Performance Improvement of Zigbee for Wireless Sensor Network

Major Project Report

Submitted in partial fulfillment of the requirements

for the degree of

Master of Technology

in

Electronics & Communication Engineering

(Communication Engineering)

By

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(13MECC28)

Electronics & Communication Engineering Branch

Electrical Engineering Department

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Under the guidance of

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Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Communication Engineering at Nirma University and has not been submitted elsewhere for a degree.
2. Due acknowledgment has been made in the text to all other material used.

- Adit Talati

Certificate

This is to certify that the Major Project entitled **Performance Improvement of Zigbee for Wireless Sensor Network** submitted by **Adit Talati (13MECC28)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Communication Engineering of Nirma University, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this Major Project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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- Adit Talati
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Abstract

Wireless sensor networks (WSNs) are being deployed in many real-life applications, such as environmental monitoring, security and surveillance, industrial automation and control due to its low cost, small size and low power consumption. This has been possible due to the advent of: (i)the IEEE 802.15.4 standard, which defines the physical and medium access control (MAC) layers of the protocol stack and (ii) the ZigBee specifications, which cover the network and application layers. A major concern in wireless sensor network (WSNs) is energy conservation, since battery-powered sensor nodes are expected to operate autonomously for a long time, e.g., for months or even years. Another critical aspect of WSNs is reliability, which is highly application-dependent. In most cases it is possible to trade-off energy consumption and reliability in order to prolong the network lifetime, while satisfying the application requirements. In our thesis performance of Zigbee is enhanced with help of fuzzy logic and modified Zigbee is called Ffuzzy based Zigbee (FZBE). Residual energy, packet dispatch ratio, data delivery ratio and sensitivity are given as input to FIS system. Fuzzy logic is used to select optimum values of output parameters: transmit power, retransmission timeout, duty cycle and back-off time of each node on the basics of applied logic which increases overall performance of Zigbee. Perforamance evaluation of FZBE is carried out in Network Simulator (ns-2) software by calculating parameters like delivery ratio, average message latency and average energy consumption per message for both single-hop and multi-hop scenarios. Simulation results show that FZBE performs better in comparison with ADAPT with Zigbee and standard Zigbee for both single-hop and multi-hop scenarios.

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Chapter 1

Introduction

1.1 Background

Wireless technology has been gaining more importance day by day in recent years. Its main advantage is there is no need to wiring and cost of cable installation and its maintainance is saved. Wireless network can be set-up easily as compared to wired one. Many wireless technologies like Bluetooth , IrDA , Zigbee , etc. are coming up.

WSN is built of many small sensors that are small in size and can monitor physical and enviromental changes. The nodes are widely spread in the area of concern. They communicate with each other to share data or any other information. Foremost use of WSN was in battlefield during war. Since then it has been used in various applications in home and industries and at many other places. WSN are widely used nowadays due to its low cost, small size and low power consumption [1]. Low power consumption feature allows it have a longer battery life.

There are a wide range of appilcations of WSNs which are increasing day by day. Key ones include:

1. **Home Automation:** For management of lighting, security, entertainment systems from anywhere in home.

2. **Industrial Automation:** For monitoring health of machines, waste water manage-

ment, Data logging and status of civil structures can be monitored.

3. **Environmental Sensing:** For air pollution, forest fire, landslide and water quality monitoring.

4. **Health Care Monitoring:** Ill patents can be monitor directly from home. Here sensors are implanted in body which collect overall body activity data.

Of all WPANs (Wireless Personal Area Network), Zigbee is perhaps the most simpler and of very low cost as compared to other WPANs like Bluetooth. Zigbee is based on IEEE 802.15.4 standards. IEEE 802.15.4 defines MAC and PHY layer of OSI model [2]. In WSN out of all nodes one or more nodes will serve as Sink and the rest will serve as reporter node. Sink node have the capability to communicate with other networks. Its has two topology: Star and Mesh. Mesh topology allows high reliability and longer range.

1.2 Motivation

Compared to wired networks wireless networks provides advantage of ease of deployment, size, and distributed intelligence. Zigbee is comparatively newly developed standard for WPAN having unique feature of low cost, low power and supports communications between large numbers of devices (sensors). Due to low power consumpion it has longer lifetime. Also it has varied applications in almost all fields.

1.3 Objective

The objective of the project is to do performance enhancement of Zigbee. First the performance evaluation of standard Zigbee is carrired out where different performance matrics such as packet delivery ratio, residual energy, latency will be analyzed. After performance evaluation performance enhancement is to be done with the help of Fuzzy Logic(FL) and comparision will be done between fuzzy based Zigbee (FZBE), ADAPT and standard Zigbee (SZBE).

1.4 Appraoch

In order to achieve our objective, we approached the project by studying:

1. Wireless Sensor network and Zigbee Protocol.
2. Network Simulator NS2
3. Performance analysis of Zigbee using NS2
4. Studying Fuzzy Logic
5. Implementing fuzzy logic in Zigbee stack.
6. Comparison with other standards.

1.5 Scope

This work has scope in mainly two layers: Phyical and MAC layer. In physical layer it is defines the services such as activation deactivation of radio transmitter, energy detection and channel frequency selection that physical devices have to perform for transmission to occur. In MAC layer it performs functions such as generation and syncronization of beacons, providing channel access scheme such as CSMA/CA so as to provide reliable link between two peer MAC entities.

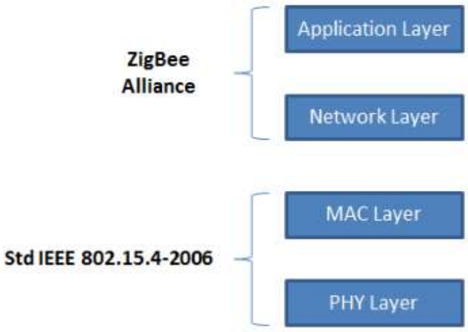

Figure 1.1: Scope of work

1.6 Thesis Organization

Chapter:2 gives the Literature Survey of the project.

Chapter:3 deals with study of Zigbee and IEEE 802.15.4.

Chapter:4 deals with the introduction of NS2, its installation steps and its tools.

Chapter:5 gives brief introduction of fuzzy logic.

Chapter:6 deals with performance enhancement of ZigBee with help fuzzy logic.

Chapter:7 gives the conclusion and future scope of the work carried out.

Chapter 2

Literature Survey

There exist a lot of literature related to Zigbee and Fuzzy logic. This chapter briefly describes related studies. Zheng and Lee in [1] develoed NS2 simulator for IEEE 802.15.4 and conducted experiments to find paramters like association efficiency, delay performance, collisions, etc. Lu. et in [3] extended work in [2] and found other parameters like throughput and energy efficiency of IEEE 802.15.4. WSN are expected to work for longer time and hence power consumption is the major issue. Also reliability of network is must under all operating conditions.

In [7] ADaptive Access Parameter Tuning (ADAPT) algorithm is proposed with network requirements under all operating conditions. In this paper both single hop and multihop scenario has been analysed. Algorithm goes this way. First delivery ratio is estimated. If it is less than lower threshold for delivery ratio then macminBE is increased by 1 and if it is higher than upper threshold then macminBE is decremented by 1. A constant 80% delivery ratio is meet under all operating conditions.

As mentioned in [8] CAP uses CSMA/CA algorithm. Back off period is generally small. So when network load increases probability of node choosing same number of back off period increases. Thus chances of collisions also increases. In [9] an energy efficient back off algorithm has been proposed which vary size of window based on collisions detected by node. Here backoff period is split in two sub back off period called temporary back off (TB) and next temporary back off (NTB). Thus node chooses TB and NTB instead of BE which is 10 to 50 % of actual delay. Thus one more random number has been introduced and hence probility of selecting same random number decreases and performance gets improved.

There are limitations of CSMA/CA algorithm too. It is contension based approach and hence there is no efficient use of bandwidth. Author in work [10] proposes an appraoch that makes efficent use of bandwidth by adjusting contension window (CW) and back off exponent (BE) based on fuzzy logic based on measured throughput and work load. CW can occupy 1 or 2 time slot. Here BE can vary from 1 to 2. Value to of CW and BE are set based on network load and throughput of node.

Ad hoc On Demand Vector(AODV) routing protocol is not optimum path finding algorithm. It selects first but not the best path. When network load is high then network performace is low and it consumes more bandwidth [11]. In [12] a new algorithm is developed based on fuzzy to mitigate drawback of AODV called Fuzzy Energy based AODV (FEAODV) with decides probability of route selection. First RREQ packet is send for route discovery from source to destination. After receiving RREQ destination sends ACK packet back and measure hop count, bandwidth and battery life of each route. This parameters are given as input to Fuzzy Inference System(FIS). After defuzzification output gives priority of each route based on rule base. Route with highest priority is selected.

[12] deals with unicast routing while in [13] Fuzzy based Multicast Algorithm Routing (FMAR) is proposed. Need to establish multiple paths is solve problems of sudden break in route. In this paper one source sends RREQ to 2 destination nodes. Receiver reply with ACK packet and hop count is measured. Fuzzy rule are based on number of hop counts, number of controlled packets and energy of node of system output is network lifetime. Route having highest network lifetime is selected. Other possible route are kept in routing table as second route.

Chapter 3

Zigbee and IEEE 802.15.4

3.1 Zigbee Overview

Zigbee origins its name from honeybee. Honeybee generally lives in hives. whenever any bee find food is communicates to other bees the location and distance by dancing in zig-zag pattern. From this method of sharing of information Zigbee name is originated [16]. Zigbee development began in 1998 when many engineers felt that in many application Bluetooth and WiFi would be unsuitable. Zigbee Allliance is the organization defining standards for low rate reliable communication. Requirement for network infrastructure for WSN applications is provided by Zigbee.

Zigbee can connect upto 65535 devices. Transmission range is between 10-100 meters. It has three operational bands: 868 Mhz, 915 Mhz and 2.4 Ghz. Since of extreme low power consumption it is used in varied application. Physical and MAC layers are defined by IEEE 802.15.4 whereas network and application layers are defined by Zigbee[2]. This section briefly introduces ZigBee and IEEE 802.15.4 standards and their features relevant for the subsequent discussion in the thesis.

Wireless Sensor built from Zigbee has some unique characteristics as mentioned below:

1. They are data centric.
2. They are deployed to perform specific task only.

3. Nodes are prone to error.
4. Physically they are small in size and battery powered.

3.1.1 Application of Zigbee

1. Home appliances and consumer electronics.
2. Destop PCs and entertainment systems.
3. Remote control for audio and video equipments.
4. Video gaming, X-box games.
5. Multimedia toys.

3.1.2 Device types

There are of three types:
1. PAN coordinator
2. Full Functional Device (Router)
3. Reduced Fucntion Device (End Device)

1. **PAN Coordinator:**

   There is only one PAN coordinator in any network. It requires maximum memory and computing power. It maintains overall network information.

2. **Full Function Device(FFD):**

   It has capability to become coordinator is provided with extra computational power. It can work in any topology. Also it can communicate with any devices (FFD/RFD). They are also called router.

3. **Reduced Function Device(RFD):**

   It cannot become coordinator in any condition. They can communicate only with FFDs. They are also called end device.

3.1.3 Topology

Zigbee supports two topologies:

1. Star Topology

2. Peer-to-Peer(Mesh) Topology

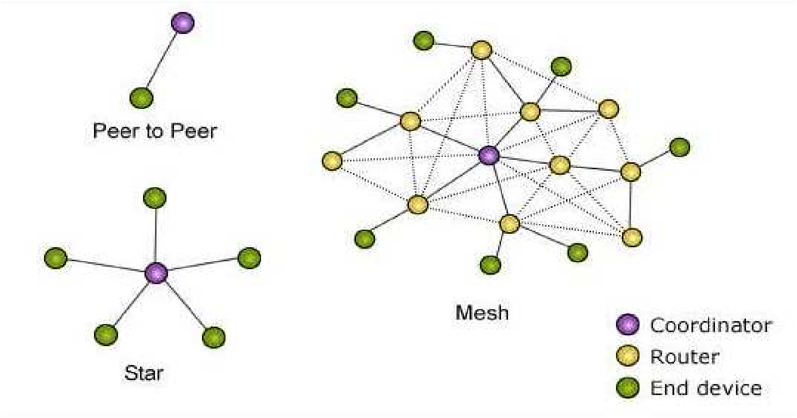

Figure 3.1: Zigbee topology

1. **Star Topology:**

   In these topology all the connections are established between devices and PAN coordinator only. Beacons are used to syncronize every device with coordinator. There is single hop of route of messages. Latency is very less in this topology. But are generally small scale. Mainly this topology is used for home automation.

