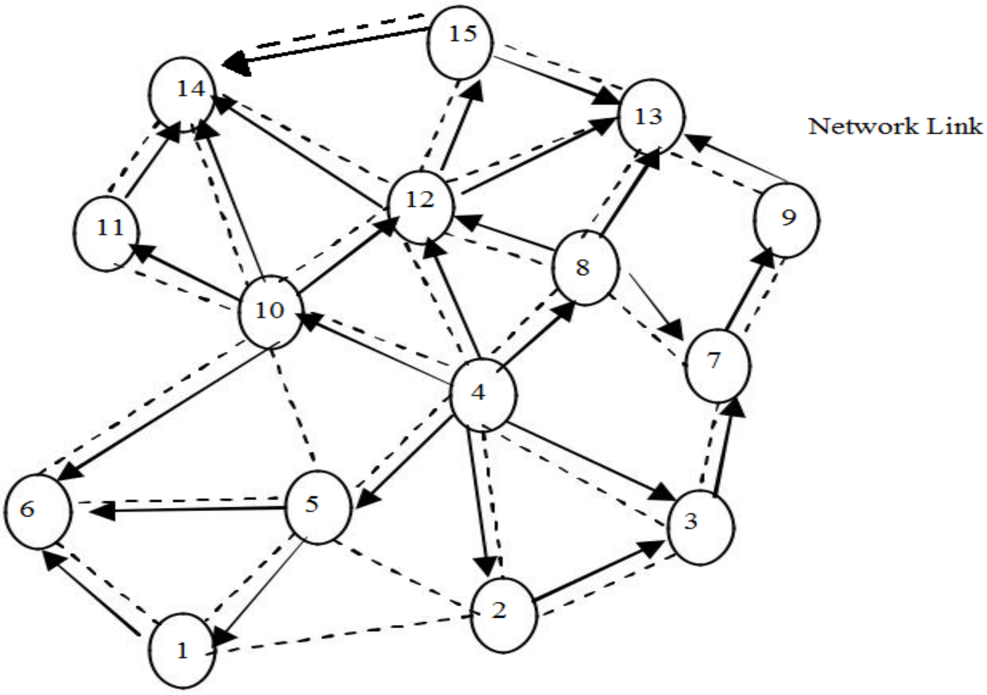


Figure. 3.7 Flooding the network by nodes

SELECTION OF MULTIPOINT RELAY NODES

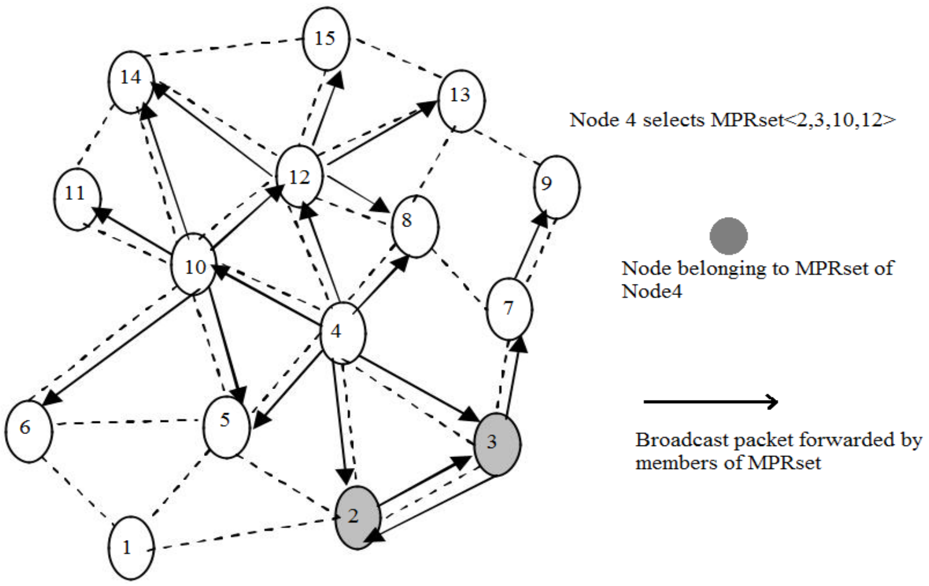


Fig. 3.8 Flooding the network by nodes

Fig above shows the forwarding of TC packets using the MPR set of node number 4. For example, node 4 selects the node 12, 10, 3 and 2 as members of its MPR set. Forwarding these nodes makes the TC packets reach all nodes inside the transmitting node's two-hop topology. The collection of optimal MPR set is NP-complete.

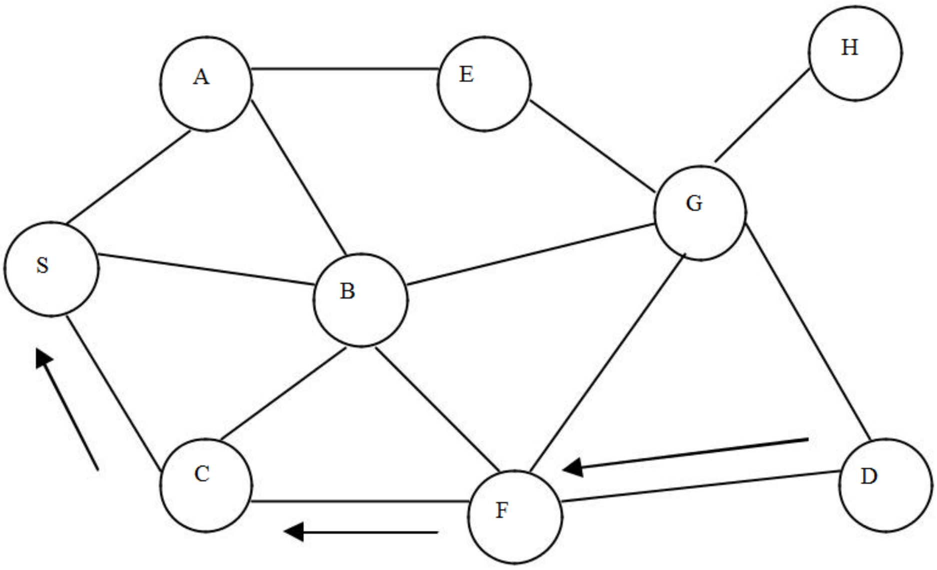


Fig. 3.9 Route Reply (RREP) packet in AODV

ADVANTAGES OF OPTIMISED LINK STATE PROTOCOL

- The OLSR is better when compared to other protocols that are driven by the table.
- Flat Routing protocol, OLSR, requires no control centrally.
- It sends data about the route to the hosts that are active in the network.
- The system makes it mandatory for each host to provide updates at a regular interval of time.
- The effectiveness of the topological changes is done by changing the interval of time of delivering of the Hello messages.
- It is easy to use in interfaces.
- It is beneficial for areas which have long delays.

3.6.1.2 DSR - DYNAMIC SOURCE ROUTING

The dynamic Source Routing protocol is a type of network which organizes and configures itself on its own without requiring any infrastructure. In DSR the overhead is very low still when there is a change in the network it is able to react rapidly. The two main mechanisms involved in DSR which makes it able to react more rapidly in spite of the change in location of nodes are:

4 Route discovery

5 Route mechanism

DSR

The Dynamic source routing protocol is a simple and effective protocol made for multi-hop wireless mobile ad hoc networks. DSR permits the network to get organized and configured on its own. The protocol is made of two mechanisms i.e. Route Discovery and Route Maintenance. These take care that the nodes determine and maintain routes to unplanned destinations. All aspects of protocol work when required thus enabling the routing packet overhead of DSR to scale on its own to only that is required to react to changes in the route which are being used.

The protocol permits various routes to any destination thus enabling the sender to select and have an influence on the routes used in sending its packets. It ensures free routing of the loop.

ROUTE DISCOVERY PHASE

The route discovery phase is applied when the source wants to send the packet to the destination. Before sending the packet the source searches in-house whether it has a route available to the required destination. On its availability the route is selected to send the packet. If the same is not available then the route discovery process is started and a request is sent for a route. This request contains the location of the source and the destination with a unique identification number. The node on receipt of the RREQ looks at its route cache to see if there is any route available to the required destination. If no route is available the node sends the request to its neighbor.

The request moves through the network until the destination is reached.

There are three ways to get the way back to the source. The first way is that the route already existed. The second way is that the network has symmetric or bi-directional links. The third way is the existence of asymmetric or unidirectional links. In such a case a new route discovery process is started. The collected information on the route is utilized to get the new route in a reverse manner.

ROUTE MAINTENANCE PHASE

The route maintenance phase is used to take care of the links that get broken in between the source and the destination. On breakage of the link the route initiated is removed by the node and simultaneously a route error message is produced. This message is sent to all the nodes through which the packet was to be routed. On receipt of this message the node deletes the hop in error from its route cache.

There is an acknowledgment message which helps to know the correct route links. The routes which are affecting the broken link should be removed from the nodes where the route error message is sent to the source. DSR effects traffic in packets which decreases the performance of routing.

3.6.1.3 ZRP - Zone Routing Protocol

ZONE ROUTING PROTOCOL

ZRP[137] is a merger of proactive and reactive type of hybrid protocol which is made for ad hoc networks. The major benefit of a hybrid protocol is it helps in decreasing the bandwidth[120] and controlling the overheads in the required networks. It works to reduce the delay due to route search operations.

3.6.1.4 AODV

This protocol is reactive by nature and unicast routing protocol designed for MANET. As a reactive protocol it is required to retain the routing information through dynamic paths. In AODV [79] routing information is stored and maintained in tables on their nodes. Each node maintains a next-hop routing of the packet table and decides its route. If no route remains then it performs a route discovery process for finding a route to the destination thus making route discovery process on-demand.

The route discovery process involves network–wide flooding of request packet message. When route gets established it maintains route maintenance procedure till the destination becomes unreachable since AODV routing is destination-based reactive routing protocol.

In AODV when a source node is required to send a packet to its destination and no route is available then the route discovery process is initiated. In this process the source node floods route request (RREQ) packets as shown in the below figure.

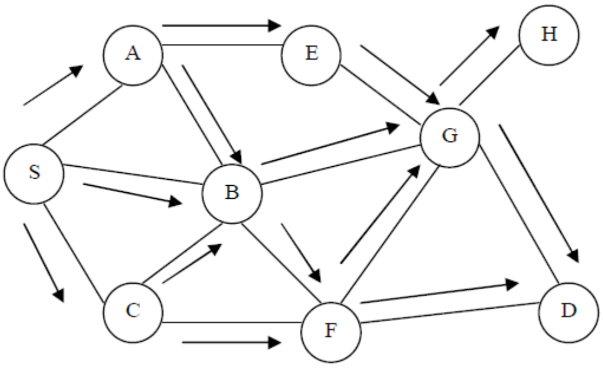


Fig. 3.10 Route Request (RREQ) packet in AODV

A route request consists of the address of the source and the destination, the broadcast ID, the source node sequence number and the sequence number of the destination matched with the source node's sequence number. Sequence numbers are important to ensure that it is loop-free.

ROUTE DISCOVERY

A route is required to exist between the source and the destination. In the absence of this route, the route discovery process is initiated. The RREQ is sent from the source to the node in its neighbor which it turns passes it to its neighbor node. The nodes generate a route request with a clear destination, sequence number and broadcast ID which is sent to its neighbor nodes. On receipt of route request the node sends a forward path to the node as shown in the figure.

On receipt of RREQ by the nodes i.e destination node and the nodes in between the source node and the destination node, the nodes send a reply back in the direction of the source. When the RREP reaches the source node a route is established between the source and the destination. The below figure gives the route of RREP starting from the destination mode and ending at the source mode.

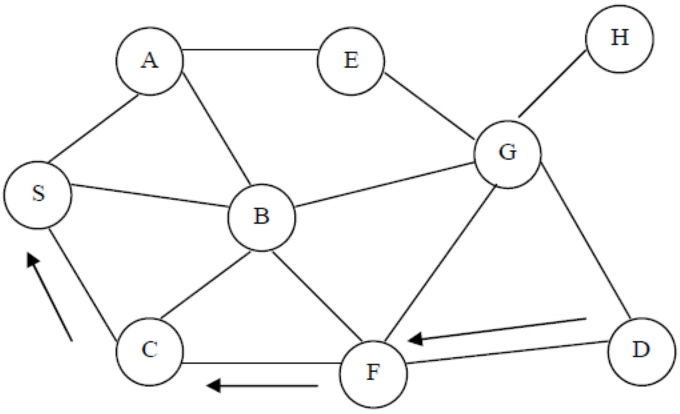


Fig. 3.11 Route Reply (RREP) packet in AODV

ROUTE MAINTENANCE

A route established between sources to the destination is maintained by the source. When this route becomes inactive, there is a need to establish another route. In this process RREQ is sent to other network nodes. RREQ propagates till the source node is reached. The affected node stops sending the data through the affected node and in turn chooses a new route for sending RREQ.

3.6.1.5 Dynamic MANET On-Demand Protocol

DYMO [53] is a follower of AODV and has got many advantages. It is easy to establish and any increments in the future are also taken care of. DYMO can work as both Proactive and as a reactive protocol i.e. routes can be discovered when needed. This process involves two steps.

1. MANET sends RREQ. It stores information of all the nodes it goes through thus enabling these nodes to remember the route back to the source.
2. On receipt of RREQ, RREP message is transmitted to the source informing that the route has been found. RREP can go back via the same route of RREP thus permitting the nodes to store the complimentary route back to the source. The nodes record two way route enabling the transfer of the packet from the source to the destination.

When a data packet is received for forwarding and the link is broken then the source of the packet is informed by sending the RERR message. On receipt of RERR the source deletes this route. The basic operations of DYMO are

- Route Discovery Process
- Route Maintenance Process.

ROUTE DISCOVERY PROCESS

In this process source send RREQ message to discover a route to send packets to the destination. The sources DYMO will send another RREQ message if the route is not discovered within the RREQ request time. Frequent attempts to discover the route of the required destination must utilize an exponential back off. Due to the limitation of buffer size the old data packets must be redundant initially. Buffering of data packets has both positive and negative effects on the network.

ROUTE MAINTENANCE

When the packet is transmitted to the destination and the link is missing then the RERR is generated as shown in the figure. It is based on the condition of an ICMP.

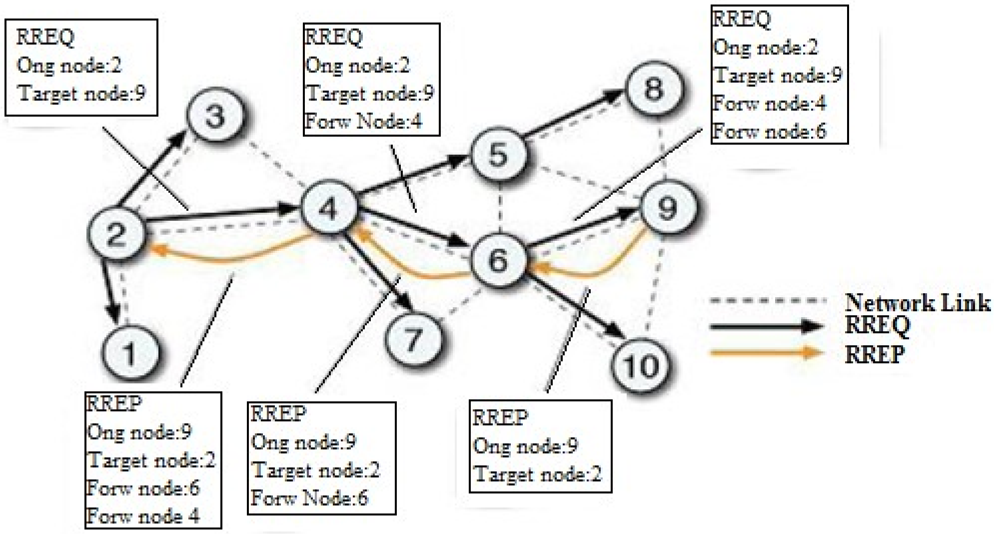


Fig. 3.12 Route Reply (RERR) packet in DYMO

A RERR should be issued only if the link is broken off the forwarding route and the DYMO routers are informed of the broken link. The DYMO [49] protocol is used for memory-constrained devices in MANET’s as it quickly finds the information of the route.

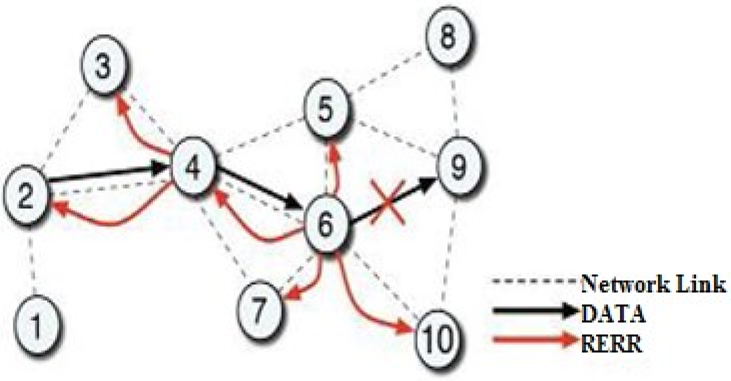


Fig. 3.13 DYMO Routing

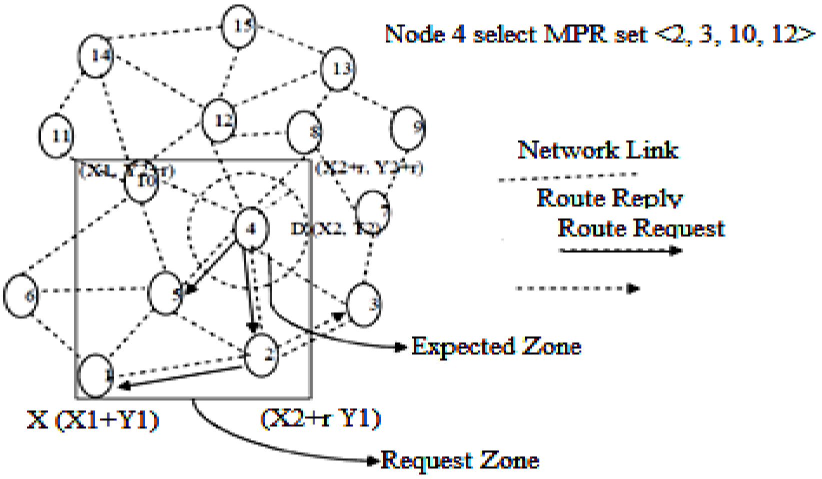
3.6.1.6 LOCATION–AIDED ROUTING PROTOCOL (LAR)

Location aided routing protocol takes the help of equipment which helps in locating thus reducing the expenses involved in routing. LAR is done with the help of the Global Positioning system i.e. GPS. With the availability of GPS, it is possible to know the physical location of the mobile host. In real terms the data provided by GPS has got some errors.

The route discovery algorithm using flooding is explained. When a route is to be determined between source node S and the destination node D, then the source node sends a route request to all its neighbors. A node, say X, on receipt of the route request compares the desired destination with its own identity. If the identity matches it means that it is the destination. In the absence of match the request is transmitted to its neighbor.

LAR designates two zones namely Request zone and Expected zone for sending the packets. The expected zone is the one in which the destination is predicted and gives the details of its location. Sometimes the whole network is regarded as the expected zone of the destination. With additional information about mobility, the destination is determined more accurately and efficiently. The Request zone geographical or environmental region inside the path found of destination and transmits the packets to be sent for transmission. This area is determined from the source which sends the data. Nodes present in the Request zone sends the packets to locate the path. In case the sender or the intermediate relay nodes are not present in the Request zone, an additional area is added for sending the packets. This happens when the initial request is not able to locate a path within the defined time.

When the destination is not traced the process is repeated and additional size of the Request zone. This is done to take care of mobility and error in the location destination. The decision to forward or destroy the packets is based on two algorithms LAR1 and LAR2. In the algorithm LAR1, the source node S specifies the Request zone in the Route request packet. The request zone is the smallest rectangle and contains the source node and the Expected zone, the sides are similar to the X and Y-axis. The node S is outside the Expected zone. When the node S is within the Expected zone the Request zone is reduced to the Expected zone. When the intermediate node gets Route request packet it checks the Request zone details in the packet and moves it forward if the node is within the Request zone, otherwise, the packet is destroyed.



In the above figure, the source node 1 starts a Route request which is sent to its neighbors 2.5 and 6. These nodes verify their position whether they are inside the Expected zone. Nodes 2 and 5 fall within the zone and thus the Route request is forwarded. Node 6 is not within the Expected zone and it discards the packet. When the Route request reaches the destination node 4, it sends a Route reply which contains the current location and time of the node [57]. As on option the present speed of the movement can be added in the Route reply if it is available with the node.