2. **Peer-to-Peer Topology:**

   This topology allows multiple hops to route message from one device to other other.

Unlike star, here any device can communicate with any other device within its range. Easy to extend network with this topology. Need routing table for storing path information.

3.2 IEEE 802.15.4 standard

IEEE 802.15.4 is standard used for personal are network. It defines MAC and PHY sublayer for wireless connectivity. This standard provides low power, low complexity connecitvity and hence it is suitable for WSN applications. It supports two topology: Star and Peer to Peer as explained in section 3.1.3 It uses CSMA/CA mechanism. It is contension based standard. It has three operational bands: 868-868.6 MHz, 902-928 MHz and 2.4-2.48 GHz [13].

Layered architecture of IEEE 802.15.4 is shown in Figure 3.2. It defines MAC and PHY sublayer for wireless connectivity. RF transreceivers are present in PHY layer. PHY enables transmission and reception of data packets, energy detection, channel selection. MAC layer provides access to PHY layer for data transfer. Other features of MAC is beacon management, security, frame validation, GTS frame management. Upper layers include

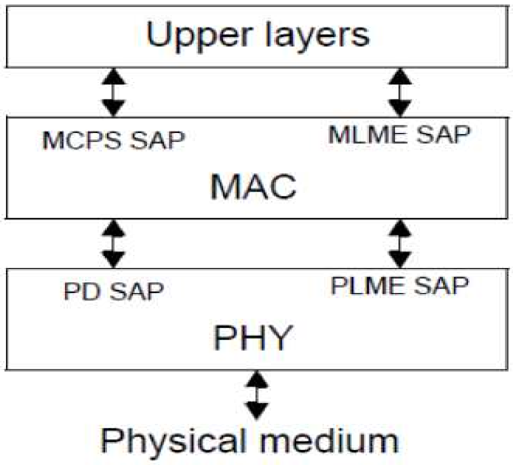

Figure 3.2: IEEE 802.15.4 architecture

network and application from OSI model. Routing mechanism and nework configuration are provided by network layer and application provides specific sevices for which device is intended to work upon [7].

3.2.1 IEEE 802.15.4 superframe

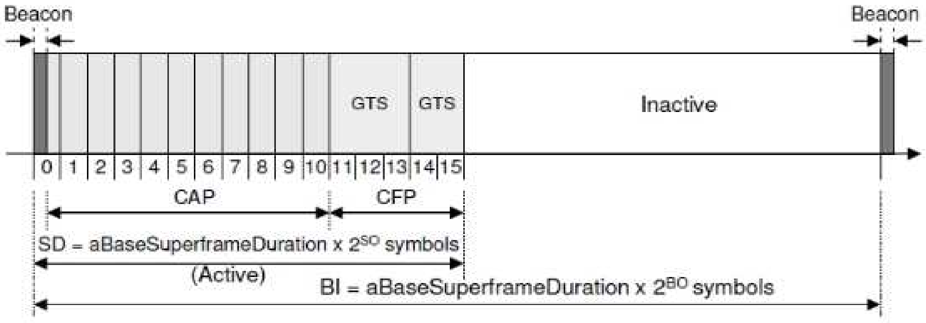

Figure 3.3: Superframe struture

Superframe structure of IEEE 802.15.4 is shown Figure 3.3. It consists of active and inactive part. Entire frame duration is called beacon interval and active part is called superframe duration.

BI = aBaseSuperframeDuration_2^{BO} [2]

SD = aBaseSuperframeDuration_2^{SO} [2]

where,

aBaseSuperframeDuration= 960 symbols;

BO = beacon order; SO = superframe order

In beacon enabled mode beacons are transmitted first before superframe. Beacons are present at the start and end of frame. In non beacon enabled mode beacons are turned off. Beacons contains all the information of superframe. As shown in Figure 3.3, active period can further be divided in two periods:

1. Contention Access Period(CAP)
2. Contention Free Period(CFP)

Time between two beacons is called Contension Access Period (CAP). For low power application coordinator eneters inactive or sleep period to save power. For some specific application which requires fast data transfer PAN coordinator dedicates a portion of its active frame for that application called Gauranteed Frame Slots (GTS). All GTS together forms CFP. Atmost 7 GTS are persent. All contention based transactions should be completed in CAP only. Whereas all transaction using GTS are done in CFP. IEEE 802.15.4 supports both beaon enbaled and non beacon enabled mode. In beacon enabled mode slotted CSMA/CA is used wheres non beacon enables uses unslotted CSMA/CA mechanism.

3.3 CSMA-CA algorithm

Step:1

Initialize contension window size (CW=2); Number of back-off (NB=0); Backoff exponent (BE=2).

Step:2

Locate boundary of back-off. Back-off is started at the end of CAP.

Step:3

When back-off is expired it senses channel and detect whether it is idle or busy.

Step:4

If channel status is busy then increment BE by 1 and CW reinitialized to 2. If maximim number of back-off is reached then Step:2 is repeated.

Step:5

If channel is found idle then CW is decremented.

Step:6

Process ends when CW=0.

Chapter 4

Network Simulator NS-2

4.1 Introduction

Network Simulator abbreviated as NS-2 is a discrete event simulator where each event occurs at an instant of time. It is used to simulate various network souting protocols. It can be used for simulation of both wired and wireless scenario. It is a open source so modification can easily be done as per user requirement. It is written in C++ language and has OTCL interpreter [18].

4.2 Tools of NS-2

There are different tools useful for performance evaluation of NS-2.

4.2.1 TCL File

TCL (Tool Command Language) file is front end in NS-2 simulator. Using TCL file we can simulate our simulation. After running TCL file it will automatically create the trace and nam file. All the required paramters are set in TCL script by writting commands.
To run TCL file we type in terminal: **ns filename.tcl**
Following steps describes functions of TCL script:

Step:1

```
set ns_      [new Simulator]
```

Creates simulator for required simulator.

Step:2

```
set tracefd      [open ./adaptso40.tr w]
$ns_ trace-all $tracefd
```

Creates trace file for simulator.

Step:3

```
set topo      [new Topography]
```

Creates topology which keeps track of number of nodes and their positions.

Step:4

```
$topo load_flatgrid $val(x) $val(y)
```

Topology is defined by grid on X and Y axis. Initially grid is 1 and then different values are passed.

Step:5

```
set god_ [create-god $val(nn)]
```

God (General Operations Director) stores global information about the state of the environment, network or nodes of simulator.

Step:6

```
$ns_ node-config -adhocRouting $val(rp)
-llType $val(ll)
-macType $val(mac)
-ifqType $val(ifq)
-ifqLen $val(ifqlen)
-antType $val(ant)
-propType $val(prop)
-phyType $val(netif)
-topoInstance $topo
-agentTrace OFF
```

-routerTrace OFF

-macTrace ON

-movementTrace OFF

-energyModel ”EnergyModel”

-initialEnergy 18400

-rxPower 0.3

-txPower 2.0

-channel $chan_1_

Before creation of any node node is configured by all general paramters.

Step:7

In mobile network nodes are in motion. But in our topology nodes are static and random variable is set as 0.

Step:8

$node_(0) set X_ 25.0

$node_(0) set Y_ 25.0

$node_(0) set Z_ 0.0

Defines X,Y and Z coordinates of nodes which defines its position in network.

Step:9

set cbr_($src) [new Application/Traffic/CBR]

Defines the type of traffic between source and destination. Here we have selected cbr traffic. *Step:10*

$ns_ at $stopTime ”stop”

$ns_ at $stopTime ”puts ”NS EXITING..” $ns_ at $stopTime ”$ns_ halt”

Defines the stop time of simulation.

Step:11

puts ”Starting Simulation...”

$ns_ run

After all setup simulator is started.

4.2.2 NAM File

NAM is the abbreviation of Network Animator. It gives visual output of the tcl script. It shows how nodes are arranged in scenario. NAM gives output for both wired and wireless scenarios. One could also visualise packet drop and traffic flow from NAM window.

4.2.3 Trace File

Trace file is a sort of output file for which tcl script is written. Its name is same as the one mentioned in tcl script. Trace file is generated in the same folder in which tcl file is present. Here entire data information is stored column wise. Different signs and symbols indicate different functions. Below example shows detail explanation of a typial trace line in Table 4.1.

s 22.005 _1_ MAC — 1 CBR 80 [0 ffffffff 0 80] [energy 99.828607 ei 0.000 es 0.000 et 0.004 er 0.167] —— [0:255 -1:255 40 1] [0x2 1 3 [1 0] [0 5]] (RREQ)

Table 4.1: Trace explanation

Symbol	**Function**
s	packet is send
22.05	time instant
_1_	node id
MAC	protocol used
- - -	Flags
1	packet sequence number
CBR	type of packet
80	packet size
energy 99.828607	initial energy
et 0.004	transmission energy
er 0.167	reception energy
ei 0.000	energy in idle mode
es 0.000	energy in sleep mode
RREQ	Route Request packet

4.2.4 AWK File

AWK derives its name from ’Aho, Weinberger & Kernighan’ who are considered to be its author [18]. It is considered to be text processing language. It is similar to C for doing mathematical operation but its syntax are different from C. AWK file should be saved in the same folder in which trace file is present. In our project we have used AWK to read trace file. Trace file are actually very long ranging from thousands to lakhs of line hence it is practically very difficult to read this file manually. Thus to find parameters from trace file suitable awk scripts are writtten.

To run awk scripts following command is written in terminal:

```
awk -f filename.awk filename.tr
```

AWK file should be saved in the same folder in which trace file is present.

4.2.5 GNU Plot

GNU plot is the command driven plotting tool. Both 2d and 3d plots can be plotted with help of this tool. It supports Linux/Unix, Mac, Windows all platforms. It is saved in file having ”.txt” extension. This tools enables user to specify format of output plot. If input data is lengthy then data is saved in the form of log file.

Following commands are written in terminal to install GNUplot in Ubuntu:

1. cd Destination file
2. cd gnuplot-4.2.4
3. ./configure
4. make
5. make install

Chapter 5

FIS for performance enhancement of Zigbee

5.1 Introduction to Fuzzy

Lotfi Zadeh first introduced the concept of Fuzzy logic while he was working on the problem of computing of natural language [15]. He suggested that natural language cannot be translated in absolute value. Japanese first utilize concept of fuzzy pratically. They introduced fuzzy logic in high speed train in Sendai. Boolean logic is eiher O or 1 i.e either true or false. Whereas fuzzy logic is based on degree of truth. It includes all the values between 0 and 1. It also includes 0 and 1 i.e true and false but as exteme cases. Comparison between height of two person may not be just tall o short but it can be 0.4 of tallness and so on. Nowadays Fuzzy logic has found its applicaion in almost all fields from simple small microcontrollers to large embedded and control systems. FL helps in decision making to arrive at any conclusion. Figure 5.1 shows basic building of fuzzy logic block. Rule base for fuzzy logic is based on user's experience.

Example: FL for Washing Machine

IF(clothes too dirty) & (large amount of clothes) THEN (add more detergent)

IF(clothes less dirty) & (less amount of clothes) THEN (add less detergent)

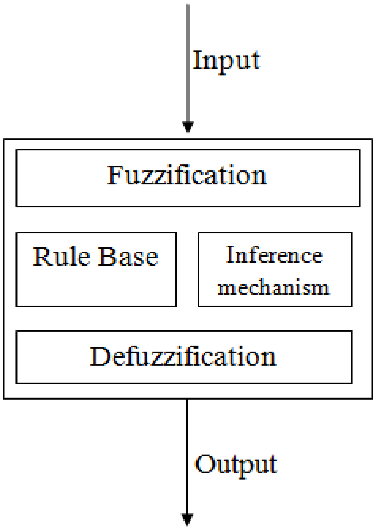

Figure 5.1: Basic building block of Fuzzy logic

1. **FIS editor:** It displays general information of the system. It decides number of input and output. There is no limit on this number. Four system we have selected 4 inputs and 6 outputs.
2. **Membership Function Editor:** It can edit and add number fo membership function for each input and output paramter. For our system we have selected 3 membership fuction for all inputs and 9 membership functions for all outputs Also the shape of membership function can also be decided through this editor. We have used triangular and trapezodial shape of membership function for our system.
3. **Rule Editor** It lets user to edit and add rules according to behaviour of system. Rules are generated by connecting inputs through AND, OR & NOT logic. We have designed 81 rules for our system using AND & OR logic.
4. **Rule Viewer:** It is the graphical representaion of rule base.
5. **Surface Viewer:** Graphical representaion of one output is related to other other outputs.