3.6.1.7 OPEN SHORTEST PATH FIRST VERSION (OSPFV2)

The OSPF protocol is a member of IP Routing Protocols and is an Interior Gateway Protocol (IGP) for the internet. It helps to send IP Routing details throughout a single Autonomous System (AS) in an IP Network.

The OSPF Protocol is a link-state routing protocol. The routers exchange topology information with their nearest neighbors. The topology details is flooded in the AS with the purpose of every router to have the image of AS. This image helps to determine end to end path through the AS, with the help of the Dijkstra Algorithm. In a link-state protocol, the next-hop address to which the data is to be sent is determined by selecting the efficient end to end path to the destination.

The main benefit of the OSPF protocol is that the complete information of topology permits routers to find routes that satisfy the required criteria. This is useful for traffic engineering purposes wherein routes are expected to have defined quality of service. The performance is affected when more routers are added. The size and the frequency of the topology increase with the increase in the number of routers the time to find routes also increases. This makes it unsuitable for routing across the internet.

Each OSPF router distributes information about its local state to other routers with the help of (LSA) message. Each router develops a similar database with the help of a received message that describes the topology of AS.

From this database each router calculates its routing table using the shortest path first (SPF) or Dijkstra algorithm. This routing table contains all the destinations the routing protocol knows about associated with a next-hop IP Address and outgoing interface.

- Whenever there is a change in the topology the route is predetermined this reducing the routing protocol traffic that is developed.
- It helps in developing multiple paths of equal cost.
- It helps in getting a multi-level hierarchy called area routing which enables the details about the topology within a defined area of AS to be isolated from routers outside this area. This additional level of routing protection is developed thus reducing the routing traffic.

- It enables all protocol exchanges to get certified thus making only trusted routers come in the routing exchanges for the AS.

3.6.1.8 Routing Information Protocol (RIPV2)

RIP is an Interior Gateway Protocol used for switching the routing information surrounded by area. This protocol change information through routing by a router in the form of nodes. Destination of nodes could be through networks, individual hosts or special destinations used to communicate a default route.RIPv2 routing protocol is an enhanced version of RIP routing. It means that the RIPv2 routing protocol is a decision based protocol that the hop count between a router, source and destination used for their implementation. RIPv2 does not change IP packets, it routes them based on destination packet address only. The router in the wireless network should be able to appear at a source packets and sent to the destination address and then establish the output ports for their best choice to obtain the packets form the address port. The router consults their decision and forwards it to the routing table.

The routing algorithm is required to make the routing tables and move this table to the router. The basic issue of routing is to find the low-cost path between any two nodes. Routing is achieved in realistic networks by managing routing protocols between the nodes. This type of protocol provides a distributed technique to solve the problem in finding the low-cost path in the event of link and node failures and shifting cost.

3.6.1.9 Landmark Ad-hoc Routing Protocol

LANMAR combines the properties of distance vector algorithm and link state algorithm and builds subnets of each group of nodes that are probable to move collectively in the sensor network.

3.6.2 Hybrid Routing Protocols

Hybrid Routing Protocol [50] is a network routing protocol that combines Distance vector routing protocol and Link state routing protocol features. HRP is used to determine optimal network destination routes and report network topology data modifications.

3.7 FACTORS AFFECTING THE DESIGN ISSUE IN WIRELESS SENSOR NETWORK

The following factors are to be considered while designing the Wireless Sensor Network[46].

1. Reliability- It is very important that the network is reliable because the presence of fault reduces the output resulting in low efficiency and performance. Nodes could be destroyed either due to external factors or battery getting depleted.
2. Scalability- Wireless Sensor Networks[55] is made up of numerous sensor nodes. The design of the network must be capable to work with such a high quantity of nodes. A sensor has a defined range that can cover a limited range of the environment.
3. Production Cost- The cost of the wireless sensors should be as minimal as possible since the network employs a large number of sensor nodes.
4. Redundancy- The number of nodes failing in WSN is very high and normally they are untraceable. Thus WSN should have high redundancy of nodes so that failure of nodes can be minimized.
5. System Life- WSN should be able to work as much as possible. The nodes have a life until they are able to provide the desired results and can be measured in terms of time.
6. Energy & Power- The nodes are usually untraceable after they are put in use. Each node requires Energy [54] and Power [88] to operate and it is important that these are used properly to have maximum life. Communication energy should be minimum as possible.
7. Power Consumption- The sensors must use power as low as possible in order to have a high lifetime. They may employ solar cells [56] to generate power. Sometimes it becomes difficult to replenish power, thus WSN design should take into consideration the limitation of power availability.
8. Environment- Nodes must be able to work under tough conditions like high-pressure areas at the bottom of the sea, or high-temperature areas, etc.
9. Latency- It refers to the time taken by the destination packet to reach the receiver from the source. As the nature of the environment changes continuously, it is required that the packet should reach the destination in time.

10. Security- WSN should be secured[106] particularly in applications like military, healthcare, etc. The data that are transmitted are mostly private or confidential.

3.8 CHARACTERISTICS OF AN IDLE ROUTING PROTOCOL

1. Idle routing protocol should be spread in different directions.
2. It should remain unaffected due to the mobility of nodes.
3. Usage of nodes in route analysis and maintenance should be minimum.
4. The collision of messages should be less.
5. The usage of limited resources should be proper.
6. Bandwidth [62] should be optimal.
7. It should have a good memory and battery power.
8. Idle routing protocol should give a minimum level of good performance.

3.9 Conclusions

The five protocol used and some more Ad- hoc is briefly explained in this chapter

With its characteristics, advantages, disadvantages and analysis of the performance.

CHAPTER IV

PERFORMANCE EVALUATION AND INVESTIGATION OF REMOTE CONTROLLED ACTUATORS OF A PETROLEUM TANK SYSTEM

4.1 FOREWORD

This discussion provides the guidance for the remote-controlled Actuators of a petroleum tank System. Design guidance on issues related to network parameter metrics such as the end to end delays, jitter, throughput for different routing protocols is also covered in this chapter. This chapter generally applies to remote controlling of the petroleum tank system and the network used is a mobile Adhoc [68] network (MANET) which is having a set of moving nodes without the support of fastened securely in position infrastructure. The connection in the mobile node of MANET is altogether relying on the nodes of its network. For the adequate functioning of MANET many router protocols have been prepared. To make the network system affected, the protocols provide the way between the mobile nodes via multi-hop links. The numerous factors affect the performance of the protocols many such factors of the protocol which affects the capabilities of remote-controlled petroleum tank system are end-end delay[90], throughput, average jitter, etc. The performance analyzed in Qual-Net. The characteristic of the system is analyzed in MATLAB.

The execution was achieved over the real world by considering the difference of the petroleum tank system with the controlling method and also defines the performance effectiveness of MANET protocols[65]. The performance was analyzed and compared on metrics like E2E delay at various protocols with a petroleum tank system with the different controlling methods and varying network protocols.

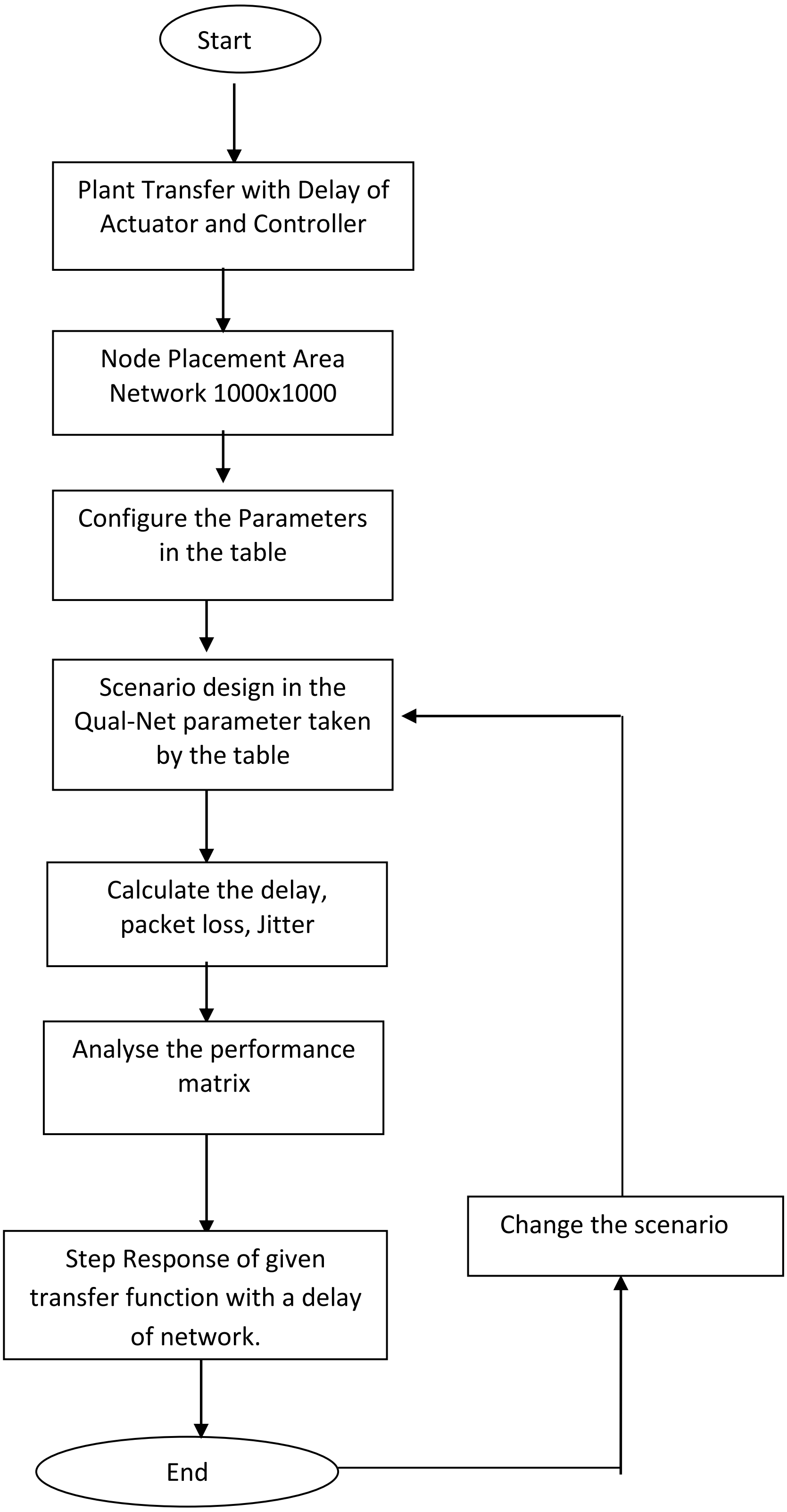
4.2 ASSOCIATED WORK

Several researchers have done the design and performance analysis of a network control system. Execution of time delay remuneration scheme is also done for NCS. They have used different protocols for this purpose.

Huang, F.D., Nguang , S.	Robust H_∞ output feedback control of networked control systems with multiple quantizer , Journal of The Franklin Institute, Elsevier Ltd.,(2012)
Torre, M.	Applied Automation supplement for Control Engineering and Plant Engineering, Halliburton, (2014)
Luan,X., Shi,P., Liu,F.	Stabilization of NCS with Random delays, IEEE, (2010)
Prasad KS,N., Puttamadappa,C.	Design and performance analysis of energy-aware routing protocol for delay-sensitive applications for wireless sensors networks, International Journal of Computer Networks and Communications Security, Vol .1(2),(2013) 46-53, E-ISSN 2308-9830
Ling, W.E.I., D.X.U.E., Yu., Zhi, E.D.	Some Basic Issues in Networked Control Systems, Second IEEE Conference on Industrial Electronics and Applications, (2007)
Vardhan,S.,Kumar,R.	An implementation of a time-delay compensation scheme for Networked Control Systems using MATLAB 7.0/MATLAB, International Conference on Computational Intelligence and Communication Systems IEEE, DOI 10.1109/CICN.2011.29, (2011)
Aggarwal,Ruchi,Kaur,Amanpreet.	Energy Efficient Zone-Based Location Aided Routing Protocol for MANET International Journal of Computer Science and Information Technologies, Vol. 5 (4) ,(2014), 4990-4994
Vir,Dharam,Agarwal,S.K.,Imam,S.A.s	Traffic Generator Based Power Analysis of Different Routing Protocol For Mobile Nodes in Wireless Sensor Network Using QualNet-5.0 (IJERA) ISSN: 2248 -9622 Vol.3(4),(2013),2548 - 2554

A.K. Dewivedi, S. Khushwaha, O.P. Vyas	Performance of Routing Protocols for MANETs and WSN: A Comparative Study," International .journal of recent trends in Engineering, vol.2, No.4, Nov 2009.
	The free encyclopedia-, Mobile ad-hoc Network, http://en.wikipedia.org/wiki/Mobile_ad-hoc_ network, Oct-2004.
Syed Akhtar Imam, Vaibhav Kumar Sachan and Vedprakash Dubey.	Design and Analysis of Energy Efficient Communication Methods for Wireless Sensor Networks, Telecommunication and Radio Engineering, Russia, 74 (19), pp-1705-1714, 2015.
M.A.A. Shoukat Choudhury, N.F. Thornhill, S.L. Shah	Modeling Valve friction, Control Engineering Practice 13,2005,641-658.
Zeeshan Ahmed	Some Studies on Smith Predictor Based Networked Control System, Department of Electrical Engineering National Institute of Technology, Rourkela-769008, Odisha, India, 2013.
Figueredo,L.F.C., Santana,P.H.R.Q.A., Alves,E.S., Ishihara,J.Y., Borges,G.A., Bauchspicess,A.	Robust Stability of Network control system, Robotics, Automation and computer Vision Group, Deptt of Electrical Engg, University of Brasilia, Brazil.
Dewivedi, A.K., Khushwaha ,S., Vyas, O.P	Performance of Routing Protocols for MANETs and WSN:A Comparative Study, International journal of recent trends in Engineering, Vol.2, No.4, (2009)

4.3 FLOW CHART DESIGN OF SCENARIOS MODEL



4.4 SYSTEM MODEL

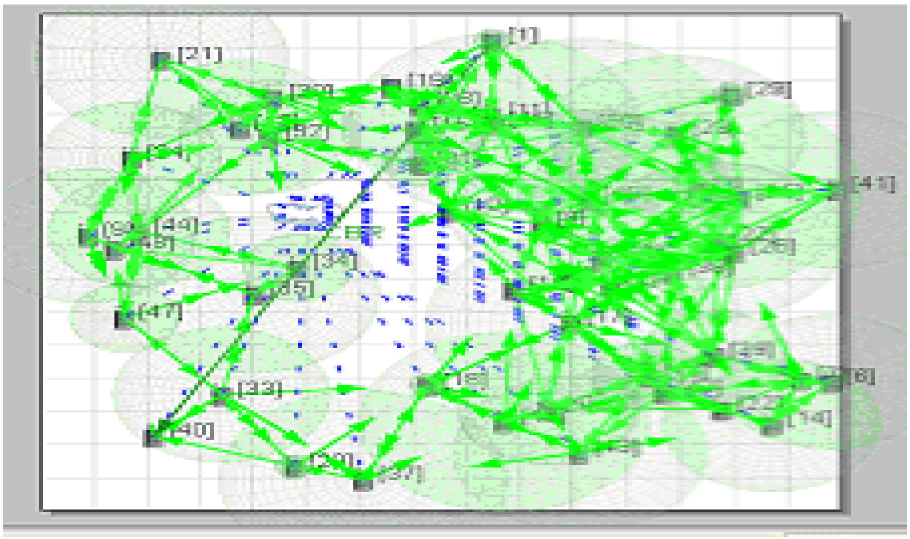


Fig.4.1: Snapshot of running scenario ZRP routing protocol using 40 network nodes.

4.5 PROPOSED PROTOCOLS

Ad-hoc routing protocols are divided broad ally in three ways. Five protocols have been taken to develop understanding as per the below image

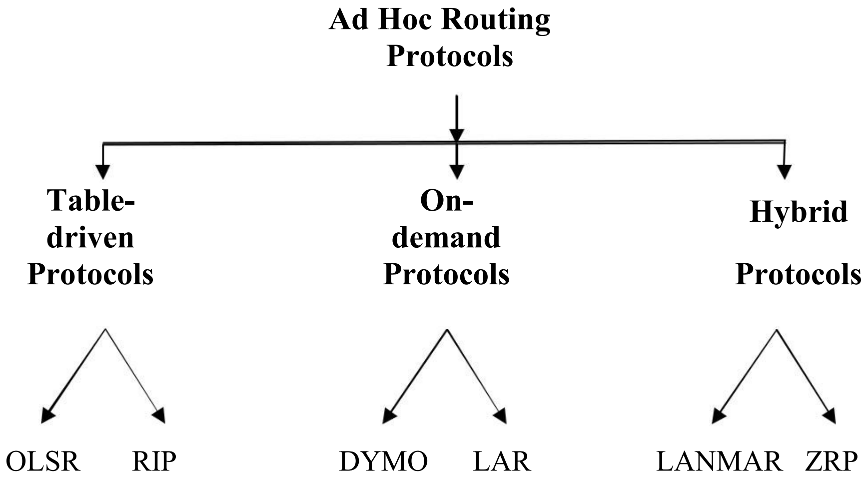


Figure 4.2 Ad-hoc Routing Protocols

4.6 SIMULATION SET UP

4.6.1 Qual-Net 5.0 setup of the virtual network for study system:-

As referred in earlier chapters Ad-Hoc network routing protocol are usually grouped in three sections. It is quite laborious to figure out the performance of the total protocol proposed till now. We have considered five protocols which are detailed in chapter 3.

To execute the protocols the setup is made with the help of variable and fixed values. These were selected to execute the simulation work and the search on various protocols to measure the outcome. A complete list of values which were chosen is given in the table4.1.

QualNet 5.0-Overview and setup of a Virtual network for studying the system.

QualNet 5.0 Simulator can be used to formulate a virtual wireless network. The simulator in which one can develop and conceptualize network situations and analyse the research results in a single graphical user interface. Qual-Net 5.0[9,10] is established by Scalable Network Technologies [11].QualNet comprises of three layers [12]

1. Model libraries
2. Simulation kernel
3. Qual-Net Developer GUI.

The Simulator has the following gears:

1. Animator: The created scenario is conceptualized using this tool. Various outputs can be deactivated or activated in the course of a simulation run such as energy exhausted in transmit mode, throughput, end to end delay, jitter, broadcast messages, successfully received packets etc.
2. Scenario Designer: This is used to Visualize and create network schemes with distinct parameters.
3. Analyzer: Different output files get created on simulation each consisting of different information. Statistical information is comprised in the primary output file (.stat)

The parameters used in the simulation of the virtual network on the QualNet5.0 are listed in Table4.1.

Network Parameter	Assigned Value
Simulator	QUALNET 5.01
Routing Protocol	RIP, LAR, OLSR, ZRP,DSR
Number of Nodes	45,50,100
Mobility Model	Random Way Point
Transmission Power	20dBm
Simulation Time	30s
Simulation Area	1500X1500
Traffic Type	CBR
MAC Protocol	IEEE 802.11e
Size of Packet	512bytes
Node Placement	Random
Radio Type	IEEEE 802.11b Radio
CCA Mode	Carrier-Sense
Energy Model	MicaZ
Item to send	100
Antenna Model	Omni-directional
Battery Model	Linear Model

Table 4.1 Network parameters value for the design of simulation setup

4.6.2 SUCCESSFUL ROUTE FORMATION THROUGH SIMULATION

This has been done with the help of Qual-Net 5.0. It uses OLSR, RIP, ZRP, DSR, LAR, etc as various protocols to find out routes between source and destination. It uses IEEE802.15.4 as a MAC protocol. Figures depict results for various protocols and nodes ranging from 0 to 60 % of the overall nodes. The experiments indicate the routes which are verified and shown in the figure.

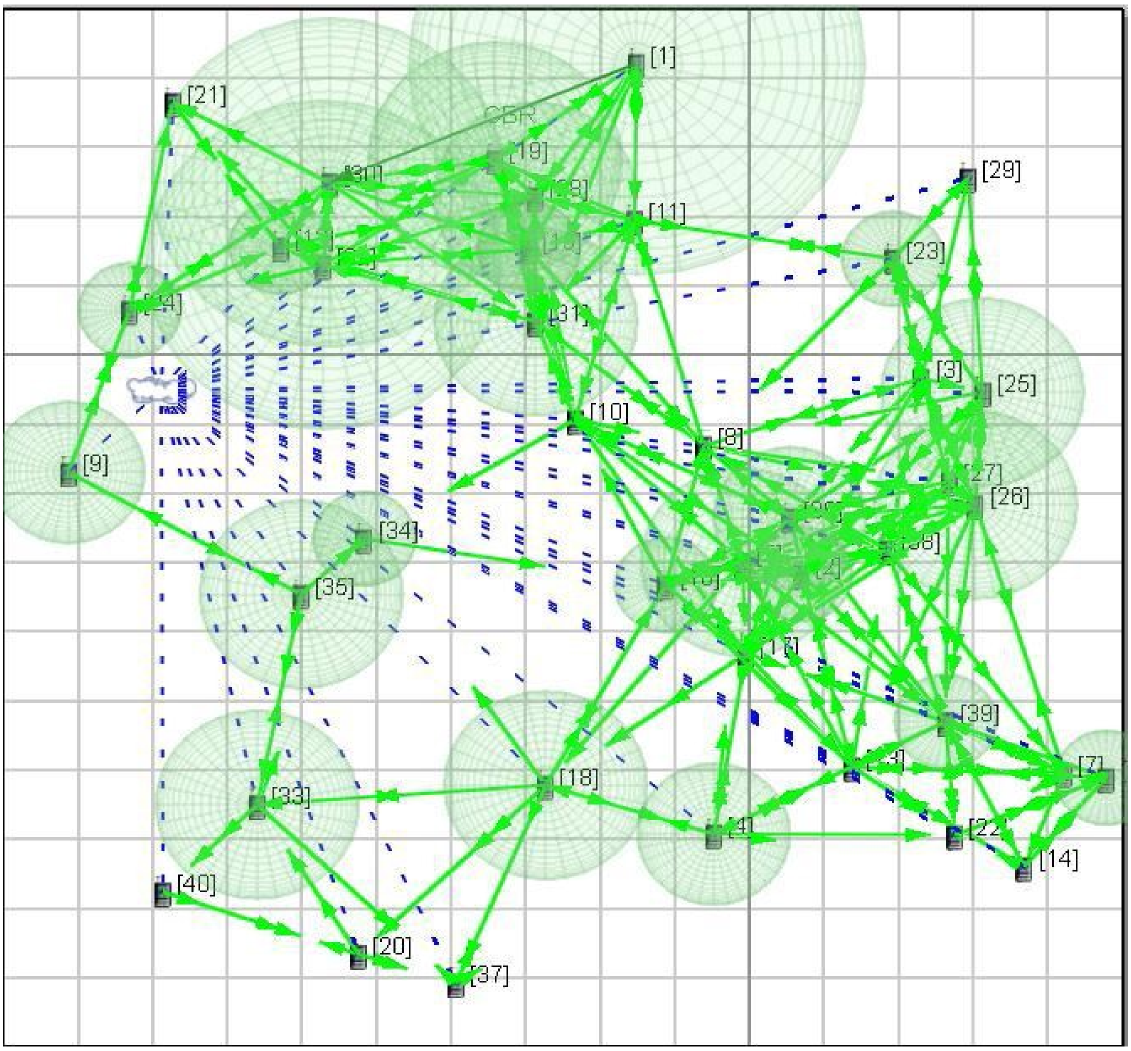


Figure 4.3 Animation View for 40 Nodes when Simulation is 60%

The two general Outcomes of the Simulation process have been shown in the below figure 4.4and figure4.5.

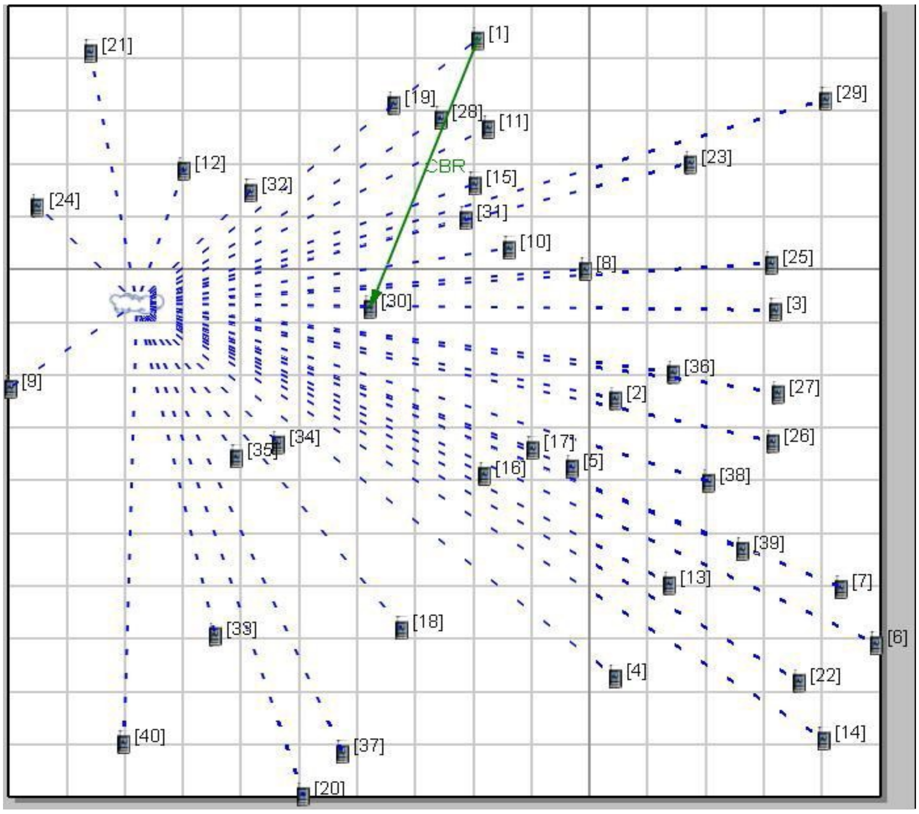


Fig. 4.4 Network with 40 Nodes

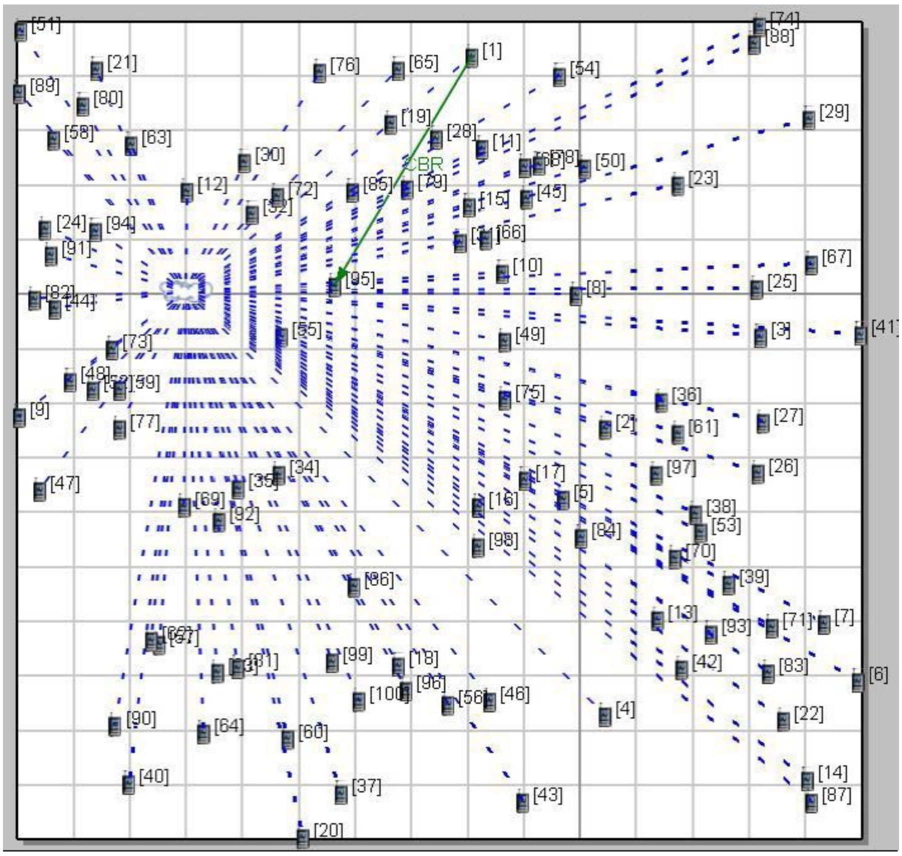


Fig. 4.5 Network with 100 Nodes

4.6.3 DESCRIPTION OF PARAMETERS / VALUES SELECTED

Examined Protocols- OLSR[79], RIP, LAR, DSR and ZRP protocols were chosen from the Ad-Hoc network routing protocol and simulate these protocols using Qual-Net 5.0 software and situation is created to get the information about various values like End to End delay, Jitter, Throughput etc.

Description of various parameters chosen in Table 4.1

Simulation Space – The testing is done on the simulation of a large number of nodes placed randomly in a rectangular area. The rectangular area is chosen to have a larger distance between Nodes.

Traffic Pattern- In the testing 1no CBR and 40 to 100 Numbers of Nodes are used which are sent at a rate of 4 packets per second. The size of the packet varies from 64 bytes per packet to 1024 bytes per packet.

Media Access Control Protocols- This protocol is used in the testing of Qual-Net 5.0. The layer looks after the state of striking, breaking and existence. It is also used to determine errors due to transmission. When the system is available it should start sending the packets or else wait for a certain amount of time before it starts sending again.

Radio Propagation Models- This is used to find out whether the data send through the air has reached correctly. It also considers delay due to the propagation and Capture effect.

Battery Model- This is considered to be uniform to be in line with the continuous loss of power when practically the atmosphere remains the same. The battery, data and load were taken as per standard.

Communication Model- MAC layer uses IEEE Standards DCF. This layer was used as All Route Request and the query packet was sent with the help of MAC with CSMA.

4.6.4 PERFORMANCE METRIC USED

Metric is a basic instrument used to find a way to a destination. This defines which route chosen be the best, effective or very efficient. The following metrics are used to find out the output of the Ad-Hoc[104] routing protocols.

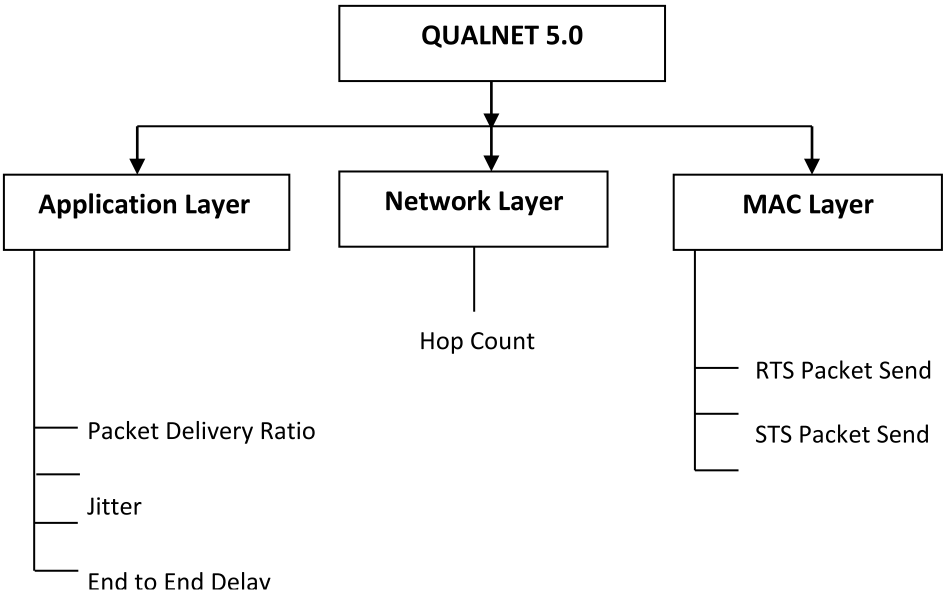


Figure 4.6 Classification of Performance Metrics used

Description of various Performance Metrics

PACKET DELIVERY RATIO

Packet Delivery ratio gives the comparison between the data received at the destination as compared to the data initiated at the source. A good value of the ratio shows the system to be more efficient and accurate.

AVERAGE END TO END DELAY

This gives the value of time taken by the first packet to be at the destination after it is transmitted from the source.

JITTER

Different packets take different time to reach the destination. Jitter is measured in terms of the delay that takes place during transmission. A higher value indicates that the quality of the signal to be poor.

THROUGHPUT

It is the average rate at which the packet is successfully transmitted in a network. A higher value of bits per second indicates that the network is having a good performance.

PACKET RECEIVED

It is the rate at which the message is received by the user from the source per second without losses. Higher efficiency is achieved when the number of such packets is maximized.

HOP COUNT

It is the number of intermittent nodes that go from source to destination.

CTS PACKET SENT

It is defined as Clear to send. It is used in MACA to solve issues like terminal problems that are hidden and exposed.

ACK PACKET SENT

It is defined as the acknowledgement packet sent by the receiver after getting the correct packet.

4.6.5 ASSUMPTION AND LIMITATIONS

The points assumed for nodes during simulation are as per the following.

1. The battery of each node has a limitation.
2. Nodes work individually and not in a group.
3. Selected Nodes cannot change the data of control packets.

4.7 Design of PID Controller for Systems

In the Thesis two systems are used which are as follows

1. Petroleum Tank System
2. Two Tank System

Considering a concentration valve, the petroleum tank transfer function [129] with a computation delay of 10 seconds and the network induced delay of 0.0224156 seconds.

The transfer function of the concentration valve using these values can be written as equation 1.

$$G_p(s) = \frac{3e^{-10s}}{10s+1} \qquad (1)$$

équation 2 represents the PID controller's transfer function[42] given as:

$$G_c(s) = \frac{K_p S + K_i + K_d S^2}{S} \tag{2}$$

The Kp, K_i and K_d as given in [42] as follows

$$K_p(\omega) = -\frac{R_P(\omega)}{|G_p(j\omega)|^2} \tag{3}$$

$$K_i(\omega) = \omega^2 K_d - \frac{\omega I_P(\omega)}{|G_p(j\omega)|^2} \tag{4}$$

$$K_d(\omega) = \frac{K_i}{\omega^2} + \frac{I_P(\omega)}{\omega |G_p(j\omega)|^2} \tag{5}$$

The plot of K_p vs K_i keeping K_d=1.0 is given in the below figure. Shaded portion gives the stability region.

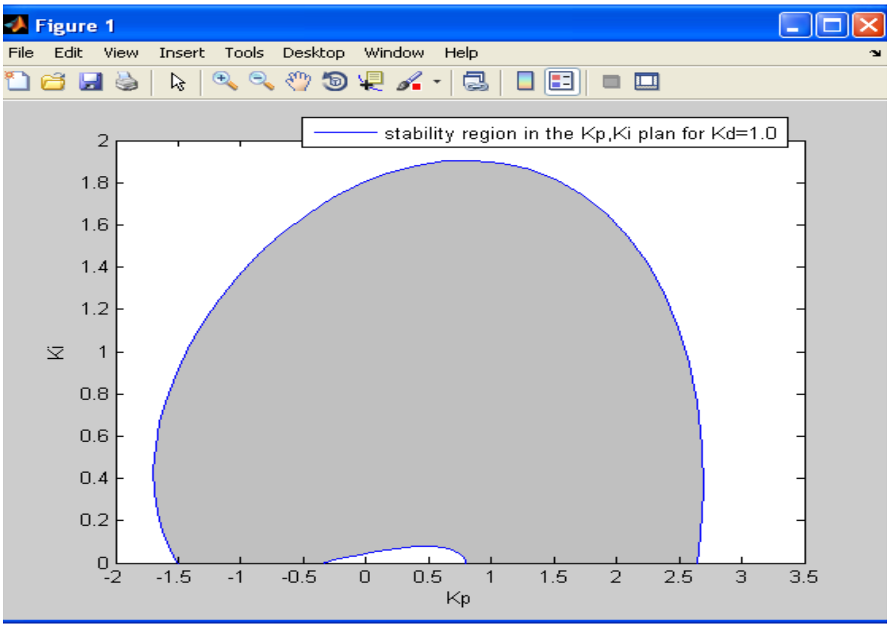


Fig. 4.7 Plot of Kp vs K_i

The graph between K_p and K_d keeping K_i=0.02 is given in the below figure.

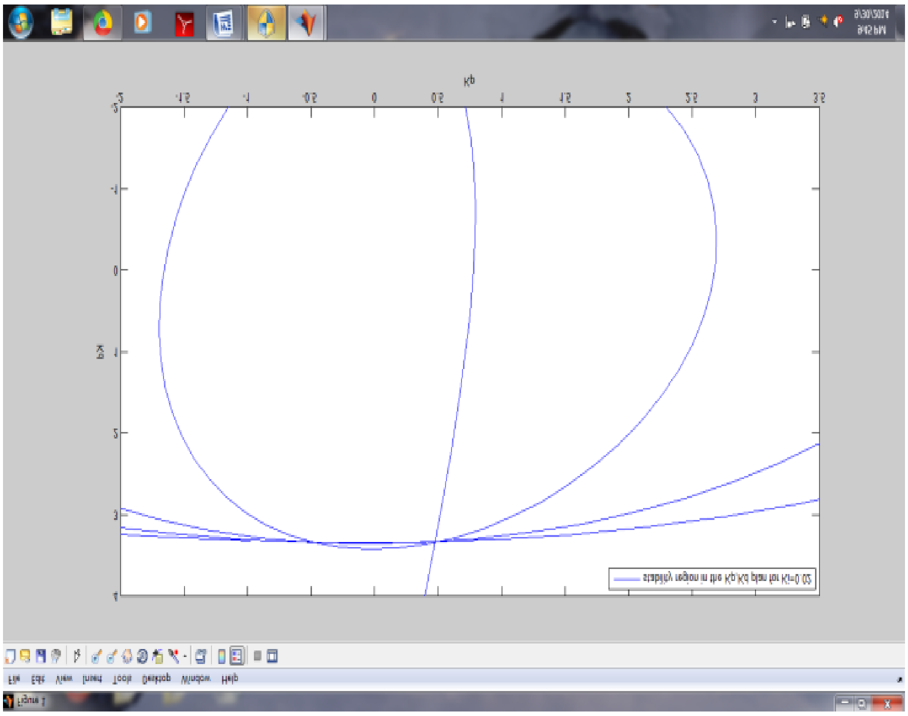


Fig. 4.8 Plot of K_P vs K_d

Using equation3, the graph of K_p and ω is plotted in the below figure .Shaded portion indicates the stability region.

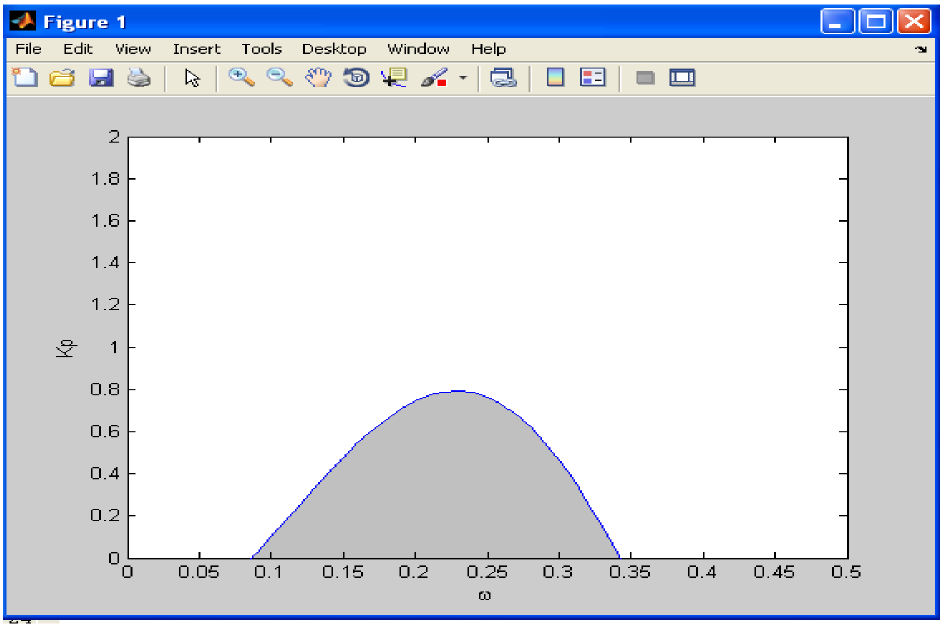


Fig.4.9 Plot of Kp vs ω

For a value of 0.2 for K_p in the above figure, the value of ω_1 and ω_2 comes out to be 0.11 and 0.32 respectively.