5.1.1 Fuzzy Toolbox

Fuzzy toolbox is present in MATLAB. By wrtting **fuzzy** in command window of Matlab fuzzy toolbox appears. It provides functions and blocks for analysing fuzzy logic systems. It lets user to built simple rules for large complicate system. Rules base supports AND, OR & NOT logic. Two types of Fuzzy Inference System:

1. Sugeno
2. Standard Mamdani

For our application we have used standard Mamdani fuzzy inference system.

5.2 Step by step approach of Fuzzy Logic

The process of using fuzzy logic to map input to output is called Fuzzy inference. This process involves deciding MF, its curve and preparing rulebase. Here rules are prepared based on human logic and decision are made according to ouput value. Rules are prepared on If-then condition [15]. This section describes the fuzzy inference process and uses 4-input, 6-output, 81-rule tipping problem.
5 steps of FIS:

5.2.1 Fuzzification of the input variables:

Deciding number of inputs and ouputs is the very first step. In any FIS input is crisp numerical value whose range can be set according to the input parameter. Whereas ouput value of parameter is always in between 0 and 1 according to degree to MF and rule evaluation.

5.2.1.1 Input paramters of FIS

1. **Residual Energy:** It refers to the amount of energy left in a particular node at some specific time.

2. **Data Delivery Ratio x Channel Assessment Ratio (represented by DDR x CAR):** DDR is a measure of link quality and collisions and CCR provides a measure of contention mainly in CSMA based protocols. When the product of CAR and DDR is high, the data link layer should decrease the back off time and increase the duty cycle of the radio board. When product is low, the back off time and the retransmission time should be increased and duty cycle should be decreased.

3. **Packet dispatch rate (represented by PDR):** A low value of PDR marks the nodes buffer occupancy is high and cannot accommodate more relay packets. Chance of the node to become relay node should be decreased when PDR is low.

4. **Sensitivity:** It refers to the ratio of successfully triggered events to total occurred events. Sensitivity = Successfully triggered events/ Total occurred events

5.2.1.2 Output paramters of FIS

1. **Tx Power:** It refers to the amount of power transmitted by a particular node.

2. **RTx Time Out:** It occurs when acknowledgement does not arrive on time or does not arrive at all. Usually, it is not a fixed value but changes to gain better network performance.

3. **Back Off Time:** A host which has experienced collision on a network waits for a certain time period before attempting to retransmit and that time period is called Back-off time.

4. **Relay Nodes:** It refers to all the client nodes excluding the base station node.

5. **Report Nodes:** It refers to all the nodes which can work as base stations.

6. **Duty Cycle:** It is a measure of amount of time channel is active in entire duration.

5.2.2 Defining membership functions

MF is generally graphical represantaion of mapping every point in input to a value in range 0 & 1. Here shape of curve is user defined. User selects simplest fuction for shape of curve. There are 11 Mfs types in fuzzy toolbox. Most common are: piecewise linear functions, the Gaussian distribution function, the sigmoid curve and quadratic and cubic polynomial curves.

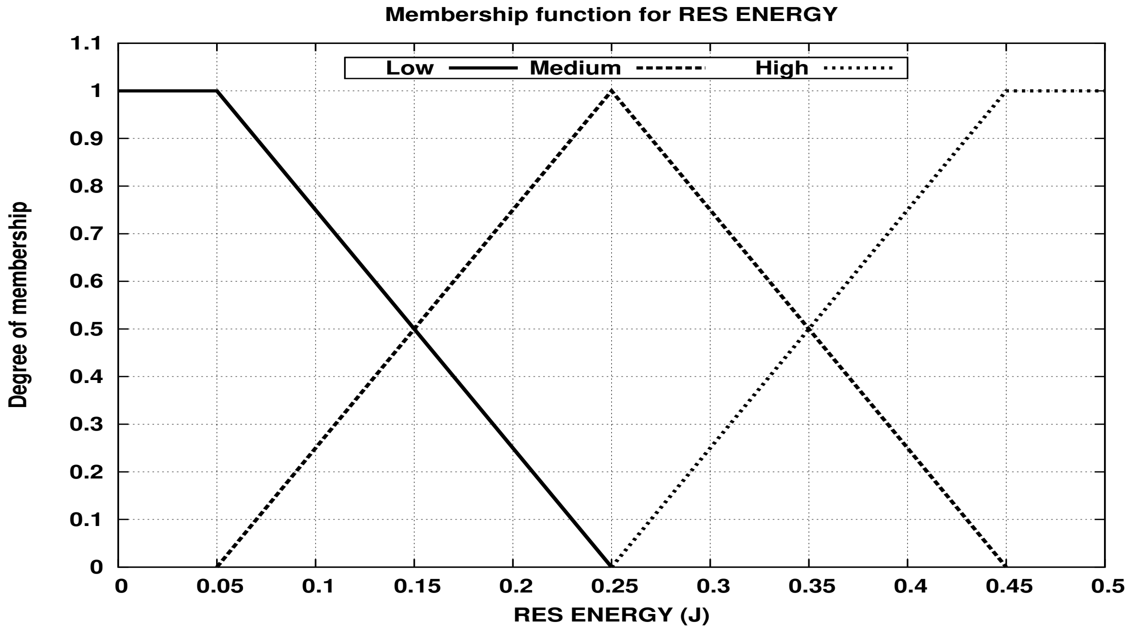

Figure 5.2: Membership function plot of residual energy

5.2.3 Rule evaluation

Main logic for any system is defined in fuzzy rule. RUles are derived based on observation and logic. Rules consists of series of if-then statements. Fuzzy logic comprises of the form of conditional statements. A fuzzy rule is commonly of form -

if m is S then n is T

where S and T are linguistic value. If part i.e. ”m is S” is called antecedent & then part i.e. ”n is T” is called consequent. FL rule base for current work is shown in Table 5.1.

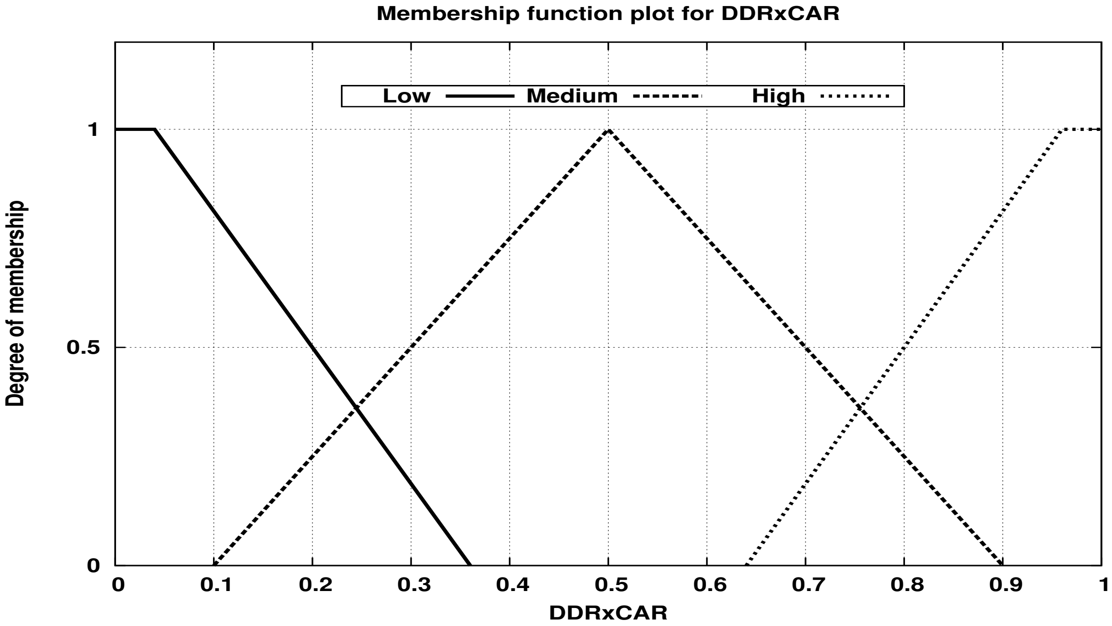

Figure 5.3: Membership function plot of DDRxCAR

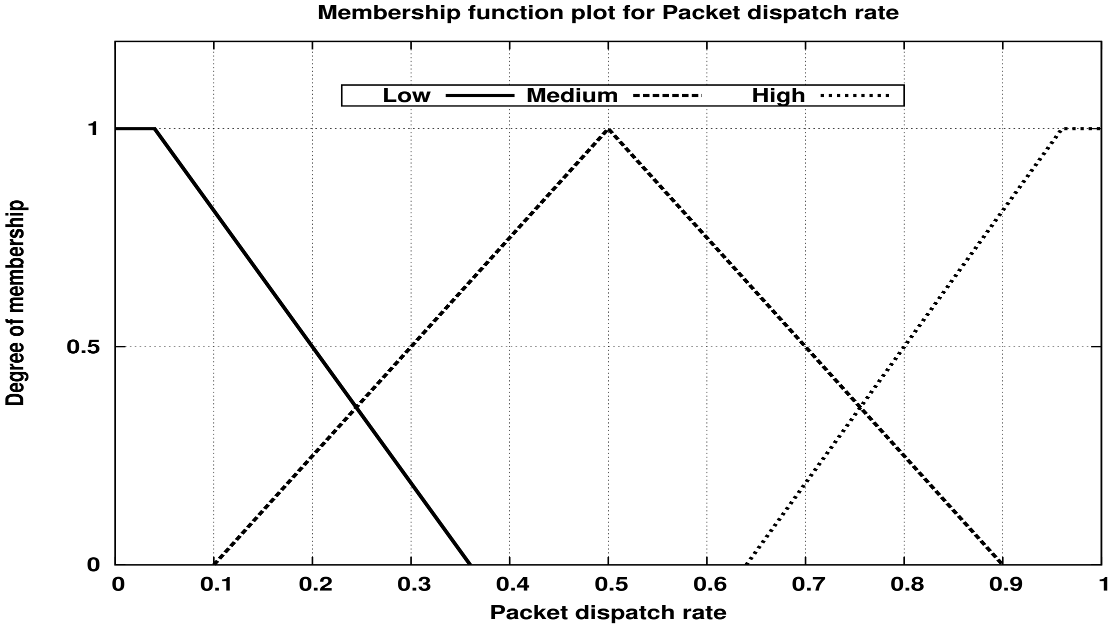

Figure 5.4: Membership function plot of packet dispatch rate

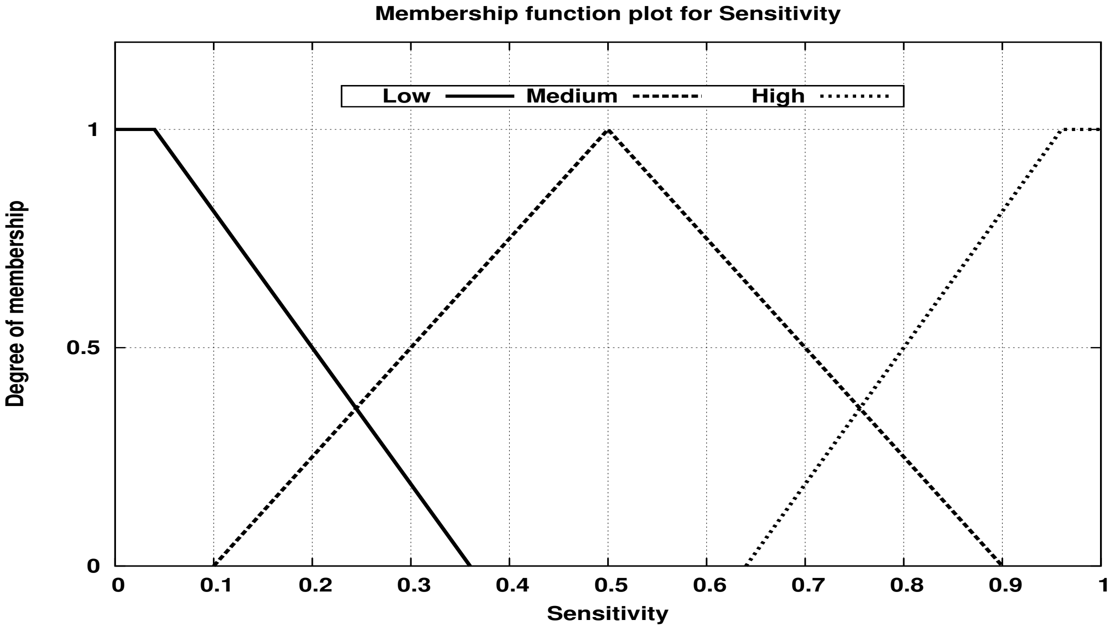

Figure 5.5: Membership function plot of sensitivity

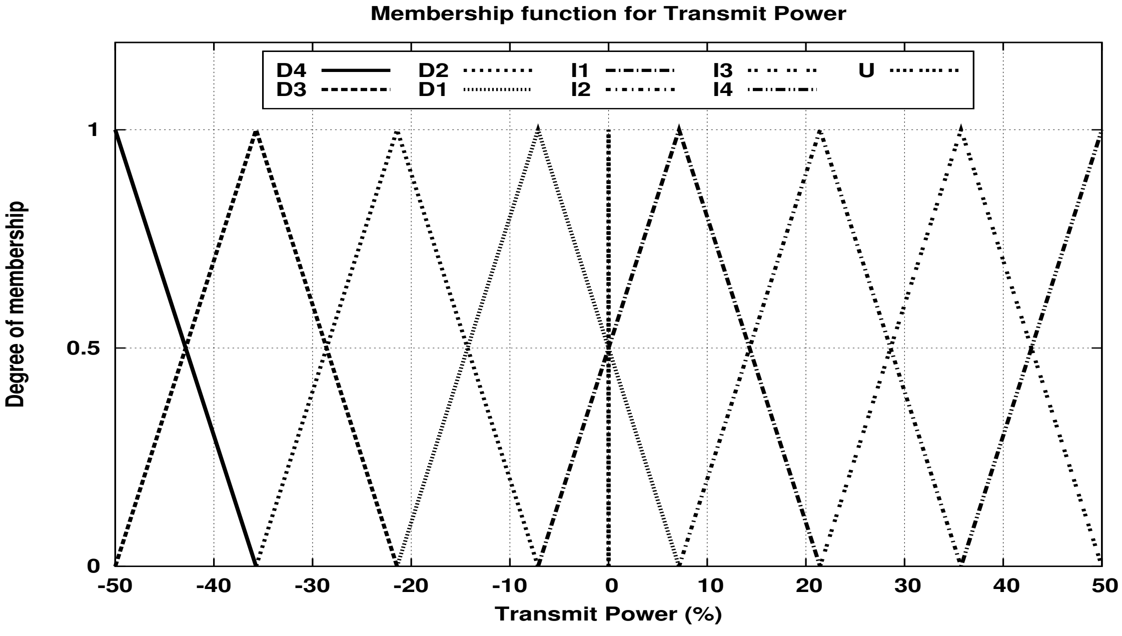

Figure 5.6: Membership function plot of transmit power

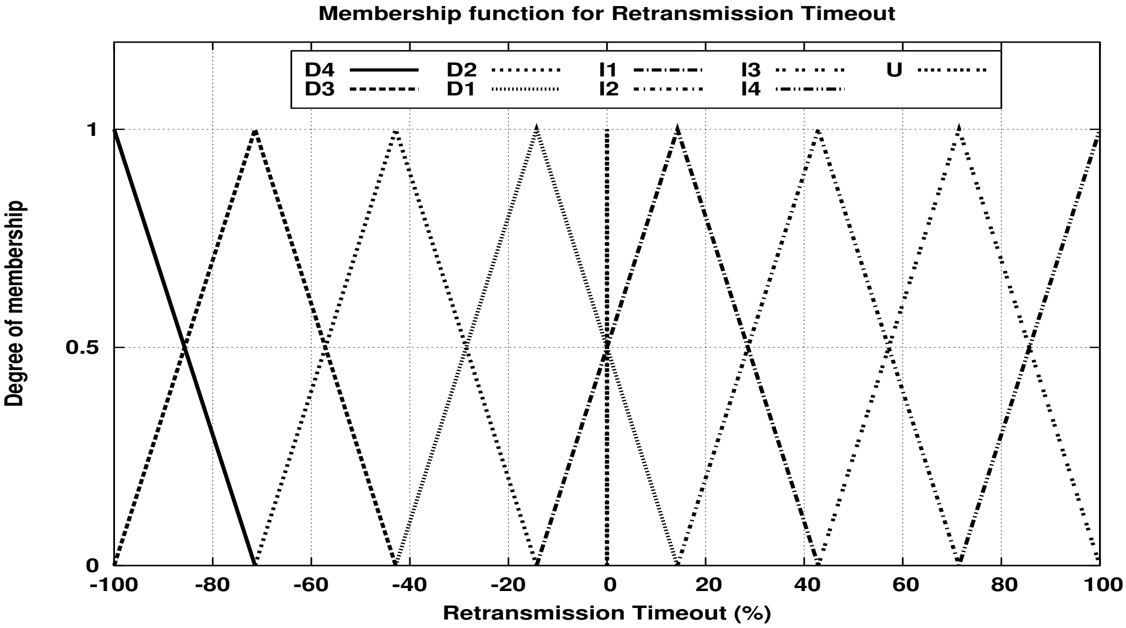

Figure 5.7: Membership function plot of retransmission timout

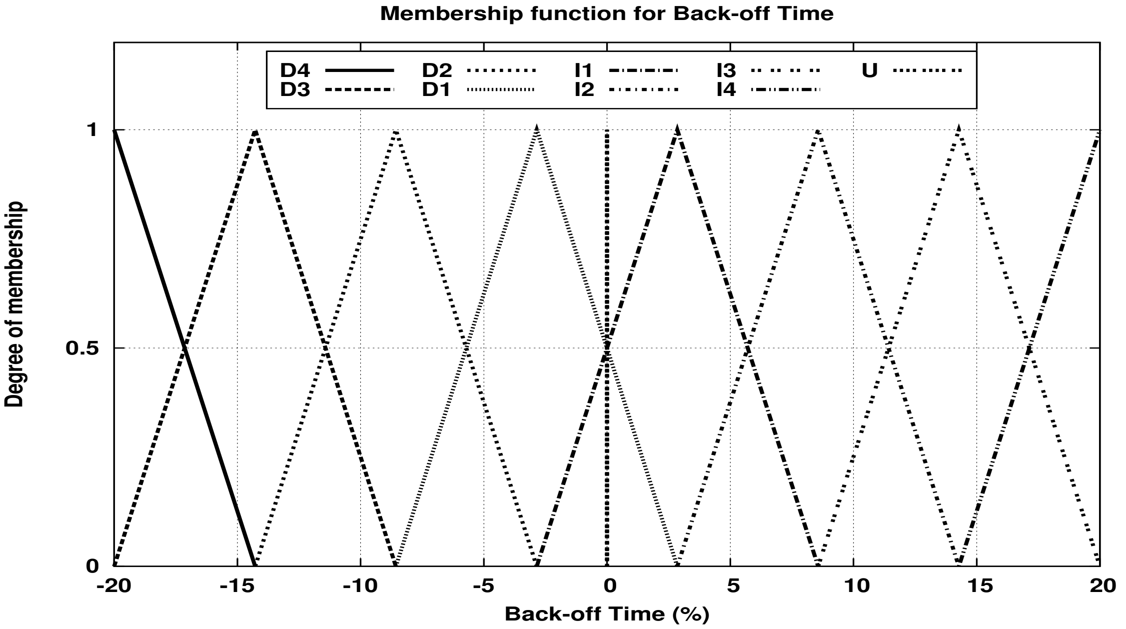

Figure 5.8: Membership function plot of backoff time

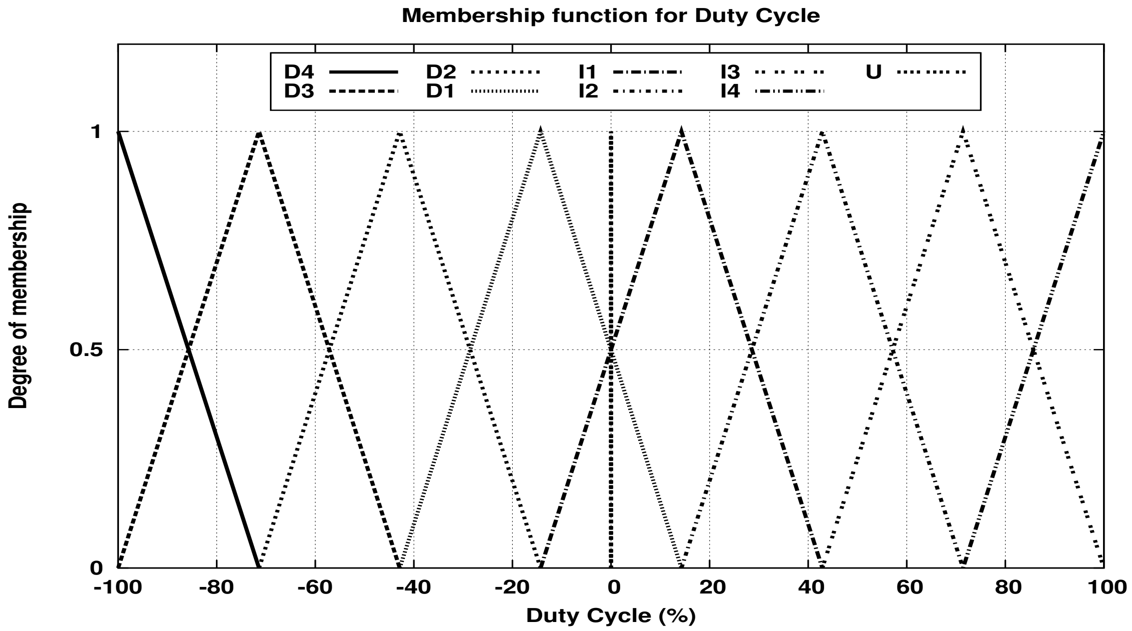

Figure 5.9: Membership function plot of duty cycle

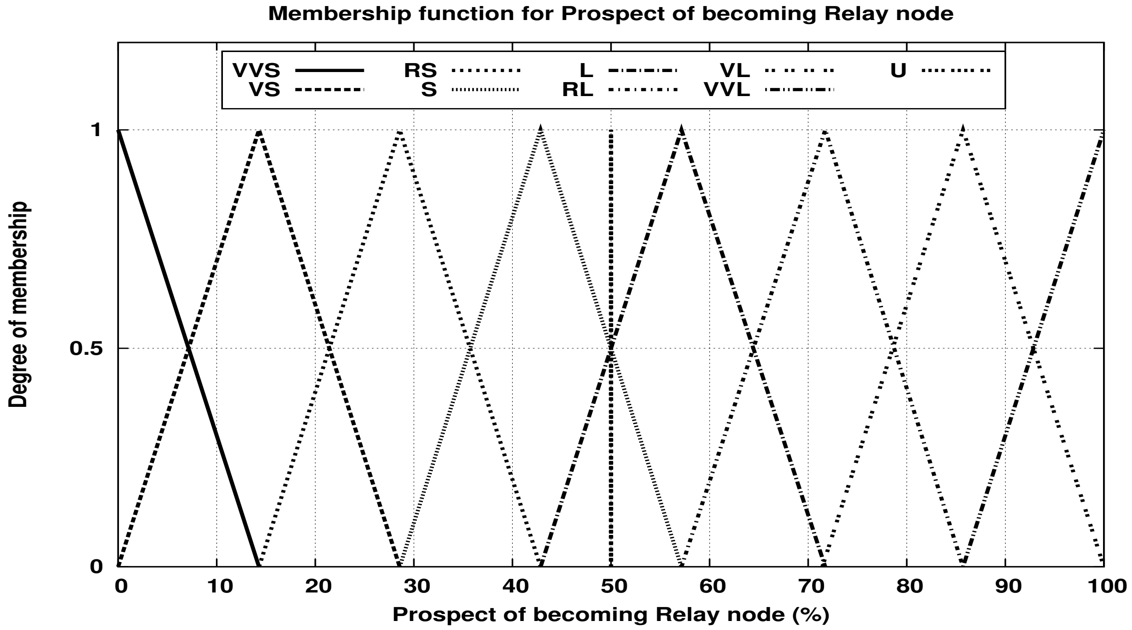

Figure 5.10: Membership function plot of prospect of becoming relay node

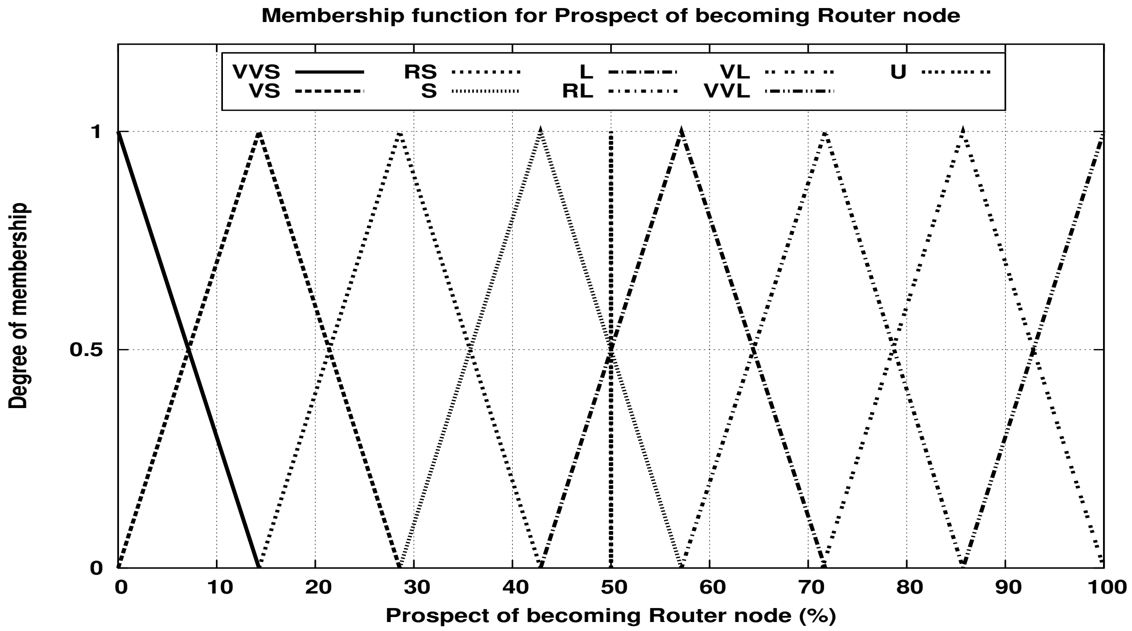

Figure 5.11: Membership function plot of prospect of becoming router node

5.2.4 Aggregate all outputs

Input to aggregation process is the output from implication process returned from each fuzzy rule. It gives single output for each fuzzy set. Each fuzzy is assigned to one output value. They are combined together to form one fuzzy set using fuzzy aggregation operator. Aggregation operators commonly used are:

1. **Maximum:** point-wise maximum over all of the fuzzy sets
2. **Sum:** point-wise sum over all of the fuzzy
3. **Probabilistic sum**

5.2.5 Defuzzification

Aggregate ouput is the input for defuzzification process. Its output is the single number. In intermediate steps according to rule evaluation desired output is fuzzified. But aggregation

of fuzzy sets provides a laerge number of output values so defuzzification is used to get a single value output.
5 methods of Defuzzification: centroid, bisector, middle of maximum, largest of maximum, and smallest of maximum. For this work, centroid method is used. In the centroid method, the crisp value of the output variable is computed by finding the variable value of the centre of gravity of the membership function for the fuzzy value.

Table 5.1: Fuzzy rule base

L=Low, M=Medium, H=High, D=Decrease, U=Unchanged,I=Increase, VVS= Very Very Small, VS= Very Small, RS=Rather Small, S= Small, L= Large, RL=Rather Large, VL = Very Large, VVL = Very Very Large										
	Antecedents				Consequents					
Layer	Physical	Data Link	Network	Application	Physical	Data Link			Network	Application
Rule	REN	DDRxCAR	PDR	SEN	TxP	RxT	BoT	DTC	PRE	PRP
1	L	L	L	L	I2	I3	I2	D3	VVS	VS
2	L	L	L	M	I2	I3	I2	D3	VVS	RS
3	L	L	L	H	I2	I2	I2	D1	VVS	S
4	L	L	M	L	I2	I2	I2	D3	VS	VVS
5	L	L	M	M	I2	I2	I2	D3	VS	VS
6	L	L	M	H	I2	I2	I4	I1	VS	S
7	L	L	H	L	I2	I3	I3	D4	RS	VVS
8	L	L	H	M	I1	I2	I3	D3	VS	VS
9	L	L	H	H	I1	I1	I4	D1	VS	S
10	L	M	L	L	D1	D1	D1	D1	RS	RS
11	L	M	L	M	D2	D1	D1	I2	VVS	S
12	L	M	L	H	D2	D1	D1	I2	VVS	S
13	L	M	M	L	D1	D2	D2	D1	RS	VS
14	L	M	M	M	D2	D2	D2	I2	VS	RS
15	L	M	M	H	D2	D2	D2	I2	VS	S
16	L	M	H	L	D1	D2	D3	D2	S	VS
17	L	M	H	M	D2	D3	D2	I1	VS	RS
18	L	M	H	H	D3	D3	D1	I2	VS	S
19	L	H	L	L	D2	D3	D2	D1	RL	S
20	L	H	L	M	D2	D4	D2	I3	L	RL
21	L	H	L	H	D2	D4	D2	I3	L	VL
22	L	H	M	L	D2	D3	D3	D1	RL	S
23	L	H	M	M	D3	D4	D3	I2	L	VL
24	L	H	M	H	D3	D4	D3	I3	L	VVL
25	L	H	H	L	D3	D4	D4	D1	VL	S
26	L	H	H	M	D4	D4	D4	I1	RL	VL
27	L	H	H	H	D4	D4	D3	I2	L	VVL
28	M	L	L	L	I3	I4	I1	D1	RS	RS
29	M	L	L	M	I2	I3	I1	D1	VVS	S
30	M	L	L	H	I2	I2	I1	I3	VVS	S
31	M	L	M	L	I3	I4	I1	D2	RS	VS
32	M	L	M	M	I2	I3	I2	D1	VVS	RS
33	M	L	M	H	I2	I2	I2	I2	VVS	S
34	M	L	H	L	I2	I2	I1	D3	S	VS
35	M	L	H	M	I1	I2	I2	D1	VS	RS
36	M	L	H	H	I1	I2	I2	I1	VS	S
37	M	M	L	L	I2	I2	D1	I1	RL	RS
38	M	M	L	M	I1	I2	D1	I1	L	S
39	M	M	L	H	I2	I1	D1	I2	L	RL
40	M	M	M	L	I2	I2	D2	D1	RL	S

Rule	REN	DDRxCAR	PDR	SEN	TxP	RxT	BoT	PRE	DTC	PRP
41	M	M	M	M	U	U	U	U	U	U
42	M	M	M	H	I2	I1	D1	I3	L	VL
43	M	M	H	L	I1	I1	D2	D1	VL	S
44	M	M	H	M	U	U	U	I1	RL	L
45	M	M	H	H	I1	I1	RL	I1	RL	VL
46	M	H	L	L	I1	D1	VL	I2	VL	S
47	M	H	L	M	I1	D1	VL	I3	VL	RL
48	M	H	L	H	I1	D1	VL	I3	VL	VL
49	M	H	M	L	U	D1	VL	I1	VL	S
50	M	H	M	M	U	D1	VL	I2	VL	VL
51	M	H	M	H	U	D1	VL	I3	VL	VVL