Line1:$K_{d1}=100*K_i-4.6$ (6)

Line2:$K_{d2}=11.111*K_i+3.143$ (7)

Line3:$K_i=0$ (obtain at $\omega=0$) (8)

The expression for K_d is given in equation 5.K_{d1}, K_{d2} and K_i given in equation 6, 7, 8 define the stability[34] region. Shaded portion shows the stability region.

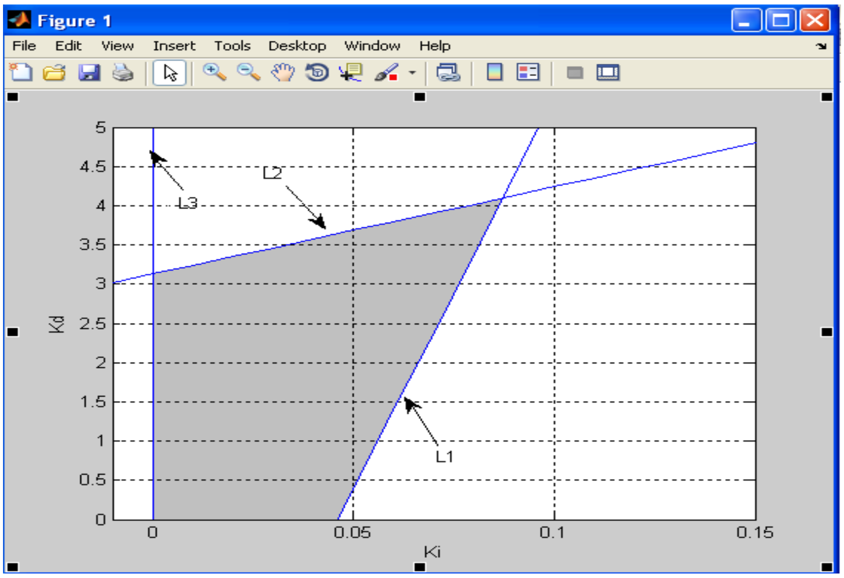


Fig. 4.10 Stability Region with K_p= 0.2.

Using figure 4.9 for a random value of K_p=0.2 , the respective values of K_i and K_d taken randomly from the stability region are 0.02 and 1.0.
equation 9 depicts the controller's transfer function used in [8].

$$G_{C1}(s) = 0.2\left(\frac{10s+1}{10s}\right) \tag{9}$$

Using equation 1 and 9, the step response of concentration valve in petroleum tank along with controller having only computation delay is represented in figure 4.11

The step response of concentration valve of petroleum tank with PID controller in the presence of computation and network delay is as obtained in the present study is given in figure 4.12

Network Delay is obtained as Adhoc[73] routing protocol named RIP Protocol is used with 50 nodes.

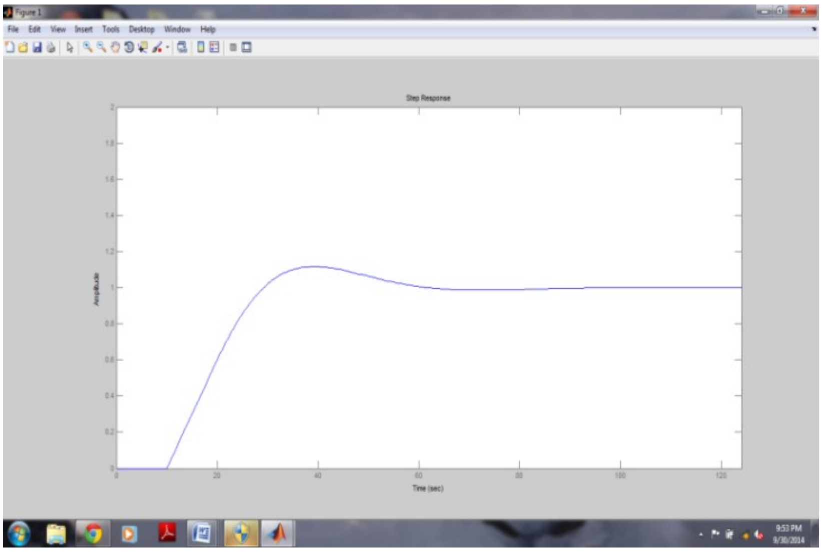


Fig.4.11 Time response of concentration valve of petroleum tank with Controller having computation delay.

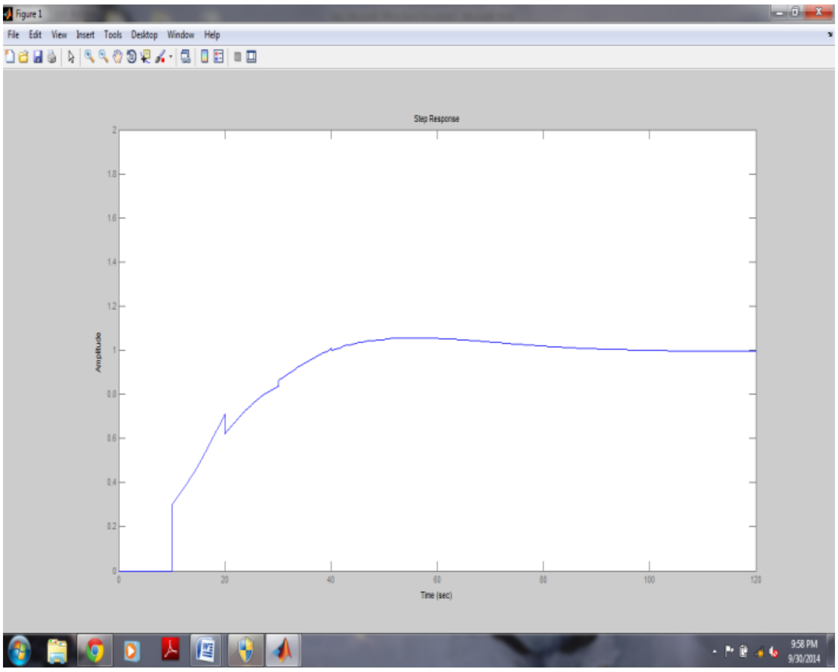


Fig 4.12Time response of concentration valve of petroleum tank with PID Controller having computation delay and network delay.

The comparison of the performance of the two systems is specified in table 4.2.

Parameter	Performance reported of a given system and controller in [8] with computation delay only	Performance of the given system with PID controller in the presence of computation and network delay as obtained in the present study
% Overshoot	12	05
Settling Time(sec)	51.7	47.1
Delay Time(sec)	18.4	15.6
Rising Time(sec)	29.2	40.7

Table 4.2 Comparison between the performance of the system with and without network

4.8 Detail Description of Performance Evaluation and Investigation of Remotely Controlled Actuators of a Petroleum Tank System using RIP Protocols

Implementation of Controller Design above using RIP Protocols with

4. Number of Nodes is 50
5. Number of Nodes is 45

4.8.1 Implementation of Remotely Controlled Actuators of a Petroleum Tank System using RIP Protocols with 50 Number of Nodes

The parameters used in the simulation of the virtual network on the QualNet5.0 are listed in Table4.3.

Network Parameter	Assigned Value
Routing Protocol	RIP
Number of Nodes	50
Mobility Model	Random Way Point
Transmission Power	20dBm

Simulation Time	30s
Simulation Area	1500X1500
Traffic Type	CBR
MAC Protocol	IEEE 802.11e
Size of Packet	512bytes
Node Placement	Random
Radio Type	IEEEE 802.11b Radio
CCA Mode	Carrier-Sense
Energy Model	MicaZ
Item to send	100
Antenna Model	Omni-directional
Battery Model	Linear Model

Table 4.3 Network parameters value for the design of simulation setup with 50 Node

Simulation of virtual network is done using 50 nodes in a portion of 1500 * 1500 m with a throughput of 4775 bit/sec and total packet send as 24.Fig.2 depicts the proposed simulation scenario.

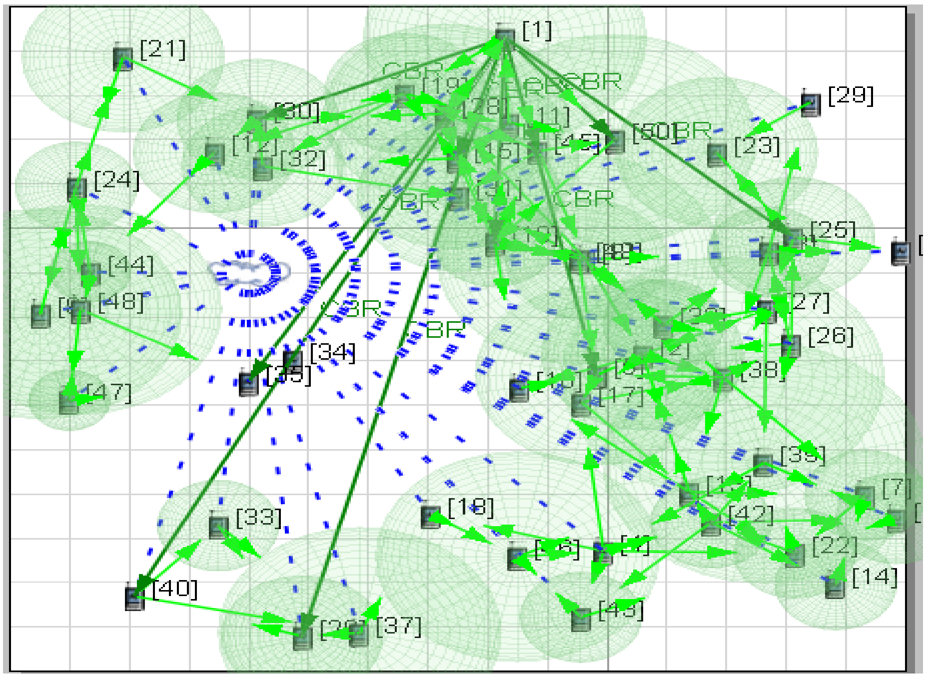


Figure 4.13 Simulation scenarios of 50 nodes with 10 CBR transmission traffic modes.

RIP protocol [133] is used to check average jitter, throughput, end-end delay, total byte acquired, the first packet received, total packet gained, the last packet received [72]. With a simulation time of 30 seconds uniform lengths of packets are transferred from the source to the destination, consuming transmission power of 20 decibels of 50 nodes.

The values of critical parameters obtain from the simulated virtual network are listed in Table 4.3.

Parameter	Observed Value
Throughput	4310 bits/sec
Average Jitter	0.000322014 sec
End to End Delay	0.0112078 sec
First Packed Received	5.01023 sec
Total Byte Received	10240
Total Packet Received	20
The last Packet Received	24.0146 sec

Table 4.3 Network parameters obtained from the simulated setup for 50 node

The step response of the concentration valve of the petroleum tank with PID controller. Network[39] Delay is obtained as an Adhoc routing protocol named RIP Protocol is used with 50 nodes.

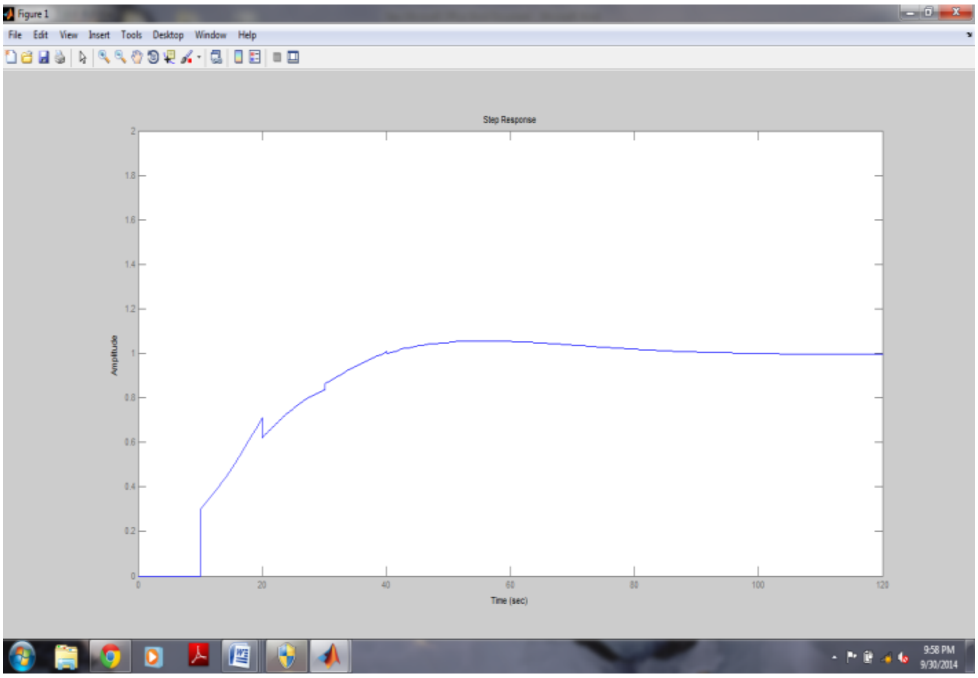


Fig 4.14 Time response of remote - controlled concentration valve of petroleum tank with PID Controller for RIP protocol with 50 Nodes.

Parameter	Performance of a given system with PID controller in the presence of computation and network delay as obtained in the present study
% Overshoot	05
Settling Time(secs)	47.1
Delay Time(secs)	15.6
Rising Time(secs)	40.7

Table 4.4 Performance of system with the network using RIP Protocol with 50 Nodes

4.8.2 Implementation of Remotely Controlled Actuators of a Petroleum Tank System using RIP Protocols with 45 Number of Nodes

Configuration of Virtual Network for the implementation of remote control petroleum tank with communication network used RIP Protocol with 45 Nodes.

Transmission of data from PID controller which is the source node, to a remotely located petroleum tank actuator and the other way round has been carried out by simulating the Adhoc network in Qualnet5.0 with various factors considered as shown in table4.5.

Network Parameter	Assigned Value
Routing Protocol	RIP
Number of Nodes	45
Mobility Model	Random Way Point
Transmission Power	20dBm
Simulation Time	30s
Simulation Area	1500X1500
Traffic Type	VBR
MAC Protocol	IEEE 802.11e
Size of Packet	512bytes
Node Placement	Random
Radio Type	IEEEE 802.11b Radio
CCA Mode	Carrier-Sense
Energy Model	MicaZ
Item to send	100
Antenna Model	Omni-directional
Battery Model	Linear Model

Table4.5 .Parametric Values for selected Ad hoc Networks for RIP and 45 Nodes.

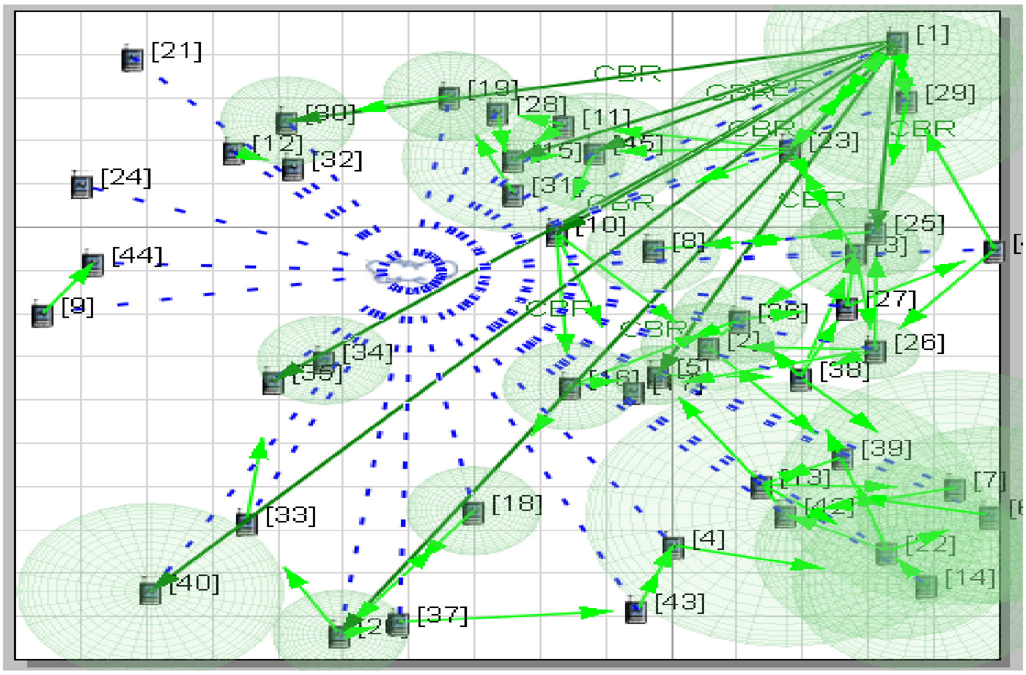


Figure 4.15. Snapshot of QualNet Animator to utilise RIP protocol consisting of 45 nodes.

For finding out parameters like jitter, end to end delay, throughput etc a simulation software like QualNet 5.0 is made into use when communication is done between the petroleum tanks and controller [135].

Taking the petroleum tank's transfer function[129] with computation delay in Equation1.

$$Gp(S) = \frac{3e^{-10S}}{10S+1} \qquad (1)$$

Equation 2 shows the PID controller's transfer function given as:

$$G_C(S) = \frac{K_P S + K_i + K_d S^2}{S} \qquad (2)$$

The below table displays the impacts of RIP Protocols through simulation in Qualnet5.0

Protocol	**End to End Delay**	**Jitter**
RIP	0.208352	0.026246

Table 4.6 :E2E Delay AND Jitter Using RIP Protocols with 45 nodes through simulation in Qualnet5.0

Considering eq1 and eq2 and assuming random values of K_d, K_i, K_p as 1.0, 0.02 and 0.2 respectively in equation 2.Figure4 and Figure5 respectively depicts the system's step response with network delay and computation delay due to RIP protocol which is simulated in Mat Lab.

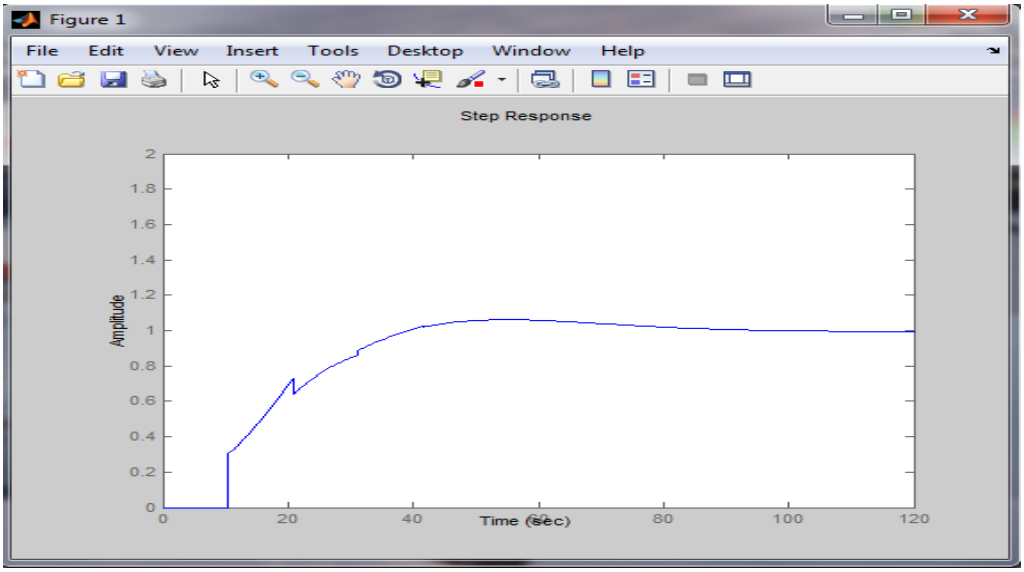


Figure 4.16 Step Response with RIP Protocol

The below table depicts the impact of the protocol on the system's time response characteristics.

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
RIP	21.6 Sec	79.58 Sec	6.14

Table4.7 Impact of RIP protocol on the system's time response characteristics.

Performance analysis of network controlled petroleum tank system with RIP protocol and 45 Nodes using Smith Predictor.

The time required by the process is defined as the dead time. The dead time generates a negative phase which makes it difficult to use conventional controllers. The output of the closed-loop system is improved with the usage of dead time compensator. Smith predictor [132] is the first dead time compensator algorithm and helps to reduce the delay from the characteristic equation. The disturbance rejection response cannot be improved by Smith predictor. The analysis and design of this type of compensator are used for only constant delays.