52	M	H	H	L	U	D1	VVL	I1	VVL	S
53	M	H	H	M	U	D1	VL	I2	VL	VL
54	M	H	H	H	U	D1	VL	I3	VL	VVL
55	H	L	L	L	I4	I3	L	D1	L	S
56	H	L	L	M	I4	I4	L	I2	L	L
57	H	L	L	H	I4	I4	L	I3	L	VL
58	H	L	M	L	I4	I4	RL	D2	RL	S
59	H	L	M	M	I4	I4	RL	I1	RL	L
60	H	L	M	H	I4	I4	VL	I2	VL	VVL
61	H	L	H	L	I4	I4	VL	D3	VL	S
62	H	L	H	M	I4	I4	VL	I1	VL	RL
63	H	L	H	H	I4	I4	VL	I2	VL	VVL
64	H	M	L	L	I3	I2	L	I4	L	S
65	H	M	L	M	I3	I2	L	I4	L	RL
66	H	M	L	H	I3	I2	L	I4	L	RL
67	H	M	M	L	I2	I1	RL	I2	RL	S
68	H	M	M	M	I2	I1	RL	I3	RL	VL
69	H	M	M	H	I2	I1	RL	I3	RL	VL
70	H	M	H	L	I2	I1	VL	I1	VL	S
71	H	M	H	M	I2	I1	VL	I2	VL	VL
72	H	M	H	H	I2	I1	VL	I3	VL	VL
73	H	H	L	L	D3	D3	L	I4	L	S
74	H	H	L	M	D3	D3	L	I4	L	RL
75	H	H	L	H	D3	D3	L	I3	L	VL
76	H	H	M	L	D4	D4	RL	I2	RL	S
77	H	H	M	M	D4	D4	RL	I3	RL	VL
78	H	H	M	H	D4	D4	RL	I3	RL	VL
79	H	H	H	L	D4	D4	VVL	I1	VVL	S
80	H	H	H	M	D4	D4	VVL	I3	VVL	VL
81	H	H	H	H	D4	D4	VVL	I4	VVL	VVL

Chapter 6

Performance evaluation of FZBE

6.1 Simulation parameters

Simulations for performance evaluation of FUCR are carried out using Matlab (Mathworks documentation, 2014) (for implementation of FIS) and network simulator NS2 ver 2.34 (Network Simulator documentation, 2014) (for network setup and performance evaluation). ZigBees protocol stack (Zigbee documentation, 2014) in network simulator NS2 is extended to incorporate FZBE structure.

For all the simulations it is assumed that the IEEE 802.15.4 (IEEE standard 802.15.4 documentation, 2014) is operating with 2.4 GHz physical layer at a maximum bit rate of 250 kbps. The nodes initial energy is 10 J, transmission range is set to 15 m, and the carrier sensing range to 30 m as suggested in (Anastasi et al., 2011). Unless otherwise specified, it is assumed that there is no message loss due to channel errors, although simulations with message losses are also carried out to broadly evaluate performance of FZBE.

IEEE 802.15.4 is made to work in beaconed mode with *aBaseSuperframeDuration*=15.36 ms, BO=13, BI=125.82 s, SO=8, active period SD=3.93 s, duration of backoff period slots=320 s, *macMinBEmin*=1, *macMinBEmax*=7, *macMaxBE*=10, *macMaxCSMAbackoffsmin* =1, *macMaxCSMAbackoffsmax* = 10, *macMaxFRAMEretriesmax* = 3. The nodes send their messages just after receiving a beacon from the coordinator. Energy model based on Chipcon CC2420 radio (CC2420 documentation, 2014) is used in the simulations. The retransmission scheme is enabled, hence the destination node sends an acknowledgement on receiving a data frame. Fuzzy logic is run in each node after every 5 BIs to assist decisions for changes in the important parameters at different layers.

The FIS output variables TXP and RTO are used to vary transmit power (from decrease by 50% to increase by 50%) of the transceiver and retransmission timer (from decrease by 50% to increase by 50%) of the sender node. Variable BOT is used to vary BE (from decrease by 20% to increase by 20%), the current back-off exponent which in turn decides nodes back-off time. DTC is used to vary SO (from decrease by 100% to increase by 100%), the superframe order which decides SD superframe duration (active period in BI). TXP and RTO are varied from decrease by 50% to increase by 50% to ensure that each node can reach its immediate neighbor and also manage its latency. BOT is varied from decrease by 20% to increase by 20% because with too much decrease in BOT, the node will have to wait for more time for carrier sensing which in turn will increase its latency.

During the multihop scenario simulation, variables PRE and PRP are used to decide cluster co coordinator nodes and ordinary nodes. To evaluate the performance of FUCR, it is compared with Standard ZigBee (SZBE) and ADAPT (Mario et al. , 2011). For SZBE and ADAPT with Zigbee the default settings described in (Zigbee documentation, 2014) and (Mario et al. , 2011) are used. SZBE is intended to show performance of ZigBee without any tuning of parameters of protocols at different layers of ZigBee stack.