Step response of the system with computation delay and network delay due to RIP protocol with PI controller and smith predictor is simulated in MATLAB 7.0 is shown in Figure.

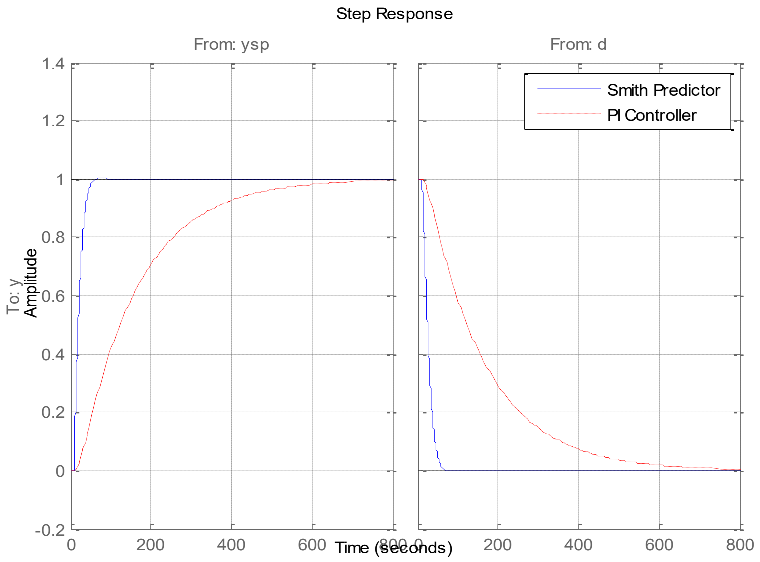


Fig 4.17: Step Response with RIP Protocol with PI Controller and Smith Predictor

The following table 4.8 shows the effect of the protocol on-time response characteristics of the system.

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
RIP	31.9	58.7	0

Table 4.8 Effect of the protocol on the time response characteristics of the system with PI Controller.

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
RIP	26.9	50.3	0.26

Table 4.9 Effect of the protocol on the time response characteristics of the system with PI Controller and Smith Predictor

4.8.3 Dynamic Approach to Optimize Time Response Characteristics of Network Controlled Petroleum Tank System having RIP Protocol with 100 nodes using Qualnet-5.0 and MATLAB7.0

Setup of Virtual Network for the Study System

Transmission of the message from PID Controller to an actuator situated remotely of a petroleum tank and back is done simulating the Ad Hoc network in Qualnet-5.0 with the following consideration as shown in table .

Network Parameter	Assigned Value
Routing Protocol	RIP
Number of Nodes	100
Mobility Model	Random Way Point
Transmission Power	20dBm
Simulation Time	30s
Simulation Area	1500X1500
Traffic Type	VBR
MAC Protocol	IEEE 802.11e
Size of Packet	512bytes
Node Placement	Random
Radio Type	IEEEE 802.11b Radio
CCA Mode	Carrier-Sense
Energy Model	MicaZ
Item to send	100
Antenna Model	Omni-directional
Battery Model	Linear Model

Table 4.10. Parametric Values for selected Ad Hoc Network with RIP,100Nodes.

Values of Jitter , Throughput, etc are determined with the usage of QualNet-5.0 simulation software in the petroleum tank system.

Performance evaluation of a remote-controlled actuator of a petroleum tank.

Considering the transfer function of the petroleum tank[13] with computation delay in equation 1.

$$Gp(S) = \frac{3e^{-10S}}{10S+1} \tag{1}$$

The following table 4.11 shows the effects of different protocols

Protocol	End to End Delay	Jitter	Throughput
RIP	0.1013849sec	0.020096947sec	3735.6

Table 4.11 E2E Delay and Jitter of RIP protocols with 100 nodes

Using Eq 1 and considering PI controller with arbitrary values as Kp= 0.2,Ki=0.02.Step response of the system with computation delay and network delay due to RIP protocol[15,16] is simulated in MATLAB7.0 and is shown in the below figures respectively.

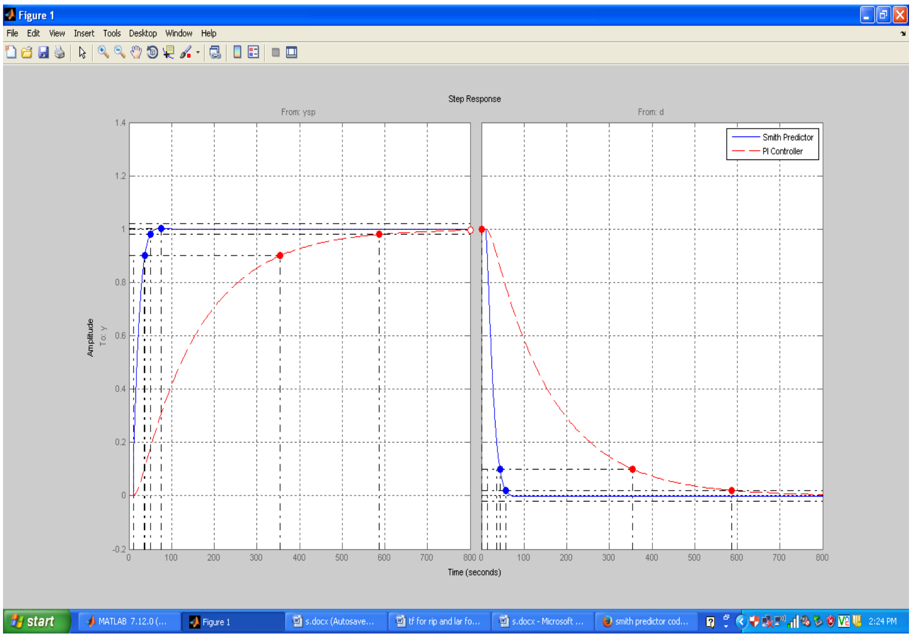


Fig.4.18 Step Response with RIP Protocol with PI Controller and Smith Predictor with RIP and 100 nodes

The below table4.12 gives the effect of the protocol on the time response characteristics of the system. With PI Controller

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
RIP	319 Sec	587 Sec	0 at time >800Sec

Table 4.12 : Time response characteristics of the system with PI Controller for RIP and 100 nodes

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
RIP	26.9 Sec	50.9 Sec	0.262 at 75 Sec

Table4.13 . Effect of the protocol on the time response characteristics of the system with PI Controller and Smith Predictor with RIP and 100 nodes

4.9 Detail Description of Performance Evaluation and Investigation of Remotely Controlled Actuators of a Petroleum Tank System using LAR Protocols

4.9.1 Implementation of Controller Design above using LAR Protocols with Number of Nodes is 45

Configuration of Virtual Network for the System using LAR Protocol with 45 number of nodes.

Transmission of data from PID controller which is the source node, to a remotely located petroleum tank actuator and the other way round has been carried out by simulating the Adhoc network in Qualnet5.0 with various factors considered as shown in the table.

Routing Protocol	LAR
Number of Nodes	45
Mobility Model	Random Way Point
Transmission Power	20dBm
Simulation Time	30s
Simulation Area	1500X1500
Traffic Type	VBR
MAC Protocol	IEEE 802.11e
Size of Packet	512bytes
Node Placement	Random

Radio Type	IEEEE 802.11b Radio
CCA Mode	Carrier-Sense
Energy Model	MicaZ
Item to send	100
Antenna Model	Omni-directional
Battery Model	Linear Model

Table4.14 Parametric Values for selected Ad hoc Network for LAR,45 Node.

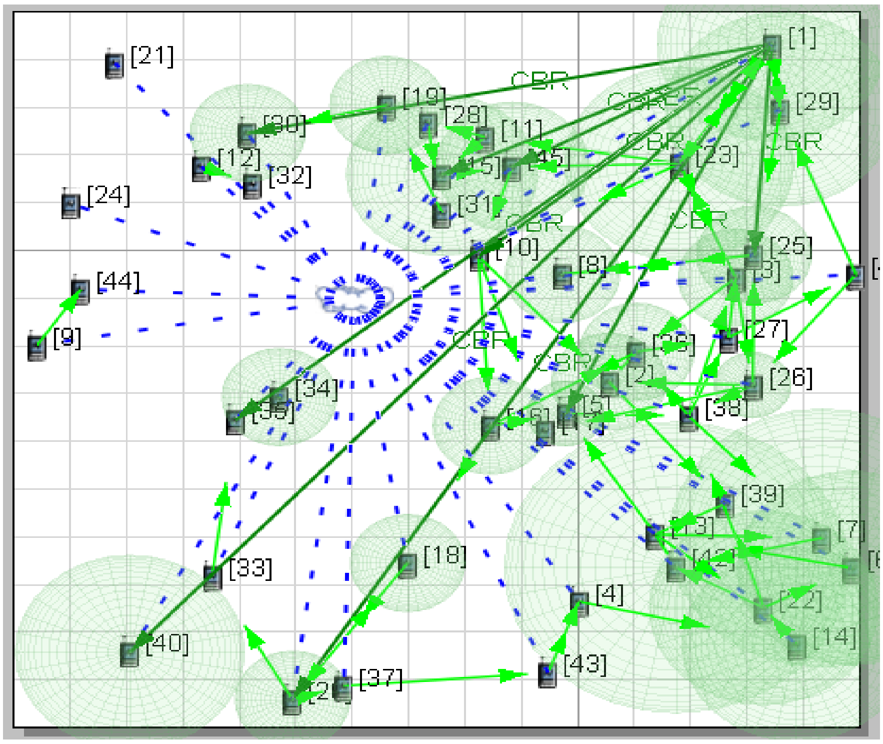


Fig.4.19 Snapshot of QualNet Animator to utilise LAR protocol consisting of 45 nodes.

For finding out parameters like Jitter, end to end delay, throughput, etc a simulation software likeQualNet 5.0 is made into use when communication is done between the petroleum tanks and controller [135].

Performance analysis of a remotely controlled petroleum tank actuator.

Considering the petroleum tank transfer function [129] having computation delay in equation1.

$$Gp(S) = \frac{3e^{-10S}}{10S+1} \qquad (1)$$

The PID controller’s transfer function given is in equation 2.

$$G_C(S) = \frac{K_P S + K_i + K_d S^2}{S} \qquad (2)$$

The below table 4.15 shows the impact of LAR protocols With 45 Nodes

Protocol	**End to End Delay**	**Jitter**
LAR	0.766082 Sec	0.170635

Table 4.15 : E2E Delay and Jitter for LAR protocols With 45 Nodes

Considering eq1 and eq2 and assuming random values of K_d, K_i, K_p as 1.0, 0.02 and 0.2 respectively in equation 2. The below figure depicts the system step response with network delay and computation delay due to LAR protocol which is simulated in Mat Lab.

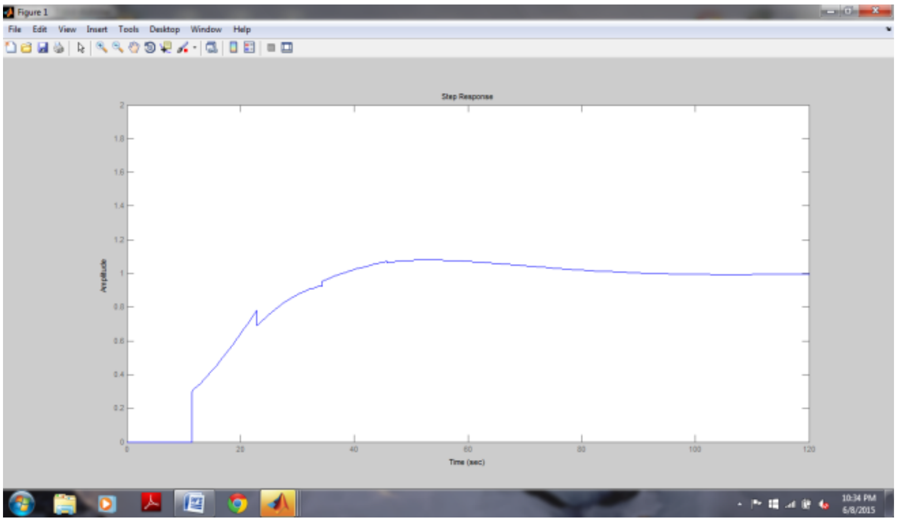


Fig 4.20 Step Response with LAR Protocol,45 Node

The impact of the protocol on the system's time response characteristics is shown in the below table.

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
LAR	20.3 Sec	79.77 Sec	8.2

Table 4.16 : Time response characteristics for LAR Protocol with 45 nodes

4.9.2 Performance analysis of network controlled petroleum tank system with LAR protocol using Smith Predictor.

The time required by the process is defined as the dead time. The dead time generates a negative phase which makes it difficult to use conventional controllers. The output of the closed-loop system is improved with the usage of dead time compensator. Smith predictor [14] is the first dead time compensator algorithm and helps to reduce the delay from the characteristic equation. The disturbance rejection response cannot be improved by Smith predictor. The analysis and design of this type of compensator are used for only constant delays.

Step response of the system with computation delay and network delay due to RIP and LAR protocol with PI controller and smith predictor is simulated in MATLAB 7.0 is shown in Figure4.19 and Figure4.20 respectively.

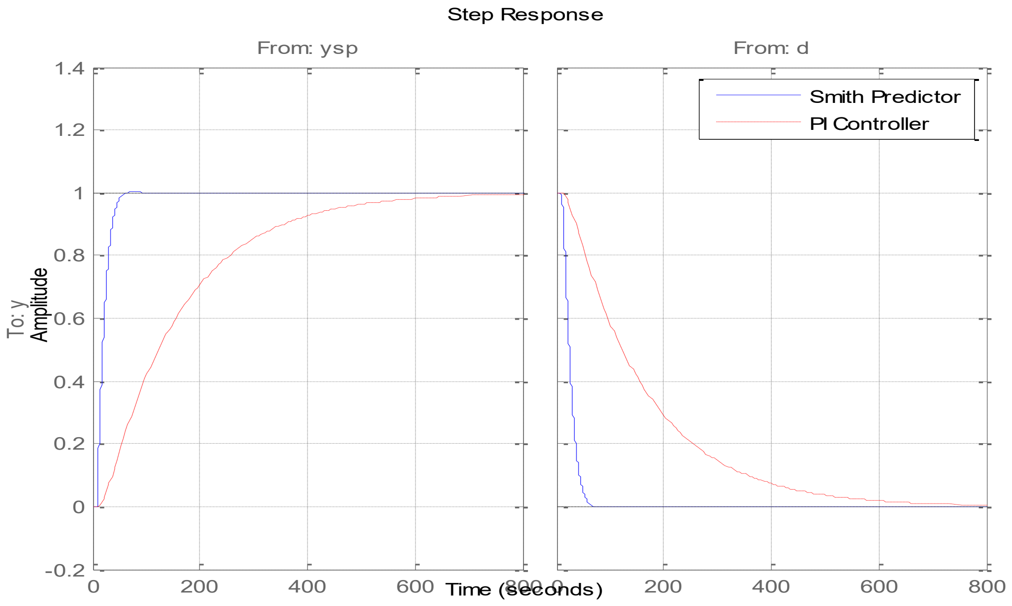


Fig 4.21: Step Response with RIP Protocol

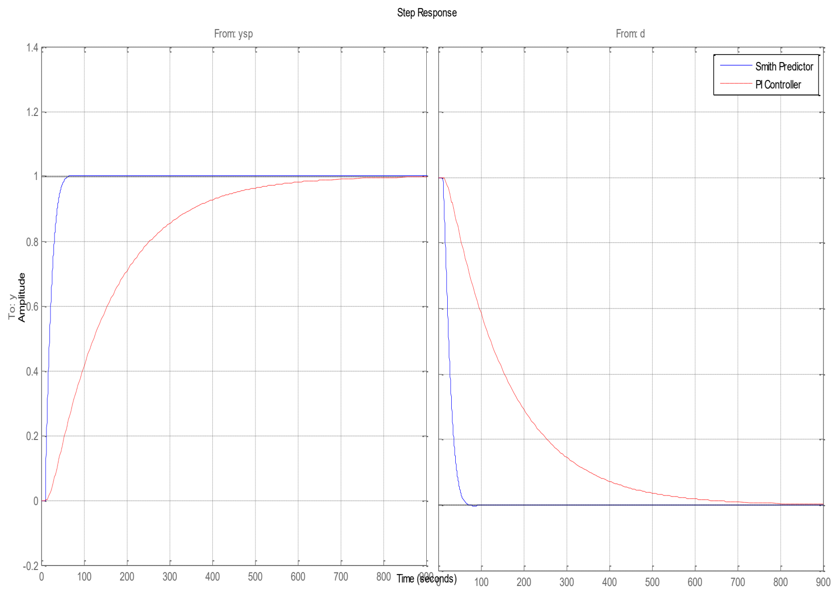


Fig 4.22: Step Response with PI Controller and Smith Predictor for LAR

The following table4.17 shows the effect of the protocol on-time response characteristics of the system.

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
LAR	31.7	58.5	0

Table4.17 Effect of the protocol on the time response characteristics of the system with PI Controller for LAR

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
LAR	26.9	50.3	0.262

Table 4.18 Effect of the protocol on the time response characteristics of the system with PI Controller and Smith Predictor for LAR.

4.9.2 Implementation of Controller Design above using LAR Protocols with Number of Nodes is 100 nodes and using Smith Predictor.

Setup of Virtual Network for the Study System

Transmission of the message from PID Controller to an actuator situated remotely of a petroleum tank and back is done simulating the Ad Hoc network in Qualnet-5.0 with the following consideration as shown in the table.

Network Parameter	Assigned Value
Routing Protocol	LAR
Number of Nodes	100
Mobility Model	Random Way Point
Transmission Power	20dBm
Simulation Time	30s
Simulation Area	1500X1500
Traffic Type	VBR
MAC Protocol	IEEE 802.11e
Size of Packet	512bytes
Node Placement	Random
Radio Type	IEEEE 802.11b Radio
CCA Mode	Carrier-Sense
Energy Model	MicaZ
Item to send	100
Antenna Model	Omni-directional
Battery Model	Linear Model

Table 4.19 Parametric Values for selected Ad Hoc Network for LAR,100Node.

Values of Jitter, Throughput, etc are determined with the usage of QualNet-5.0 simulation software in the petroleum tank system.

Performance evaluation of a remote-controlled actuator of a petroleum tank.
Considering the transfer function of the petroleum tank[13] with computation delay in equation 1.

$$Gp(S) = \frac{3e^{-10S}}{10S+1} \qquad (1)$$

The following table4.20 shows the effects of different protocols

Protocol	End to End Delay	Jitter	Throughput
LAR	0.2389732sec	0.10083686sec	4478.8

Table4.20 E2E Delay and Jitter of LAR protocols and 100 nodes

Using Eq 1 and considering PI controller with arbitrary values as Kp= 0.2,Ki=0.02. Step response of the system with computation delay and network delay due to LAR protocol[15,16] is simulated in MATLAB7.0 and is shown in the below figures.

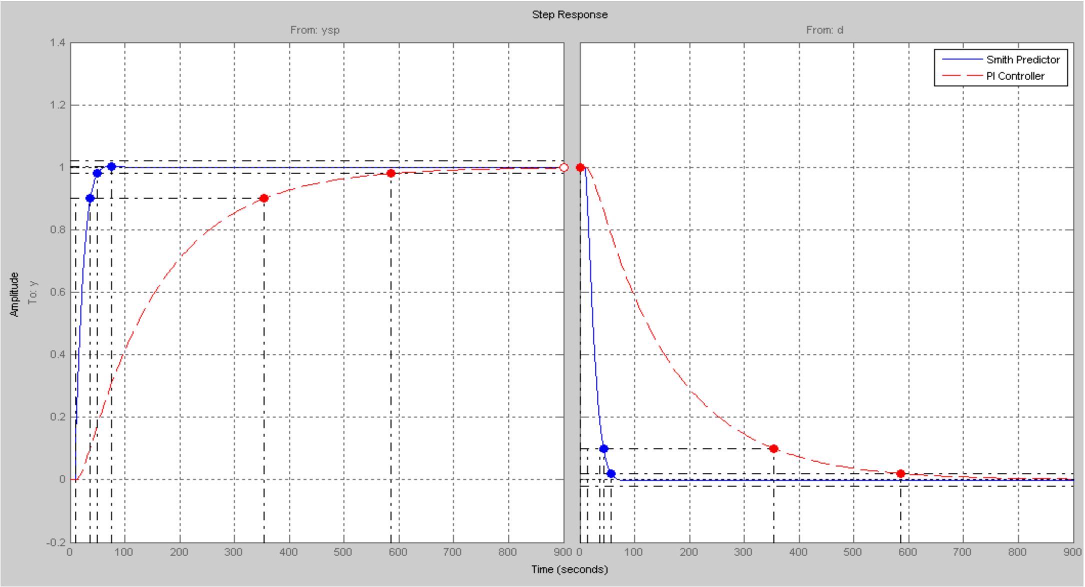


Fig 4.23 Step Response with LAR Protocol with PI Controller and Smith Predictor for LAR 100 Nodes

The below table gives the effect of the protocol on the time response characteristics of the system With PI Controller

Protocol	**Rising Time**	**Settling Time**	**Overshoot (Percentage)**
LAR	318 Sec	586 Sec	0 at time >900Sec

Table 4.21: Effect of the protocol on the time response characteristics of the system with PI Controller for LAR with 100 Nodes

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
LAR	26.9 Sec	50.9 Sec	0.262 at 75 Ec

Table 4.22 . Effect of the protocol on the time response characteristics of the system with PI Controller and Smith Predictor for LAR 100 Nodes

4.10 Detail Description of Performance Evaluation and Investigation of Remotely Controlled Actuators of a Petroleum Tank System using OLSR Protocols

Implementation of Controller Design above using OLSR Protocols with Number of Nodes is 100.