The next two subsections investigate performance of FZBE, SZBE and ADAPT with Zigbee for single-hop and multi-hop networks, respectively. In all the cases, twenty simulation runs (each lasting for 5 BIs) with different seeds were run for each scenario and average values of different metrics were accepted as results.

Table 6.1: Simulation parameters

Parameter	**Value**
Simulaton Time	100 seconds
Number of nodes	20
Simulation area	100m x 100 m
Carrier Sense Range	30m
Transmission Range	15m
Routing Protocol	AODV
Type of Traffic	CBR
Initial Energy	18400J
Beacon order	13
Superframe order	8
Packet size	128 bytes
Frequency	2.4 GHz
Data rate	250 kbps
MacMaxFrameRetries	3

6.2 Singlehop analysis

6.2.1 Simulation setup

As shown in Figure 6.1, a single-hop topology consisting of a star network with 20 nodes in a circle of 10 m radius and a PAN coordinator node at the center is created. The PAN coordinator acts as Master Station (MS) of WSN that collects sensed data from the ordinary nodes.

6.2.2 Performance as a function of nodes

The effect of number of nodes on the delivery ratio, energy consumption and latency is shown in Figure 6.2, 6.3 and 6.4 respectively. Figure 6.2 shows that performance of SZBE with default ZigBee and IEEE 802.15.4 parameters gives delivery ratio below 70% when there are 20 nodes. ADAPT tries to give the promised 80% delivery ratio. Delivery ratio of FZBE is between 83% to 92%. Figure 6.3 shows that FZBE is up to 12% energy efficient compared to ADAPT and as seen in in Figure 6.4 data latency of FZBE is up to

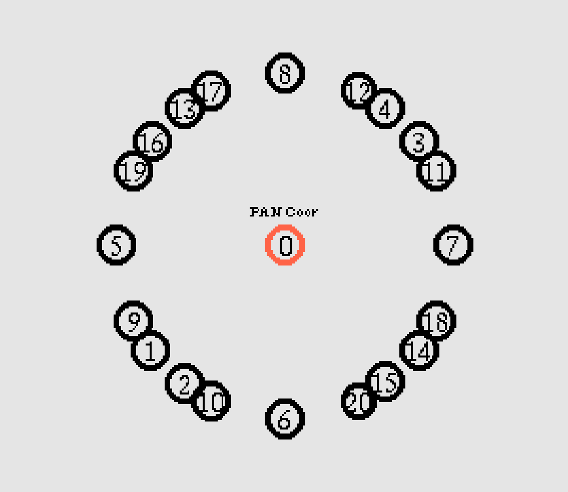

Figure 6.1: Simulation setup for single hop scenario

19% less for single hop network. The increase in delivery ratio and energy efficiency in FZBE is because nodes data link layer adjusts retransmission timer, back off time and duty cycle using fuzzy logic with input from physical (residual energy), data link (data delivery ratio, channel assessment ratio). This reduces number of collisions and hence the energy waste and packet loss arising due to it. Figure 6.5 shows that the number of collisions is least in the case of FZBE. This is because as the back off time of each node is FZBE is adjusted based on data delivery ratio, channel assessment ratio and residual energy there are very less chances of simultaneous transmissions (nodes picking the very same backoff period slot after sensing the channel clear).

6.2.3 Performance as a function of message generation rate

Next, performance as a function of message generation rate is shown in Figure 6.6, 6.7 and 6.8. As shown, in Figure 6.6, FZBE has up to 7% greater delivery ratio compared to ADAPT. The trend of energy consumption, depicted in Figure 6.7, looks a bit unusual, as it is seen that energy consumption decreases with message generation rate for all the architectures. This is because as message generation rate increases, total time spent by nodes for accessing the media increases as well. This decreases the contentions and collisions and

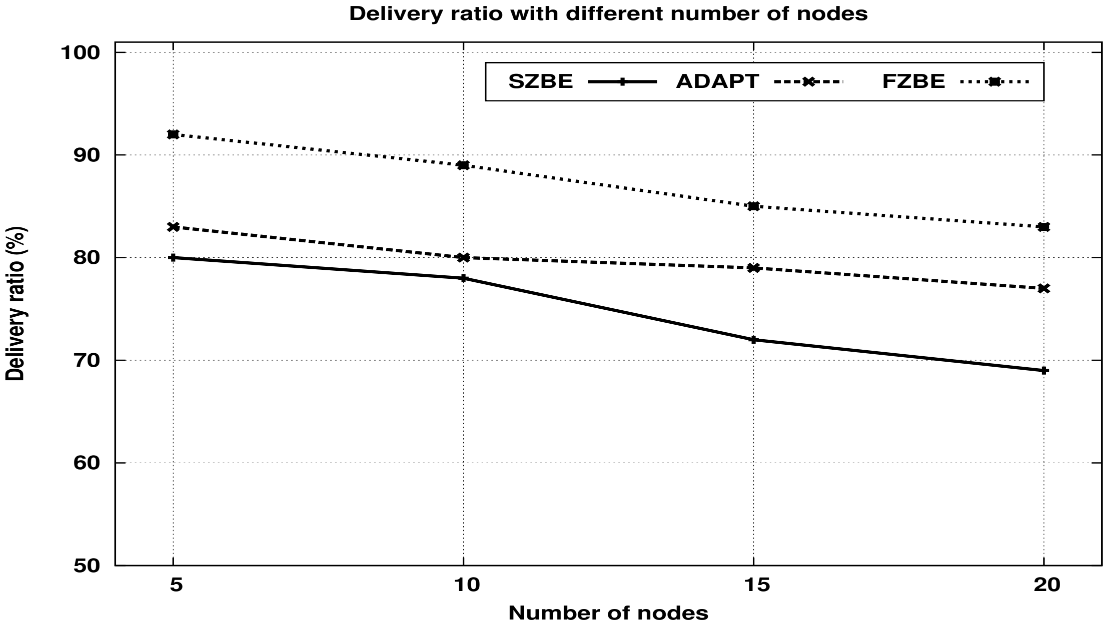

Figure 6.2: Delivery ratio as a function of number of nodes

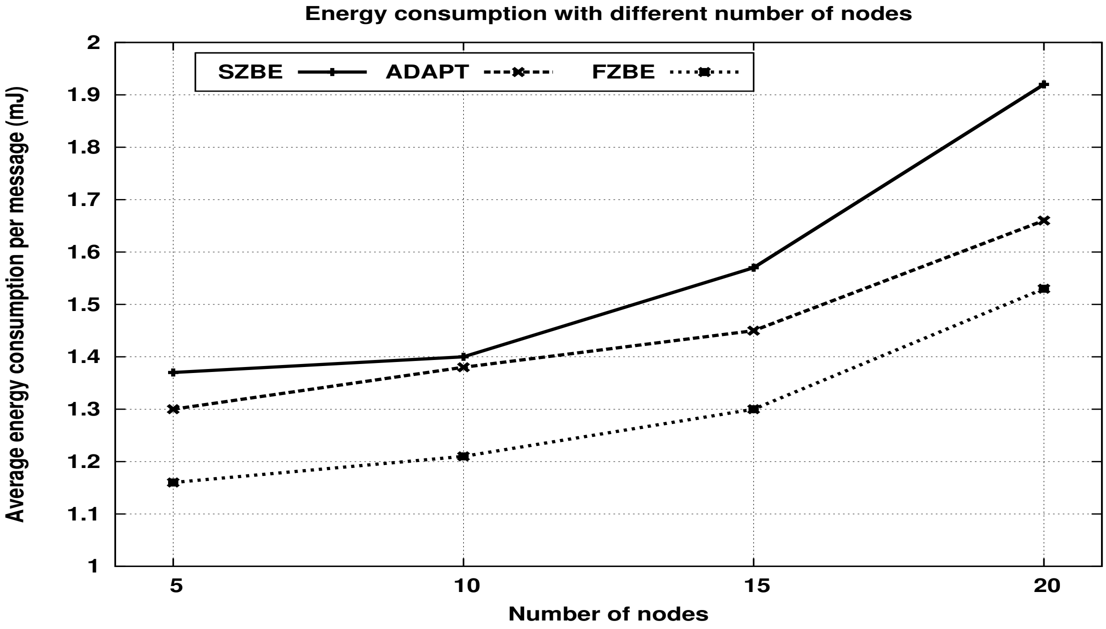

Figure 6.3: Energy consumption as a function of number of nodes

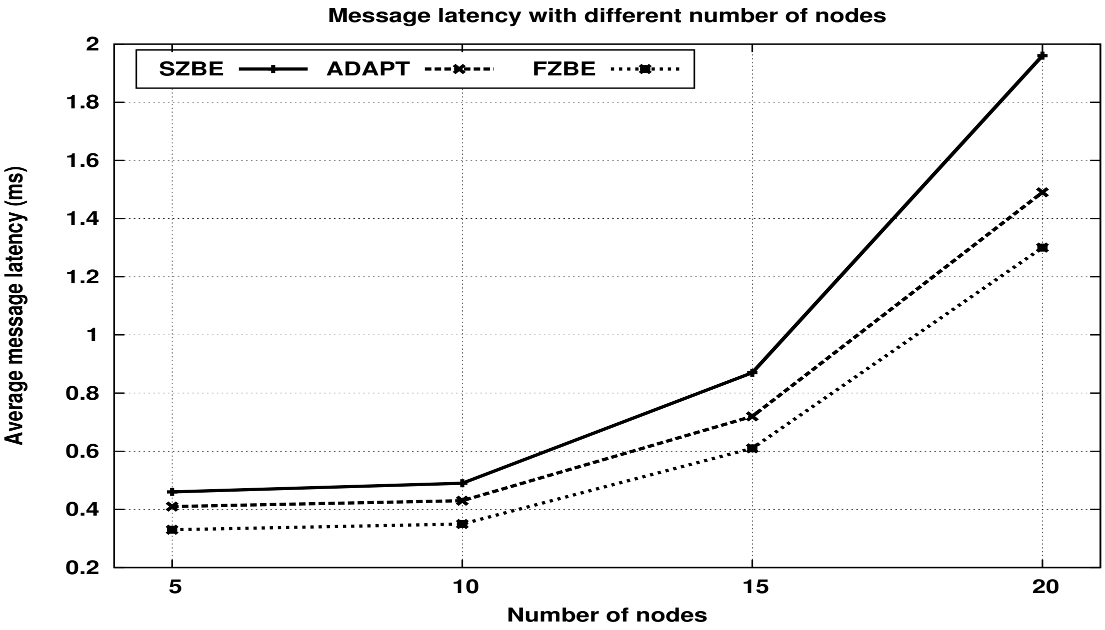

Figure 6.4: Latency as a function of number of nodes

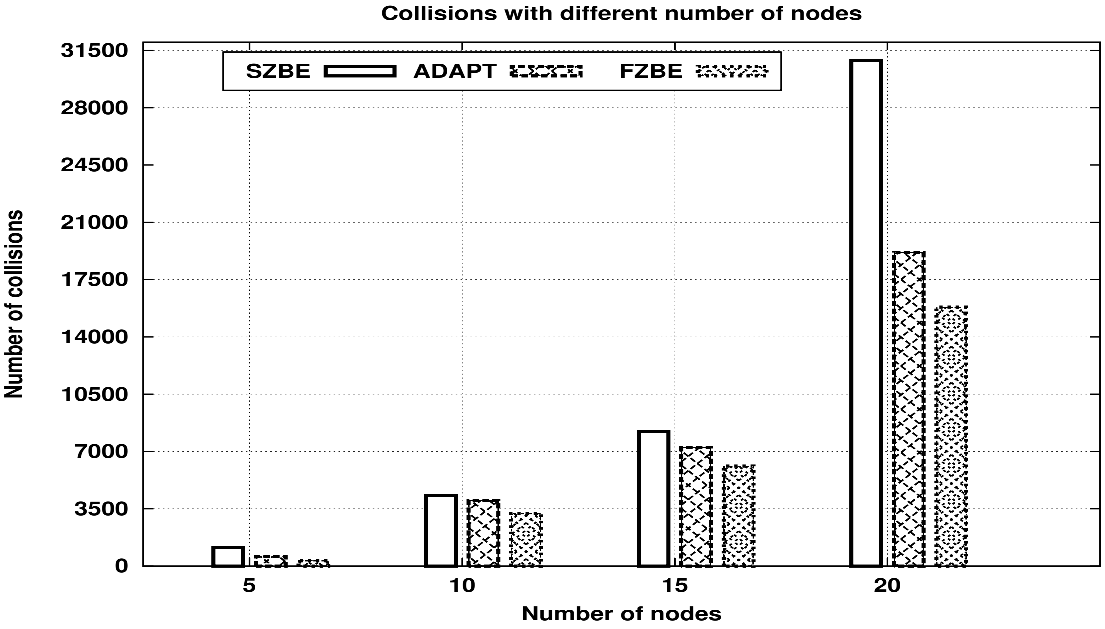

Figure 6.5: Number of collisions with different number of nodes

the nodes remain in the idle mode for majority of the time which in turn results in a lower energy expenditure. FZBE is up to 12% more energy efficient compared to ADAPT and 20% more energy efficient compared to SZBE. This is because in FZBE, nodes duty cycle is adjusted using fuzzy logic with input from data link layer (data delivery ratio, channel assessment ratio). For data latency, as shown in Figure 6.8, all the architectures are less sensitive to increase in message generation rate mainly because it is a single hop network. However, latency of FZBE is up to 16% less compared to ADAPT. This is because ADAPT is run for each beacon interval which takes some computation time of node and increases the latency. In FZBE, with less number of collisions the number of retransmissions decrease which in turn decreases the overall latency of the network.