Setup is done for Virtual Network for the Study System

Transmission of the message from source node i.e. PID controller to the actuator of a petroleum tank situated remotely and back is done by simulating the network of Qualnet5.0 as depicted in Fig. with selections as shown in Table.

Network Parameter	**Assigned Value**
Routing Protocol	OLSR
Number of Nodes	100
Mobility Model	Random Way Point
Transmission Range	600m
Simulation Time	30s

Simulation Area	1500X1500
Traffic Type	Constant-Bit Rate
MAC Protocol	IEEE 802.11e
Size of Packet	12288 bytes
Node Placement	Random
Radio Type	IEEEE 802.11b Radio
Total Packet sent	24
Antenna Model	Omni-directional
Channel frequency	2.4GHZ

Table 4.23. Parametric Values for selected Ad hoc Network for OLSR,100Node

Values like Jitter , Throughput, End to End Delay are found with the usage of QualNet 5.0 simulation software when communication takes place from the controller to petroleum tanks [9].

The transfer function of the petroleum tank [129] with computation delay is given below in equation 1.

$$Gp(S) = \frac{3e^{-10S}}{10S+1} \quad . \qquad (1)$$

The value of the transfer function of PID controller is given in equation 2. For an arbitrary value of K_p= 0.2 , the value of K_i and K_d is taken arbitrarily from the stability region as 0.02 and 1.0 respectively[42].

$$G_C(S) = \frac{K_P S + K_i + K_d S^2}{S} \quad . \qquad (2)$$

The Below Table4.24 gives the effects of protocol

Protocol	End to End Delay	Jitter
OLSR	0.23901779	0.175369469

Table4.24: E2E Delay and Jitter for OLSR protocols with 100 Nodes

In equations 1 and 2, put the random value of K_p, K_i, K_d as 0.2, 0.02 and 1.0 respectively in eq2. The output of the system with computation delay and network delay due to OLSR, protocol is simulated in Mat Lab is shown in Figures respectively

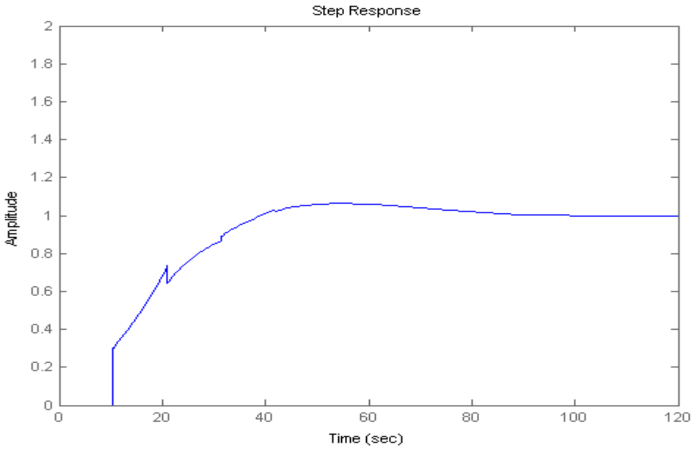


Fig. 4.24. Step Response with OLSR Protocol with 100 Nodes

The following table4.25 shows the effect of the protocol on the time response characteristics of the system.

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
OLSR	21.4691	79.6170	6.2778

Table4.25: Time response characteristics of the system of OLSR with 100 Nodes

4.11 Detail Description of Performance Evaluation and Investigation of Remotely Controlled Actuators of a PetroleumTank System using DSR Protocols

Implementation of Controller Design above using DSR Protocols with Number of Nodes is 100.

Transmission of the message from source node i.e. PID controller to the actuator of a petroleum tank situated remotely and back is done by simulating the network of Qualnet 5.0. Parametric value selections as shown in Table.

Network Parameter	**Assigned Value**
Routing Protocol	DSR
Number of Nodes	100
Mobility Model	Random Way Point
Transmission Range	600m
Simulation Time	30s
Simulation Area	1500X1500
Traffic Type	Constant-Bit Rate
MAC Protocol	IEEE 802.11e
Size of Packet	12288 bytes
Node Placement	Random
Radio Type	IEEEE 802.11b Radio
Total Packet sent	24
Antenna Model	Omni-directional
Channel frequency	2.4GHZ

Table 4.26 Parametric Values for selected Ad hoc Network for DSR,100 Nodes

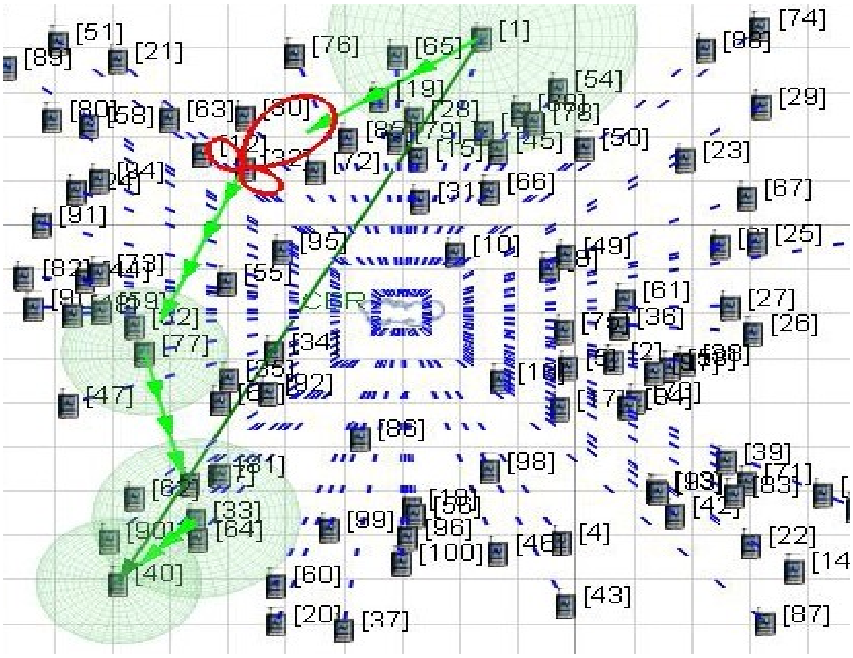


Fig 4.25. Snapshot of QualNet Animator to exploit DSR protocol of 100 nodes using the route discovery mechanism

Values like Jitter, Throughput, and End to End Delay are determined with the usage of QualNet 5.0 simulation software when communication takes place from the controller to petroleum tanks [9].

The transfer function of the petroleum tank [13] with computation delay is given below in equation 1.

$$Gp(S) = \frac{3e^{-10S}}{10S+1} \quad . \tag{1}$$

The value of the transfer function of PID controller is given in equation 2. For an arbitrary value of K_p=0.2 ,the value of K_i and K_d is taken arbitrarily from the stability region as 0.02 and 1.0 respectively[14].

$$G_C(S) = \frac{K_P S + K_i + K_d S^2}{S} \quad . \tag{2}$$

The Below table4.27 gives the effects of protocols

Protocol	End to End Delay	Jitter
DSR	0.40202679	0.18200939

Table4.27: E2E Delay and Jitter for DSR with 100 nodes

In equations 1 and 2, put the random value of K_p, K_i, K_d as 0.2, 0.02 and 1.0 respectively in eq2. The output of the system with computation delay and network delay due to DSR protocol is simulated in Mat Lab is shown in Figure.

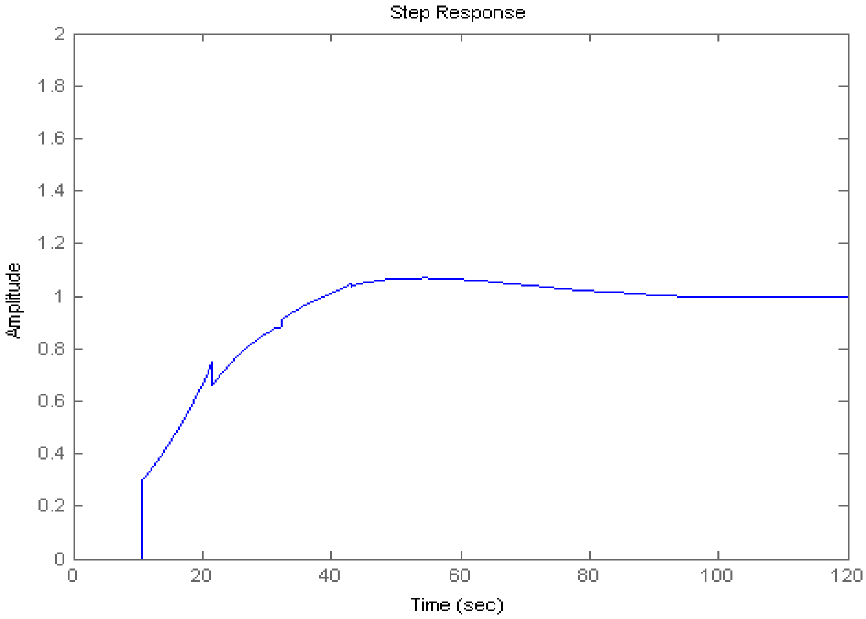


Fig 4.26 Step Response with DSR Protocol,100 Nodes

The following table4.28 shows the effect of the protocol on the time response characteristics of the system.

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
DSR	21.6082	79.7207	6.8348

Table 4.28: Time response characteristics of the system for DSR with100 Nodes

4.12 Detail Description of Performance Evaluation and Investigation of Remotely Controlled Actuators of a PetroleumTank System using ZRP Protocols

Implementation of Controller Design above using ZRP Protocols with Number of Nodes is 100.

Transmission of the message from source node i.e. PID controller to the actuator of a petroleum tank situated remotely and back is done by simulating the network of Qualnet5.0 with selections as shown in Table.

Network Parameter	**Assigned Value**
Routing Protocol	ZRP
Number of Nodes	100
Mobility Model	Random Way Point
Transmission Range	600m
Simulation Time	30s
Simulation Area	1500X1500
Traffic Type	Constant-Bit Rate
MAC Protocol	IEEE 802.11e
Size of Packet	12288 bytes
Node Placement	Random
Radio Type	IEEEE 802.11b Radio
Total Packet sent	24
Antenna Model	Omni-directional
Channel frequency	2.4GHZ

Table 4.29. Parametric Values for selected Ad hoc Network for ZRP,100 Nodes

Values like Jitter, Throughput, End to End Delay are determined with the usage of QualNet 5.0 simulation software when communication takes place from the controller to petroleum tanks [9].

The transfer function of the petroleum tank [129] with computation delay is given below in equation 1.

$$Gp(S) = \frac{3e^{-10S}}{10S+1} \quad . \qquad (1)$$

The value of the transfer function of PID controller is given in equation 2. For an arbitrary value of K_p=0.2 ,the value of K_i and K_d is taken arbitrarily from the stability region as 0.02 and 1.0 respectively[42].

$$G_C(S) = \frac{K_P S + K_i + K_d S^2}{S} \quad . \qquad (2)$$

The Below table4.30 gives the effects of protocol

Protocol	End to End Delay	Jitter
ZRP	0.36043164	0.153206493

Table4.30 :E2E Delay and Jitter for ZRP with 100 Nodes

In equations 1 and 2, put the random value of K_p, K_i, K_d as 0.2, 0.02 and 1.0 respectively in eq2. The output of the system with computation delay and network delay due to ZRP protocol is simulated in Mat Lab is shown in Figure.

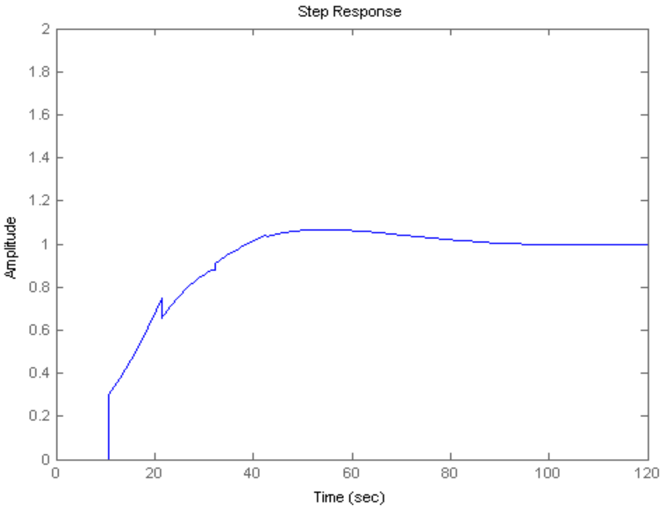


Fig 4.27. . Step Response with ZRP Protocol,100 Nodes

The following table4.31 shows the effect of the protocol on the time response characteristics of the system.

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
ZRP	21.4420	79.7011	6.7280

Table4.31: Time response characteristics of the system for ZRP and 100 Nodes

4.13 Comparison of LAR and RIP Protocol with 45 nodes

Simulation of RIP and LAR protocols in a Qualnet5.0

The below table shows the impacts of RIP and LAR protocols on a network used for a system

Protocol	**End to End Delay**	**Jitter**
RIP	0.208352	0.026246
LAR	0.766082	0.170635

Table 4.31 Comparison of E2E Delay and Jitter for RIP and LAR protocols,45 Nodes on a network

Considering above E2E Delay and Jitter observed of RIP and LAR protocols in a Qualnet5.0

This above E2E Delay with computational delay is implemented in Matlab

Protocol	**Rising Time**	**Settling Time**	**Overshoot (Percentage)**
RIP	21.6 Sec	79.58 Sec	6.14
LAR	20.3 Sec	79.77 Sec	8.2

Table4.32: Comparison of Impact of protocol RIP and LAR with 45 Nodes on the system’s time response characteristics

4.14 Comparison of OLSR, DSR, ZRP Protocol with 100 nodes

Values like Jitter, Throughput, End to End Delay are determined with the usage of QualNet 5.0 simulation software when communication takes place from the controller to petroleum tanks [129].

The Below table gives the Values like Jitter, End to End Delay of OLSR,DSR,ZRP protocols

Protocol	End to End Delay	Jitter
OLSR	0.23901779	0.175369469
DSR	0.40202679	0.18200939
ZRP	0.36043164	0.153206493

Table4.33: Comparison Jitter, E2E Delay of OLSR,DSR, ZRP protocols,100 Nodes

The following table shows the effect of protocols on the time response characteristics of the system.

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
OLSR	21.4691	79.6170	6.2778
DSR	21.6082	79.7207	6.8348
ZRP	21.4420	79.7011	6.7280

Table 4.34: Comparison of protocols OLSR, DSR,ZRP with 100 Nodes on the time response characteristics of the system.

4.15 Comparison of RIP Protocol with 45 and 50 nodes

Values like Jitter, Throughput, End to End Delay are determined with the usage of QualNet 5.0 simulation software when communication takes place from the controller to petroleum tanks [135].

The Below table gives the Values like Jitter, End to End Delay of RIP protocols

Number of Nodes	End to End Delay	Jitter
45	0.208352 sec	0.026246 sec
50	0.0112078 sec	0.000322014 sec

Table 4.35: Comparison of Jitter, E2E Delay of RIP protocols with 45,50 Nodes

The following table shows the effect of protocols on the time response characteristics of the system.

Number of Nodes	Rising Time	Settling Time	Overshoot (Percentage)
45	21.6 sec	79.58 sec	6.14
50	40.7sec	47.1sec	05

Table 4.36: Comparison of protocol RIP with 45 and 50 Nodes on the time response characteristics of the system.

4.16 Comparison of RIP and LAR Protocol with 100 nodes

The following table shows the simulation result of RIP and LAR protocols with 100 Nodes in Qualnet5.0

Protocol	**End to End Delay**	**Jitter**	**Throughput**
RIP	0.1013849sec	0.020096947sec	3735.6
LAR	0.2389732sec	0.10083686sec	4478.8

Table 4.37: Comparison of E2E Delay and Jitter for RIP and LAR protocols with 100 Nodes

The below table gives the effect of the protocol on the time response characteristics of the system With PI Controller implemented in MatLab

Protocol	**Rising Time**	**Settling Time**	**Overshoot (Percentage)**
RIP	319 Sec	587 Sec	0 at time >800Sec
LAR	318 Sec	586 Sec	0 at time >900Sec

Table 4.38: Comparison of Time response characteristics of the system of RIP and LAR with PI Controller

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
RIP	26.9 Sec	50.9 Sec	0.262 at 75 Sec
LAR	26.9 Sec	50.9 Sec	0.262 at 75 Sec

Table 4.39 : : Comparison of Time response characteristics of the system of RIP and LAR with PI Controller and Smith Predictor.

4.17 CONCLUSION

We have studied RIP, OLSR, DSR, ZRP and LAR protocols in our working. In all three different types of protocols were studied namely Proactive, Reactive, Hybrid These models were studied as a function of varying mobile models and the size of the network. Three types from each of the above models i.e RIP of Proactive, LAR of Reactive were chosen and ZRP is chosen from Hybrid. Earlier also the output of these protocols was done and the parameters measured were E2E Delay and Jitter. In mobile Adhoc Networks, the devices change there working locations. Scalability[134] indicates whether the protocol will work or fail when the number of users goes up in the mobile Adhoc network.

This chapter analyses and compares the performance of the Petroleum tank system using five routing protocols RIP, OLSR, DSR, ZRP and LAR with PI controller and smith predictor in QualNet-5.0 and MATLAB 7.0 by simulators. Comparison of time response characteristics of the open-loop and closed loop Petroleum tank system is being done in Tables. The Network performance metric such as average Jitter, End to End delay, is put on display in Tables. The simulation results in QualNet5.0 such as end to end delay is taken into consideration as network delay and thus analyze the characteristic of the system in MATLAB 7.0 with PI and smith predictor and shown in Tables. A comparison of all Protocols with variable nodes is successfully done.

CHAPTER V

PERFORMANCE EVALUATION AND INVESTIGATION OF REMOTE CONTROLLED ACTUATORS OF A TWO TANK SYSTEM

5.1 INTRODUCTION

This discussion provides the guidance for the remote controlled[15] Actuators of a Two tank System[. Design guidance on issues related to network parameter metrics such as an end to end delays, jitter, throughput for RIP and LAR routing protocols are also covered in this chapter. The design of the controller has been done in chapter 4 which is used here for Two Tank System. This chapter generally applies to remote controlling of Two tank systems and the network used is a mobile Adhoc[117] network (MANET) which is having a set of moving nodes without the support of fastened securely in position infrastructure. The connection in the mobile node of MANET is altogether relying on the nodes of its network. For the adequate functioning of MANET many router protocols have been prepared. To make the network system effected, the protocols provide the way between the mobile nodes via multi-hop links. The numerous factors affect the performance of the protocols many such factors of the protocol which affects the performance of remote control Two tank system is end to end delay, average jitter throughput etc. The performance analyzed in Qual-Net5.0[135]. The characteristic of the system is analyzed in MATLAB7.0.

The execution was achieved over the real world by considering the Two tank systems with controlling methods and also define the performance effectiveness of MANET protocols. The performance was analyzed and compared on metrics like E2E delay at various protocols with Two tank system with the different controlling method and varying network nodes.

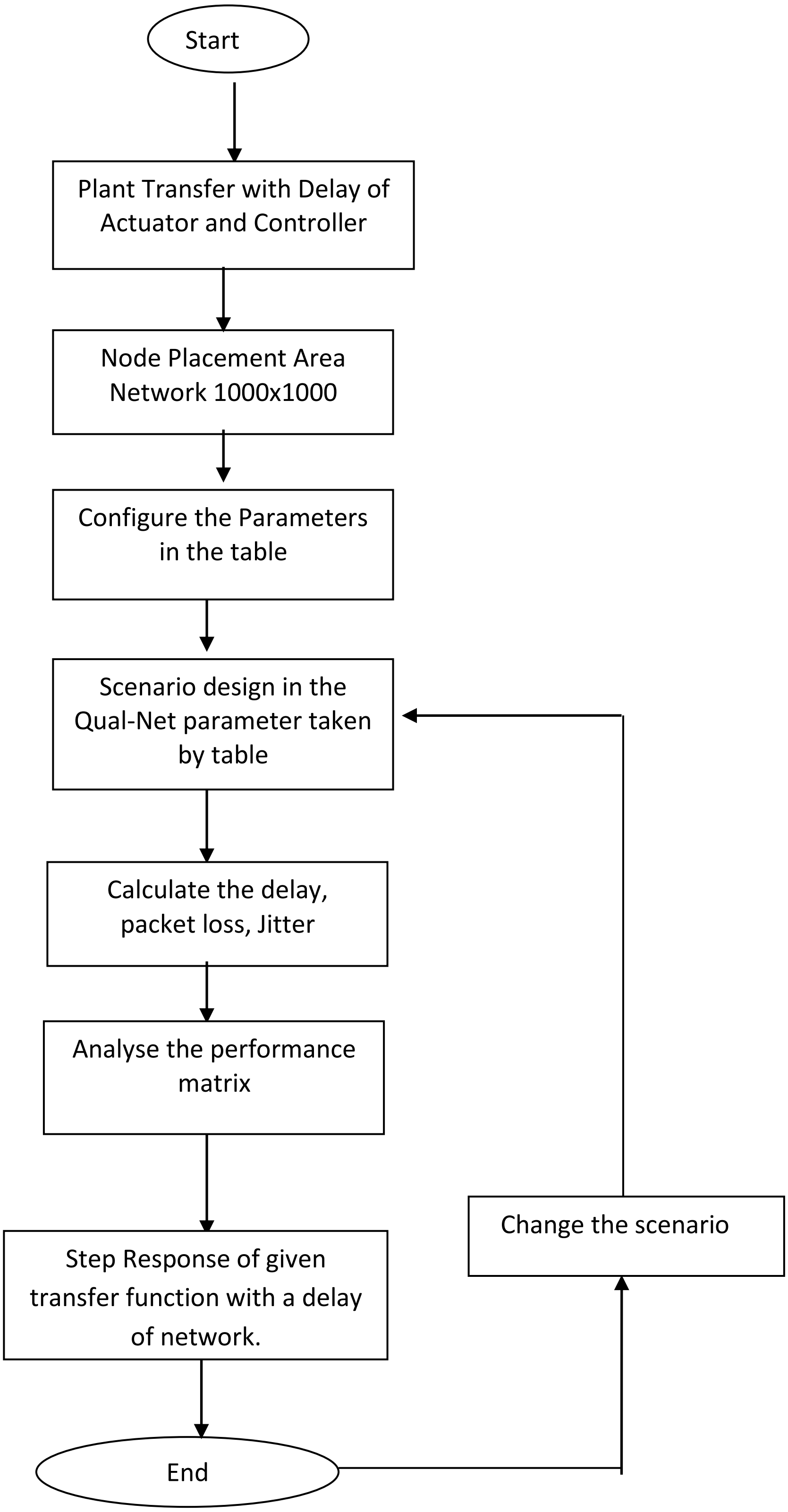
5.2 RELATED WORK-

Several researchers have done the design and performance analysis of a network control system. Implementation of a time delay compensation scheme is also done for the network control system. They have used RIP and LAR protocols for this purpose.

Torre,M.	Applied Automation supplement for Control Engineering and Plant Engineering,Halliburton,(2014)
Huang, F.D., Nguang, S.	Robust H_∞ output feedback control of networked control systems with multiple quantizers, Journal of The Franklin Institute, Elsevier Ltd.,(2012)
Luan,X., Shi,P., Liu,F.	Stabilisation of NCS with Random delays, IEEE,(2010)
Ling,W.E.I., D.X.U.E., Yu., Zhi, E.D.	Some Basic Issues in Networked Control Systems, Second IEEE Conference on Industrial Electronics and Applications, (2007)
Prasad KS,N., Puttamadappa,C.	Design and performance analysis of energy-aware routing protocol for delay-sensitive applications for wireless sensors networks, International Journal of Computer Networks and Communications Security, Vol .1(2),(2013) 46-53, E-ISSN 2308-9830
Vardhan,S.,Kumar,R.	An implementation of time-delay compensation scheme for Networked Control Systems using MATLAB 7.0/MATLAB, International Conference on Computational Intelligence and Communication Systems IEEE, DOI 10.1109/CICN.2011.29, (2011)
Aggarwal,Ruchi.,Kaur,Amanpreet.	Energy Efficient Zone-Based Location Aided Routing Protocol for MANE International Journal of Computer Science and Information Technologies, Vol. 5 (4) ,(2014), 4990-4994
Vir,Dharam.,Agarwal,S.K.,Imam,S.A.s	Traffic Generator Based Power Analysis of Different Routing Protocol For Mobile Nodes in Wireless Sensor Network Using QualNet-5.0 (IJERA) ISSN: 2248 -9622 Vol.3 (4), (2013),.2548 -2554
A.K. Dewivedi, S. Khushwaha, O.P. Vyas	Performance of Routing Protocols for MANETs and WSN:A Comparative Study," International .journal of recent trends in Engineering, vol.2, No.4, Nov 2009.

	The free encyclopedia-, Mobile ad-hoc Network, http://en.wikipedia.org/wiki/Mobile_ad-hoc_ network, Oct-2004.
Syed Akhtar Imam, Vaibhav Kumar Sachan and Vedprakash Dubey.	Design and Analysis of Energy Efficient Communication Methods for Wireless Sensor Networks, Telecommunication and Radio Engineering, Russia, 74 (19), pp-1705-1714, 2015.
J.A. Ramos and P. Lopes dos Santos	Mathematical Modeling, System Identification, and Controller Design of a Two Tank System, IEEE Conference on Decision and Control New Orieans,LA,USA,Dec.12-14,2007
Zeeshan Ahmed	Some Studies on Smith Predictor Based Networked Control System, Department of Electrical Engineering National Institute of Technology, Rourkela-769008, Odisha, India, 2013
Figueredo, L.F.C., Santana, P.H.R.Q.A., Alves, E.S., Ishihara, J.Y., Borges, G.A., Bauchspicess, A.	Robust Stability of Network control system, Robotics, Automation and computer Vision Group, Deptt of Electrical Engg, University of Brasilia, Brazil.
Dewivedi, A.K., Khushwaha, S., Vyas, O.P	Performance of Routing Protocols for MANETs and WSN:A Comparative Study, International journal of recent trends in Engineering, Vol.2, No.4, (2009)

5.3 FLOW CHART DESIGN OF SCENARIOS MODEL



5.4 PROPOSED PROTOCOLS

Ad-hoc routing protocols are divided broad ally in three ways. Five protocols have been taken to develop understanding as per the below image.

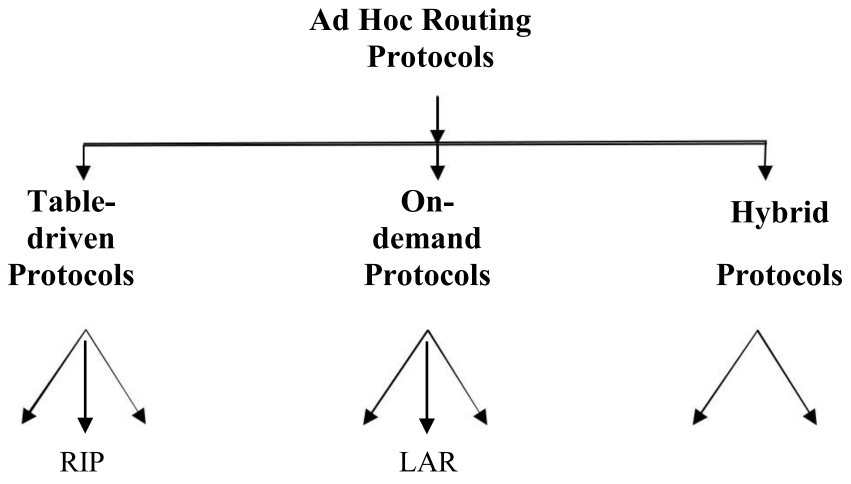


Figure 5.1 Routing Protocols

5.6 SIMULATION SETUP

5.6.1 Qual-Net 5.0 setup of the virtual network for study system:-

As referred in earlier chapters Ad-Hoc network routing protocol is usually grouped in three sections. It is quite laborious to figure out the performance of the total protocol proposed till now. We have considered five protocols which are detailed in chapter 3. To execute the protocols the setup is made with the help of variable and fixed values. These were selected to execute the simulation work and the search on various protocols to measure the outcome. A complete list of values which were chosen is given in the below table.

QualNet 5.0-Overview and setup of a Virtual network for studying the system.

QualNet 5.0 Simulator can be used to formulate a virtual wireless network. The simulator in which one can develop and conceptualize network situations and analyze the research results in a single graphical user interface. Qual-Net5.0[135] is established by Scalable Network Technologies [136].QualNet comprises of three layers [135]

3. Model libraries
4. Simulation kernel
6. Qual-Net Developer GUI.

   The Simulator has the following gears:

4. Animator: The created scenario is conceptualized using this tool. Various outputs can be deactivated or activated in the course of a simulation run such as energy[109] exhausted in transmit mode, throughput, end to end delay, jitter, broadcast messages, successfully received packets, etc.
5. Scenario Designer: This is used to Visualize and create network schemes with distinct parameters.
6. Analyzer: Different output files get created on simulation each consisting of different information. Statistical information is comprised in the primary output file (.stat)

The parameters used in the simulation of the virtual network on the QualNet5.0 are listed in Table5.1.

Network Parameter	Assigned Value
Simulator	QUALNET 5.01
Routing Protocol	RIP, LAR
Number of Nodes	45
Mobility Model	Random Way Point
Transmission Power	20dBm
Simulation Time	30s
Simulation Area	1500X1500
Traffic Type	CBR
MAC Protocol	IEEE 802.11e
Size of Packet	512bytes
Node Placement	Random
Radio Type	IEEEE 802.11b Radio
CCA Mode	Carrier-Sense
Energy Model	MicaZ

Item to send	100
Antenna Model	Omni-directional
Battery Model	Linear Model

Table 5.1 Network parameters selected of simulation setup, for Two Tank system

5.6.2 SUCCESSFUL ROUTE FORMATION THROUGH SIMULATION

This has been done with the help of Qualnet 5.0. It uses RIP,LAR etc as various protocols to find out routes between source and destination. It uses IEEE802.15.4 as a MAC protocol. Figures depict results for various protocols and nodes ranging from 0 to 60 % of the overall nodes. The experiments indicate the routes which are verified and shown in the figure.

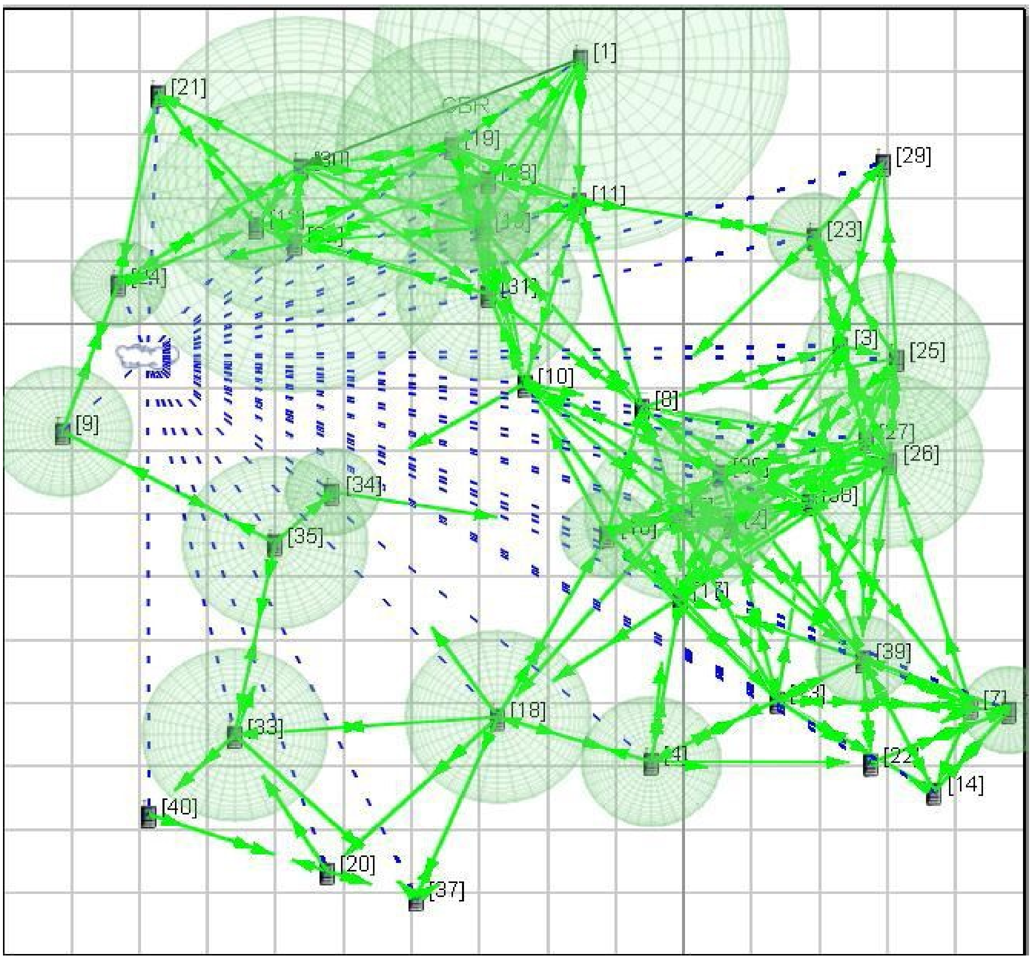


Figure 5.3 Animation View for 40 Nodes when Simulation is 60%

The two general Outcomes of the Simulation process have been shown in the below figures

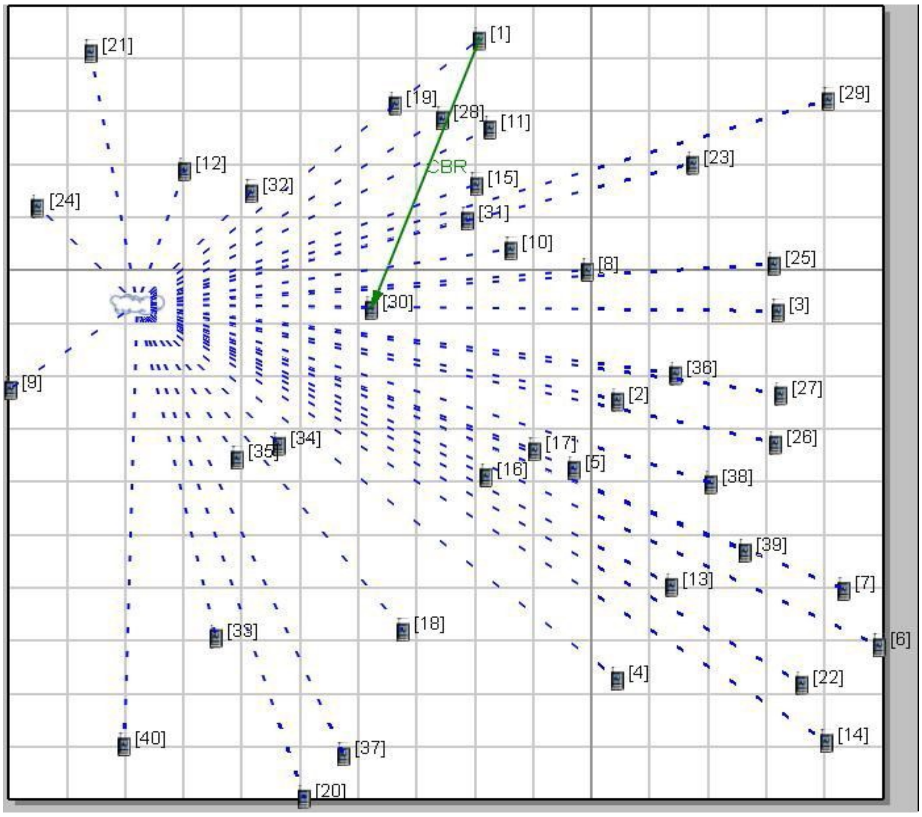


Figure 5.4 Network with 40 Nodes

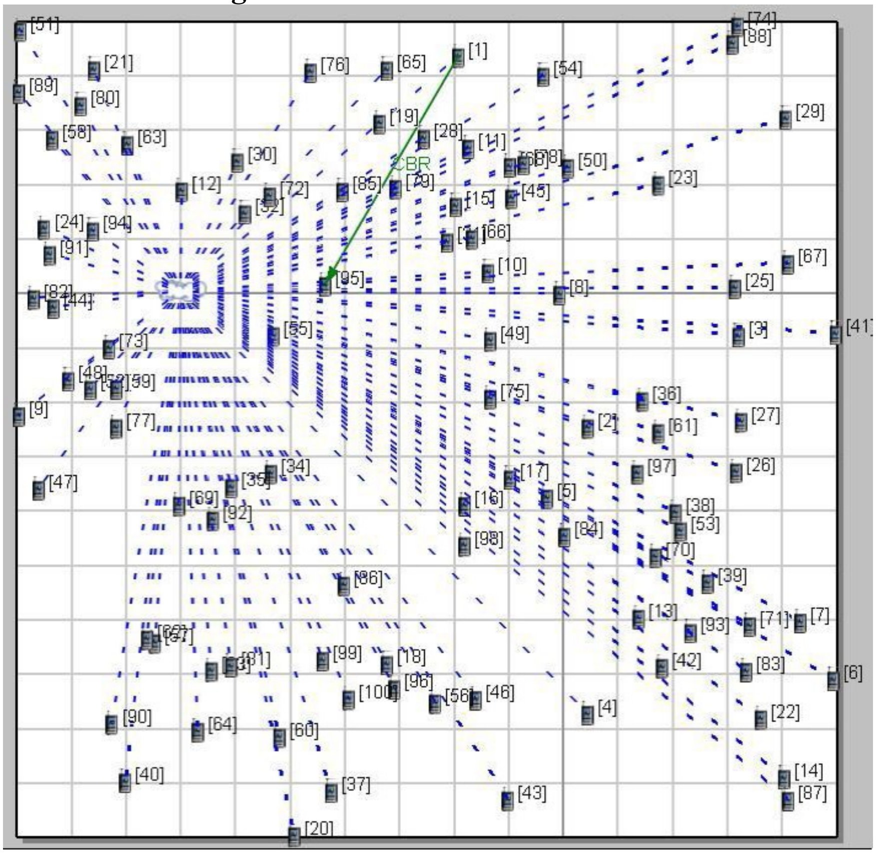


Figure 5.5 Network with 100 Nodes

5.6.3 DESCRIPTION OF PARAMETERS / VALUES SELECTED

Examined Protocols- RIP and LAR protocols were chosen from the Ad-Hoc network routing protocol and simulate these protocols using Qual-Net 5.0 software and the situation is created to get the information about various values like End to End delay, Jitter, Throughput, etc.

Description of various parameter chosen in Table 5.1 is as follows

Simulation Space – The testing is done on the simulation of a large number of nodes placed at randomly in a rectangular area. The rectangular area is chosen to have a larger distance between Nodes.

Traffic Pattern- In the testing 1no CBR and 40 to 100 Numbers of Nodes are used which are sent at a rate of 4 packets per second. The size of the packet varies from 64 bytes per packet to 1024 bytes per packet.

Media Access Control Protocols- This protocol is used in the testing of Qual-Net 5.0. The layer looks after the state of striking, breaking and existence. It is also used to determine errors due to transmission. When the system is available it should start sending the packets or else wait for a certain amount of time before it starts sending again.

Radio Propagation Models- This is used to find out whether the data send through the air has reached correctly. It also considers delay due to the propagation and Captures effect.

Battery Model- This is considered to be uniform to be in line with the continuous loss of power when practically the atmosphere remains the same. The battery, data and the load were taken as per standard.