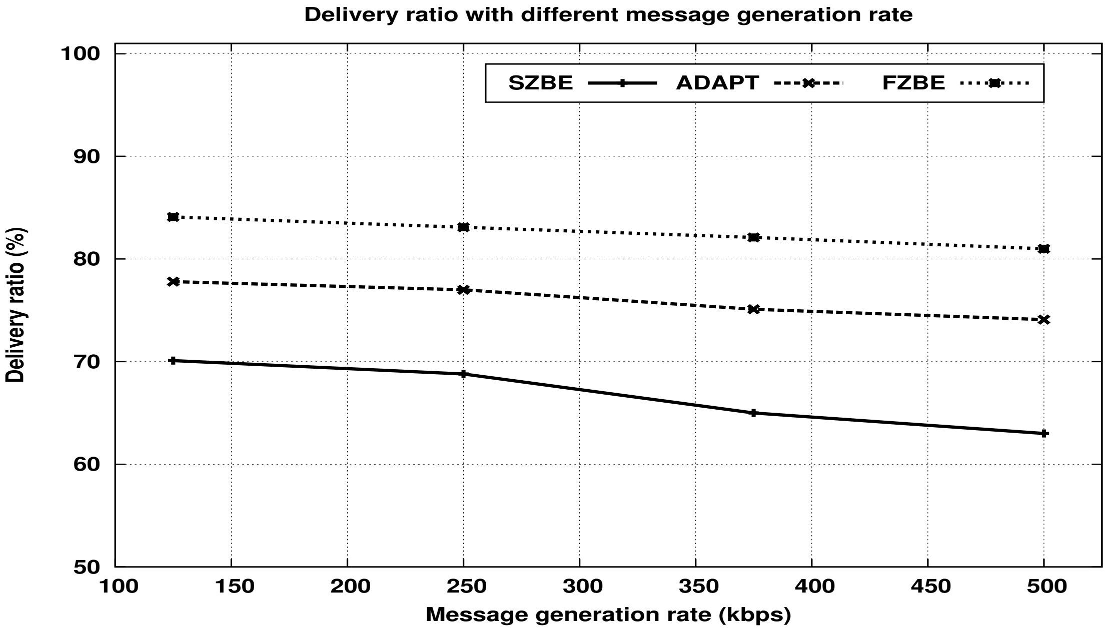

Figure 6.6: Delivery ratio as a function of message generation rate

6.2.4 Performance as a function of message loss rate

Performance as a function of message loss rate is presented in Figure 6.9, 6.10 and 6.11. Figure 6.9 shows delivery ratio of FZBE is up to 9% more than ADAPT. Figure 6.10 and

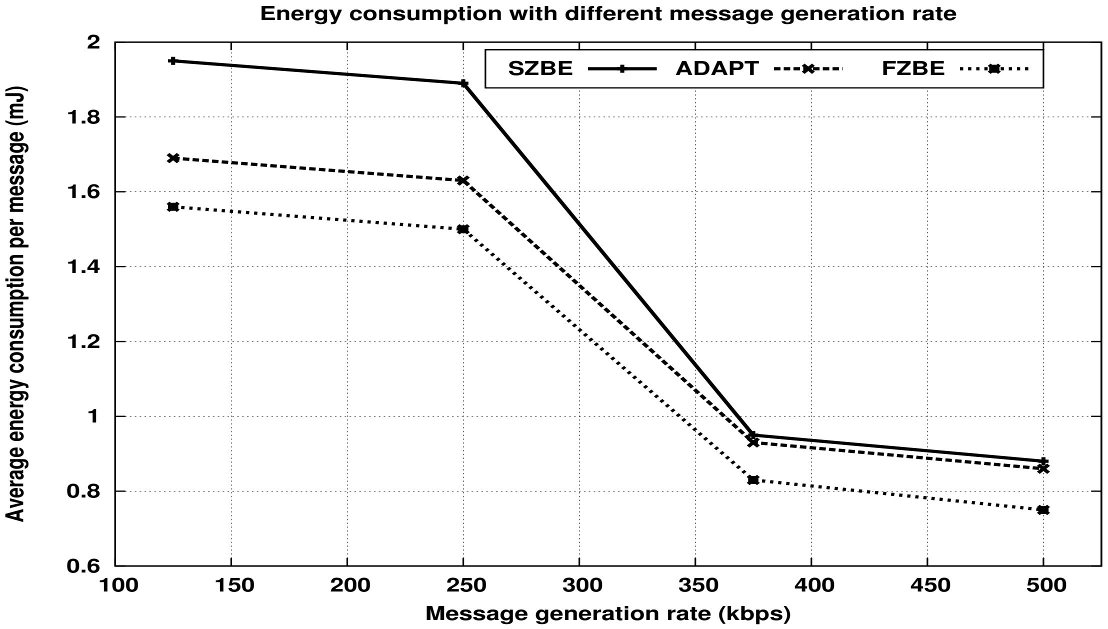

Figure 6.7: Energy consumption as a function of message generation rate

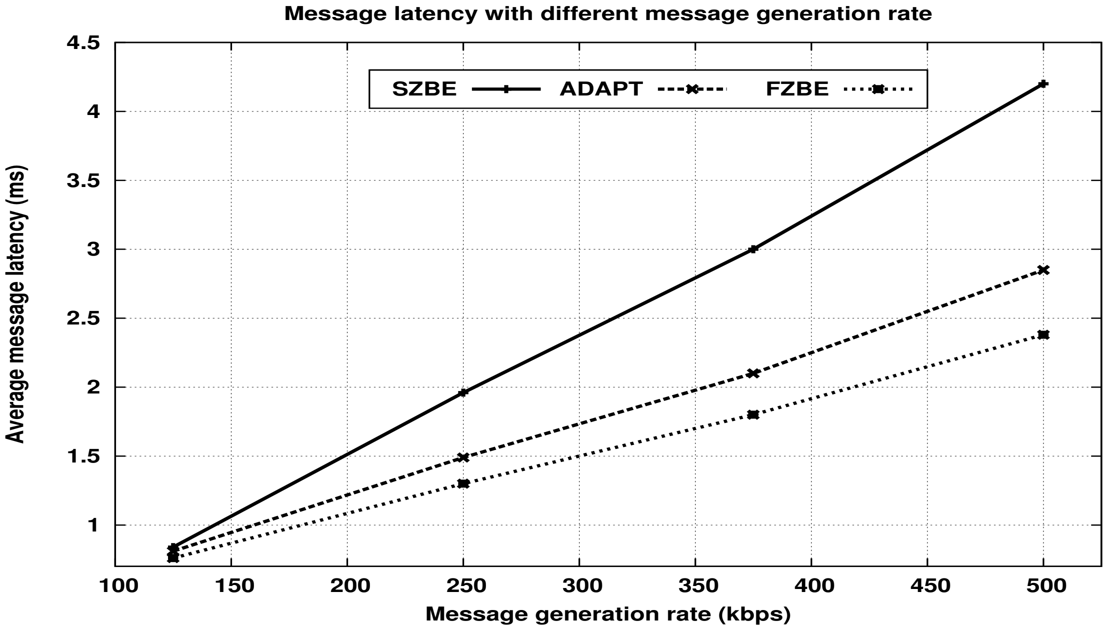

Figure 6.8: Latency as a function of message generation rate

6.11 show that both energy consumption and latency increase with the message loss rate for all the architectures. This is because a large number of messages are to be retransmitted due to channel errors. However, FZBE is seen to be up to 10% more energy efficient compared to ADAPT. Latency of FZBE is up to 23% less compared to ADAPT. This is because data link layer of nodes running FZBE adjusts retransmission timer using fuzzy logic with data delivery ratio and channel assessment ratio as its input. Thus, appropriate adjustment of retransmission timer leads to higher data delivery, lesser energy consumption and latency.