Communication Model- MAC layer uses IEEE Standards DCF. This layer was used as All Route Request and the query packet was sent with the help of MAC[111] with CSMA.

5.6.4 PERFORMANCE METRIC USED

Metric is a basic instrument used to find a way to a destination. This defines which route chosen is the best, effective or very efficient. The following metrics are used to find out the output of the Ad-Hoc routing protocols.

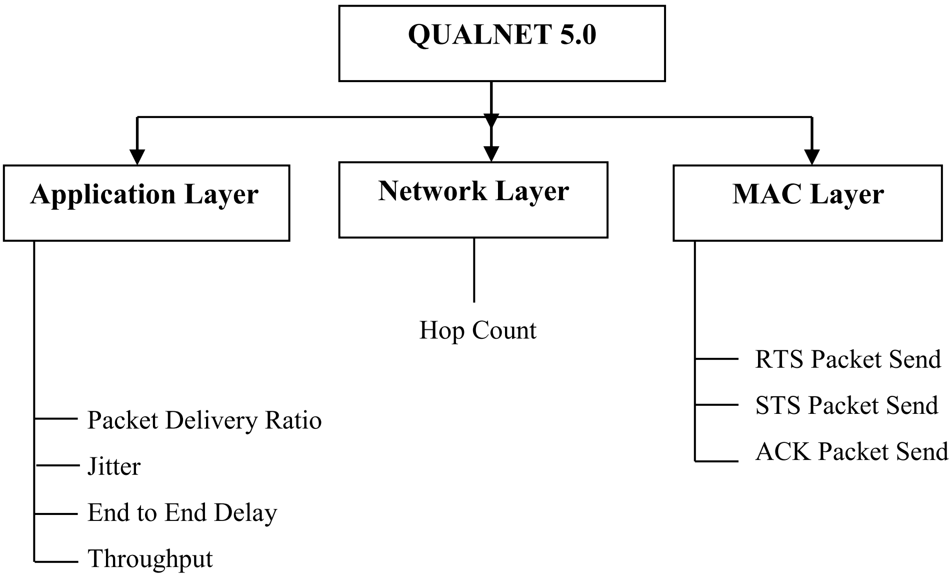


Figure 5.6 Classification of Performance Metrics used

Description of various Performance Metrics used are as follows

PACKET DELIVERY RATIO

Packet Delivery ratio gives the comparison between the data received at the destination as compared to the data initiated at the source. A good value of the ratio shows the system to be more efficient and accurate.

AVERAGE END TO END DELAY

This gives the value of time taken by the first packet to be at the destination after it is transmitted from the source.

JITTER

Different packets take different time to reach the destination. Jitter is measured in terms of the delay that takes place during transmission. A higher value indicates that the quality of the signal to be poor.

THROUGHPUT

It is the average rate at which the packet is successfully transmitted in a network. A higher value of bits per second indicates that the network is having a good performance.

PACKET RECEIVED

It is the rate at which the message is received by the user from the source per second without losses. Higher efficiency is achieved when the number of such packets is maximum.

HOP COUNT-

It is the number of intermittent nodes that go from source to destination.

CTS PACKET SENT

It is defined as Clear to send. It is used in MACA to solve issues like terminal problems that are hidden and exposed.

ACK PACKET SENT

It is defined as the acknowledgement packet sent by the receiver after getting the correct packet.

5.6.5 ASSUMPTION AND LIMITATIONS

The points assumed for nodes during simulation are as per the following.

1. The battery of each node has a limitation.
2. Nodes work individually and not in a group.
3. Selected Nodes cannot change the data of control packets.

5.7 EXPERIMENTAL STUDY AND ANALYSIS:-

Performance analysis of network controlled two-tank system with RIP and LAR protocol using Smith Predictor

Setup of Virtual Network for the Study System

Let us take the specified parameters given in Table5.2, the communication of data from source node i.e. PI controller to a remotely placed actuator of the two-tank system and vice versa is simulating in the Ad Hoc network in QualNet-5.0 to find out End to End delay, Jitter, etc.

Network Parameter	Assigned Value
Routing Protocol	RIP,LAR
Number of Nodes	45
Mobility Model	Random Way Point
Transmission Power	20dBm
Simulation Time	30s
Simulation Area	1500X1500
Traffic Type	VBR
MAC Protocol[99]	IEEE 802.11e
Size of Packet	512bytes
Node Placement	Random
Item to send	100
Antenna Model	Omni-directional

Table 5.2 .Parametric Values for Ad Hoc Network for RIP,LAR & 45Nodes

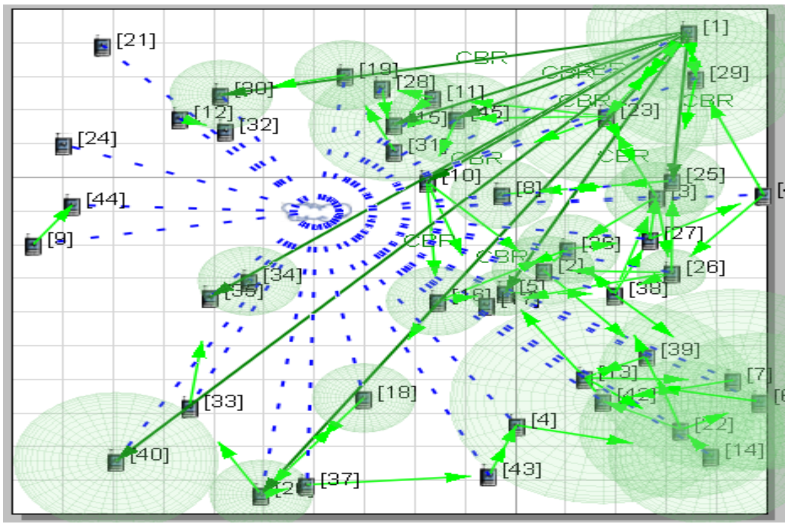


Fig 5.7 Snapshot of QualNet-5.0 Animator to exploit LAR protocol using 45 nodes.

Considering the transfer function of two- tank system [130] with computation delay is given in equation 1.

$$Gp(S) = \frac{1.83e^{-10S}}{S2 + 1.6000\,S + 1.8310}$$

Assume that in the Two Tank System the type of controller used is PI. The parameter like End to End delay, Jitter, Throughput, etc of Ad Hoc network used in the two tank system is found using simulation software QualNet-5.0[135]

The following table 5.3 depicts the effects of RIP and LAR protocols via simulation.

Protocol	End to End Delay	Jitter
RIP	0.208352	0.026246
LAR	0.766082	0.170635

Table 5.3: E2E Delay and Jitter of RIP and LAR protocols with 45 Nodes.

In control industries, the dead time is the time elapsed between the signal is issued and the signal first begins to respond in the process. The negative phase introduced by the dead time makes it difficult to use the traditional controller in processes. Thus to improve the performance of the closed-loop system the compensator for dead time is used. Smith predictor [132] is one such type of first dead time compensator algorithm that is used to compensate for the dead time and its mainly used to compensate for the delay from the close-loop controlled system. Smith's predictor is used in stable processes. Improvement of the disturbance rejection response cannot be done by smith predictor. The analysis and design of this type of compensator are used for only constant delays. Step response of the system with computation delay and network delay due to RIP and LAR protocol [133, 134] with PI controller and smith predictor is simulated in MATLAB 7.0 is shown in Figure5.8 and Figure5.9 respectively.

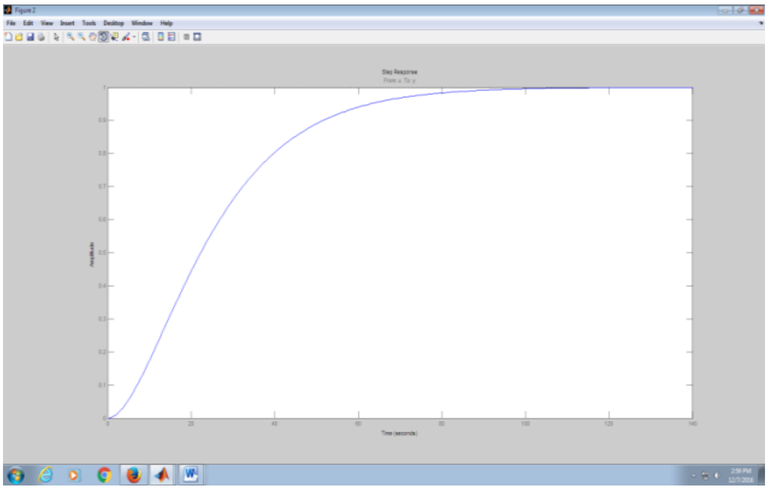


Fig. 5.8 Step Response of open- loop Two Tank System

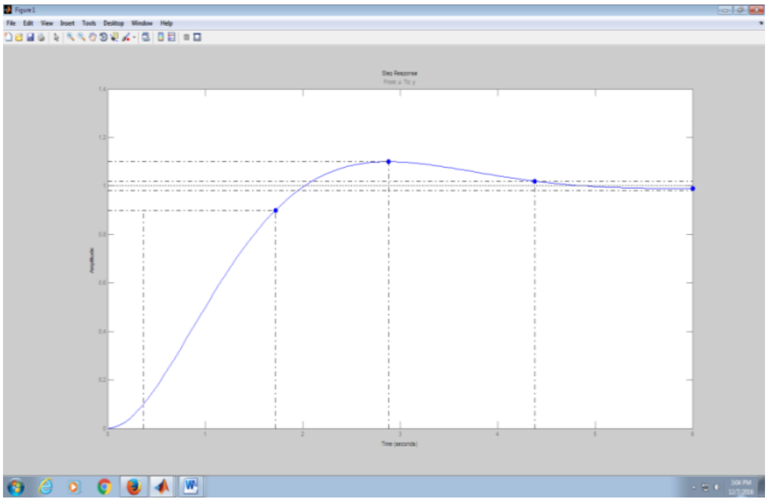


Fig 5.9 Step Response of close loop Two Tank System

Protocol	**Rising Time**	**Settling Time**	**Overshoot** **(Percentage)**
Smith Predictor	29.3	63.7	0% at >900sec
PI	314	618	0% at >900sec

Table 5.4 Comparison chart of time response characteristics of the open- loop and closed loop two-tank system without Network delay

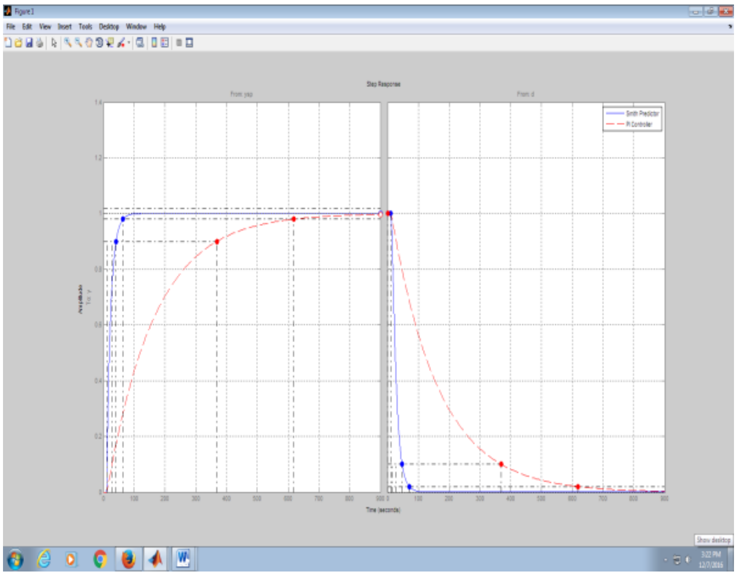


Fig 5.10. Step Response with RIP Protocol for Two Tank

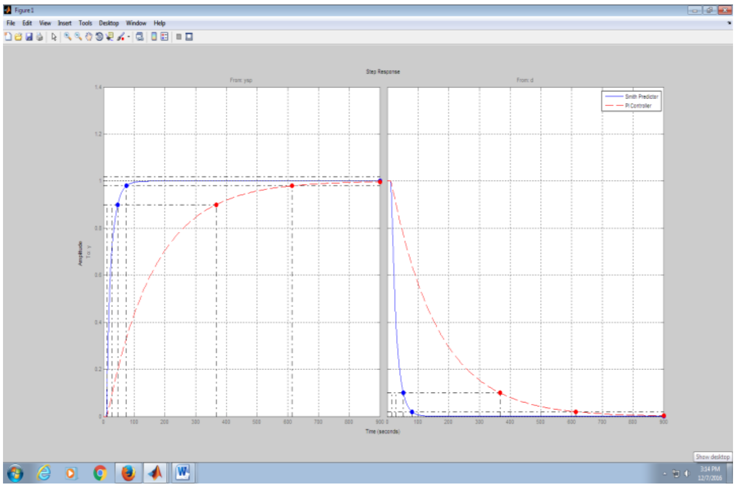


Fig. 5.11 Step Response with LAR Protocol for Two Tank

The following table shows the effect of the protocol on- time response characteristics of the system.

Protocol	**Rising Time**	**Settling Time**	**Overshoot (Percentage)**
Smith Predictor	29.3	63.7	0% at >900sec
PI	314	618	0% at >900sec

Table 5.5 Effect of RIP Protocol on the time response characteristics of the system with PI Controller and Smith Predictor for Two Tank

Protocol	Rising Time	Settling Time	Overshoot (Percentage)
Smith Predictor	35.1sec	615	Nil
PI	338	75.2	Nil

Table 5.6 Effect of LAR Protocol on the time response characteristics of the system with PI Controller and Smith Predictor for Two Tank

5.11 CONCLUSION

We have studied RIP and LAR protocols in our work . In all two different types of protocols were studied namely Proactive, Reactive. These models were studied as a function of varying mobile model and the size of the network. Two types from each of the above models i.e RIP of Proactive, LAR of Reactive were chosen. Earlier also the output of these protocols was done and the parameters measured were E2E Delay and Jitter. In mobile Adhoc[103] Network, the devices change there working locations . Scalability indicates whether the protocol will work or fail when the number of users goes up in the mobile Ad hoc [87] network.

This chapter analyses and compares the performance of the two tank systems using two routing protocols RIP and LAR with PI controller and smith predictor in QualNet-5.0 and MATLAB 7.0 by simulators. A comparison of time response characteristics of the open-loop and closed-loop two-tank system is being done in Table 5.4. The Network performance metric such as average Jitter, End to End delay, is put on display in Table 5.3. The simulation result in QualNet5.0 such as end to end delay is taken into consideration as network delay and thus analyzes the characteristic of the system in MATLAB 7.0 with PI and smith predictor and shown in Table 5.5 and 5.6

CHAPTER VI

CONCLUSION

This chapter describes the conclusion and future scope of the network control system used for communication between nodes for different protocols. Because of the end, a different type of delays and jitter occurred in Network Control System (NCS) has received increased attention among researchers in recent years. Several efficient protocols have been developed for the ad-hoc network such as RIP, LAR, OLSR, ZRP, etc. to reduce communication delay jitter and increase the throughput while transmitting the signal from source node to the destination node and thus increase the efficiency of the system. In this chapter conclusion of all chapters included in the thesis and its future scope is explained briefly below:-

6.1 CONCLUSION

In this dissertation work the performance of different protocols is investigated over the Network Control System (NCS). It explains the profoundness analysis of the system and gives the optimum solution or strategy for an efficient petroleum tank system and two-tank system. In adjoining some alterations are performed at Network Control System (NCS) by using a smith predictor in the control system in order to have better performance of the system. The following statement describes the result and analysis of the complete thesis.

- The routing protocol is classified into three Proactive (Table driven[75,102,104,105]), Reactive (On Demand[74,75,76,77]) and Hybrid (Proactive and Reactive) which are further classified into Uniform and Non-Uniform. Uniform is again classified into Flat and Geographical base and Non-Uniform is again classified into Flat and Hierarchical.
- The two commonly used Protocol RIP and LAR which is Proactive, Non-Uniform and Flat categories are compared and analysed with PIP and 45 nodes come under Reactive, Uniform and Flat. End to End Delay, Jitter is more for LAR than RIP and using this protocol with PID controller, the rising time is less in LAR but overshoot is more. The setting time is the same approximate in both cases.

- The modification in the system is done by using PI controller and Smith Predictor, but the communication Protocol are the same i.e RIP and LAR and with nodes i.e 45. Here in this with the only PI, Rising time, setting time, Overshoot is the same. Overshoot is observed as equal to zero. With PI + Smith predictor.
- The communication protocol used is same i.e. RIP and LAR but considering 100 Nodes with PI Controller. End to End delay is more in LAR and rising time, settling time and overshoot is the same. The Overshoot is observed as zero. With PI + Smith predictor.
- The system is analysed using the same controlling method ie PID controller with three different types of protocol ie according to the classification ie Proactive, Reactive and Hybrid protocol. The protocol used is OLSR, DSR[121] and ZRP. End to End delay is less in OLSR and Jitter is less in ZRP. Rising and Setting time are approximately the same. Overshoot is approximately the same DSR and ZRP but less in the case of OLSR.

6.2 FUTURE SCOPE

In the future, the investigation of the efficiency of petroleum tank and two tank system is done by designing different control methods and rest of the protocols which are not used in the thesis will be applied to check the performance of the system. The future scope of the submitted work is implemented with all use protocols in a real scenario and compare the results. The considered protocols have been elongated to the conventional RIPv3 and OSPFv3 protocols. The proposed control methods can also be done with other different ad-hoc network protocols such as LEACH, LANMAR, OLSRv2, etc. All these used protocols performances are studied experimentally in the QUALNET simulation software scenario and MATLAB also. Here in the aforementioned research various classes of protocols have been examined such as reactive proactive and hybrid routing[101] protocols. With this modification with the control, methods have been suggested by using a smith predictor with the view to improve the system performance of both the petroleum tank and two tanks [40] system. Furthermore, along with this, there are some field that requisites to be taking cure which is as follows:-

.

- In both the petroleum tank and two tank systems all the protocols use are tried in a QUALNET simulator. The systems used all the protocols are to be tried in a real scenario.
- There are only five types of protocols are tested so we need to test the system with the rest of protocols. The system is tested with protocol in the Qualnet simulator. It needs to be tested in a realistic environment
- .A very important issue that has to be considered is the security and accuracy of the signal sent in Ad hoc network. The signal should not be lost and the time taken to the destination should be approximately zero.
- Another important issue is the use of NCS in the medical profession to treat the patient by sitting only wherein the world which needs accuracy and fast communication.
- The main consideration in nodes of MANET is battery power. The future work would be to increase the lifetime of the battery.
- Many types of new and demand on Adhoc[67,69] and wireless sensor networks make the researcher use the new trend to make a robust controller and thus wireless communication[128] is endless tried and it keeps on developing forever.
- Bandwidth is also one of the most important constraints in wireless communication and is precious in Adhoc[70,71] network too. End to End delay, Jitter researcher can also consider and analyse the bandwidth aspects for the NCS.
- Researchers can design a special type of protocol only for NCS for specific applications [18,19,23] so that we get the optimum solution and NCS technology will become a boom for mankind.

BRIEF PROFILE OF THE RESEARCH SCHOLAR

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LIST OF PUBLICATIONS OUT OF THESIS

Paper Published in International Journals:5

National Conference-1

Accepted Paper-2

S.No	Title of the paper	Name of Journal where Published	ISBN /ISSN No.	Volume & Issue	Year	Pages
1.	Networked Control System: Survey and Directions	Journal of Engineering Research and Studies	0976-7916	I &II	2011	
2.	Performance analysis of network controlled petroleum tank system with RIP and LAR protocol	IEEE Xplore	2325-9418		2016	
3.	Performance Evaluation of Network Controlled Petroleum Tank System with LAR protocol through simulation	National Conference on Role of Science and Technology towards "Make In India" RSTTMI 2016			2016	
4.	Performance analysis of Reactive, Proactive and Hybrid Routing Protocol used in Petroleum tank over Network Control Systems	Springer Advances in Intelligent Systems& Computing (AISC)		479	2016	
5.	Performance analysis of network controlled petroleum tank system with RIP and LAR protocol using Smith Predictor	Global Journal of Embedded System in Engineering Research		4 & 2	2016	

6.	Dynamic Approach to Optimize Time Response characteristics of Network Controlled Petroleum Tank System having RIP or LAR Protocol using Qualnet-5.0 and MATLAB7.0	International Journal of Telecommunication and Radio Engineering Russia	1943-6009	75 & 17	2016	
7.	Performance analysis of network controlled two tank system with RIP and LAR protocol using Smith Predictor.	Journal of Electronic Control systems and Control Instrumentation Engineering		2&1	2017	
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