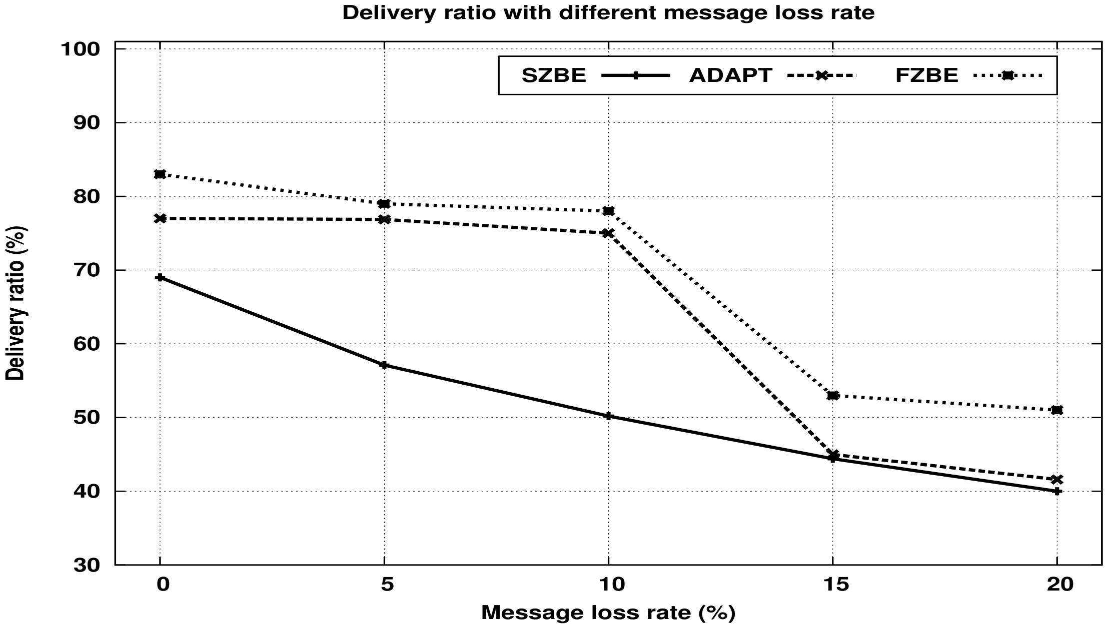

Figure 6.9: Delivery ratio as a function of message loss rate

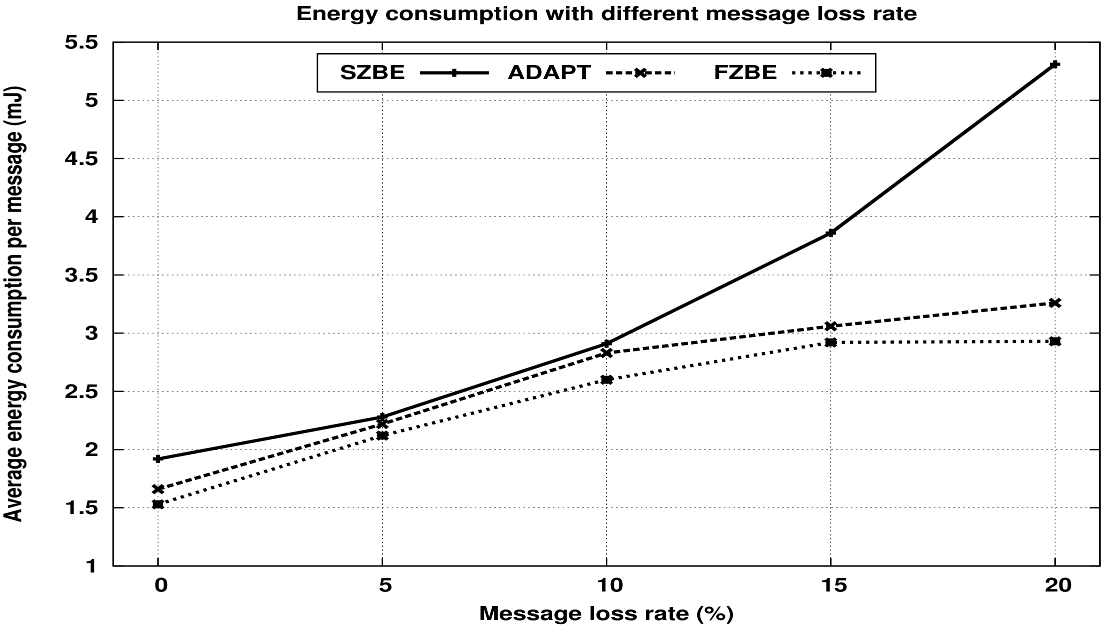

Figure 6.10: Energy consumption as a function of message loss rate

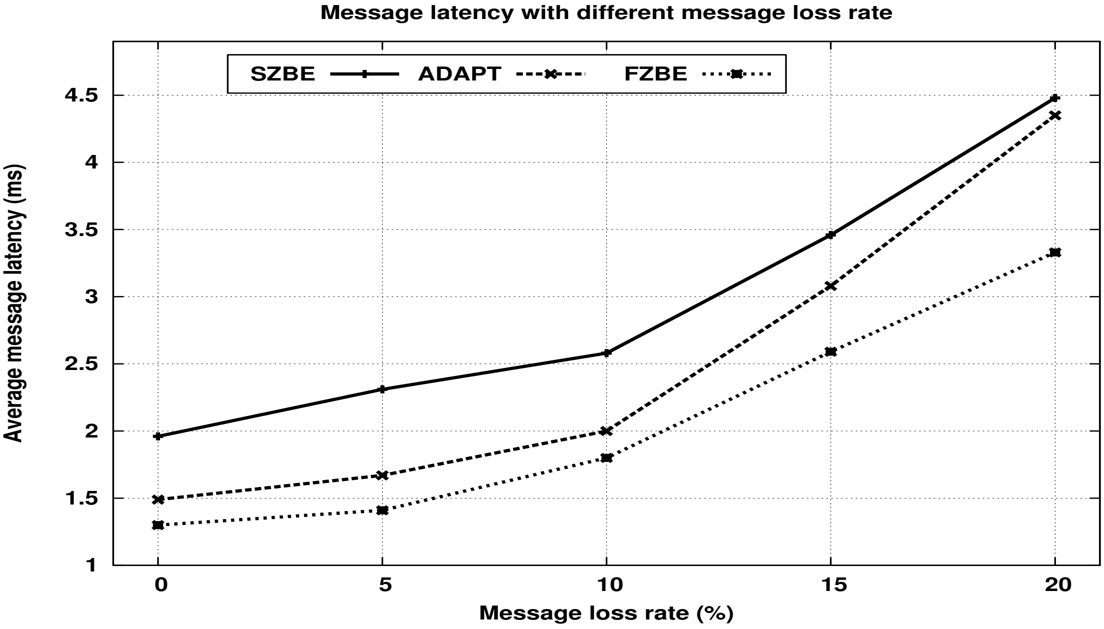

Figure 6.11: Latency as a function of message loss rate

6.3 Multihop analysis

6.3.1 Simulation setup

In the next set of simulations a multi hop WSN with a cluster based tree architecture is considered. The nodes are organized into clusters based on their level in the routing tree. Each cluster consist of a single cluster head and several cluster members. The multi-hop simulation scenario is setup with 20 nodes within a 50 m 50 m area as shown in the Figure 6.12. The nodes are organized in a logical tree with 5 levels using a spanning tree construction algorithm based on minimum hop count. For FZBE, nodes with high values of PRE become cluster coordinator and those with high values of PRP become cluster members. The active period SD is set to 15.7 s to accommodate increased traffic resulting from increased number of nodes and multi-hop message delivery. Rest of the parameters are same as set for single-hop scenario. The active portions of superframe are scheduled in a TDMA-like fashion, such that only a single cluster head and its cluster members are simultaneously active. Further, the superframes are arranged such that all messages are collected by a cluster head from its cluster members before it starts communicating with its relay cluster head.

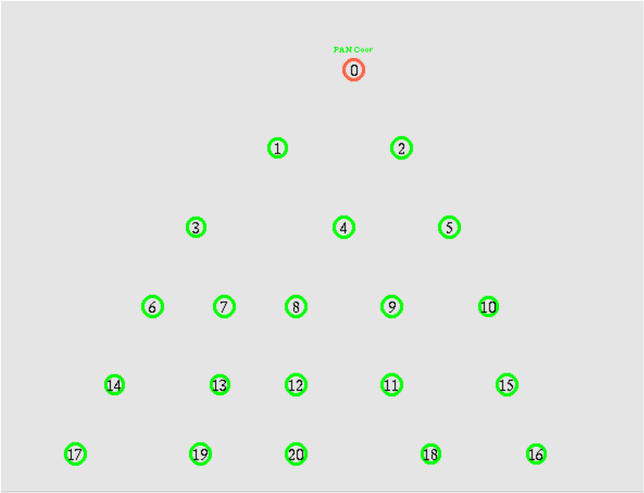

Figure 6.12: Simulation setup for multi hop scenario

6.3.2 Performance as a function message generation rate

The effect of message generation rate on delivery ratio, energy consumption and latency is shown in Figure 6.13, 6.14 and 6.15 resp. Figure 6.13 shows that delivery ratio of FZBE is up to 9 % more than ADAPT. Energy consumption is low when the message rate increases. However, FZBE is up to 16% energy efficient compared to ADAPT. In a multi-hop network the traffic sources for non-leaf nodes consist of data generated by its sensing unit and transit data received from its children as a part of its relay duty. The latter traffic is maximum for the nodes at one-hop distance from the MS. Hence, it is it is important to consider total energy consumed by one-hop neighbors of the MS. This is seen to be higher in ADAPT compared to FZBE (refer Fig. 6.14). Latency is depicted in Fig. 6.15, and it is seen that FZBE again outperforms ADAPT and SZBE irrespective of the workload with latency up to 16% less. This is because in the multi-hop network, the major contributor of latency is the nodes sleep/wakeup schedules (or duty cycle), i.e. the duration of the active periods of the superframes. FZBE manages the nodes duty cycle based on the suggestion given by fuzzy logic. Fuzzy logic uses number of messages queued (PDR) in nodes to suggest increase or decrease in nodes duty cycle. Further, FZBE selects the next hop for data routing to MS based on nodes PRE which in turn depends on nodes residual energy, packet dispatch rate, data delivery and channel assesment ratio.

6.3.3 Performance as a function of message loss rate

Next, performance as a function of the message loss rate is shown in Figure Figure 6.16, 6.17 and Figure 6.18. Figure 6.16 shows, FZBE obtains a delivery ratio above ADAPT and SZBE each time and substantially independent of the message loss rate. FZBE has upto 26% adn 9% more delivery ratio as compared to SZBE and ADAPT resp. SZBE is seen to be sensitive to message loss rate and gets negatively affected by a high message loss, leading to a low delivery ratio. Figure 6.17 shows energy consumption per received message. It is seen that energy consumption increases almost linearly with the message

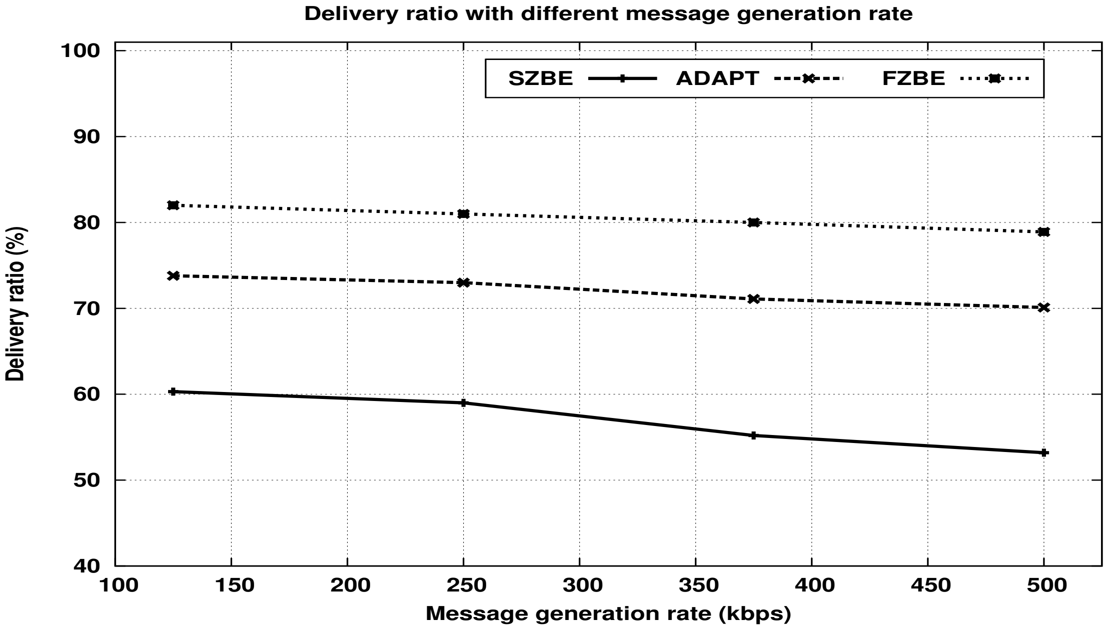

Figure 6.13: Delivery ratio as a function of message generation rate

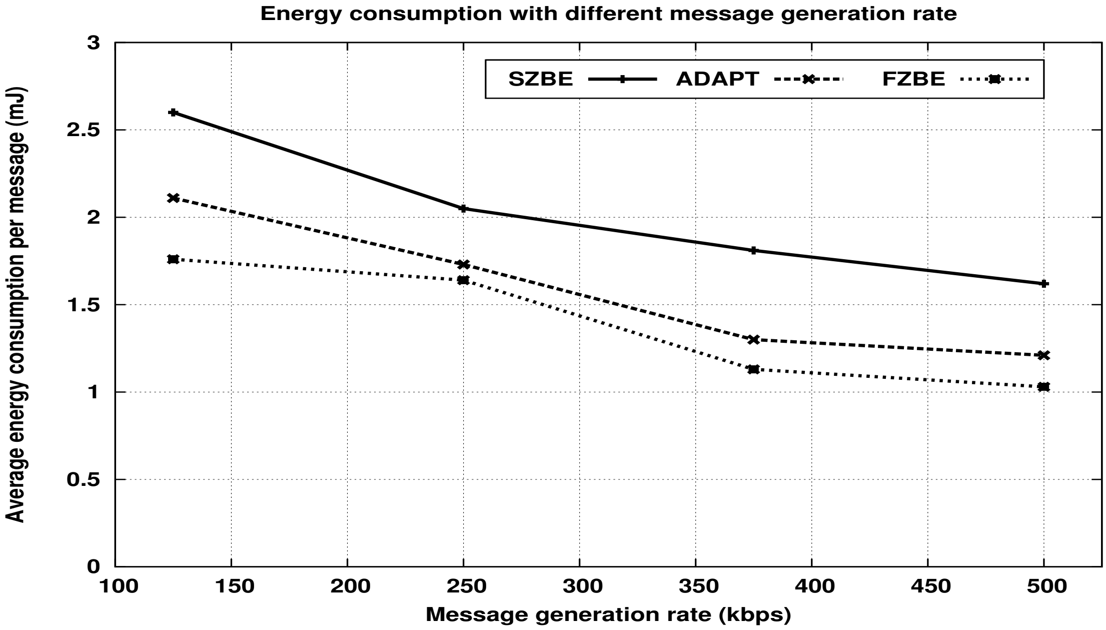

Figure 6.14: Energy consumption as a function of message generation rate

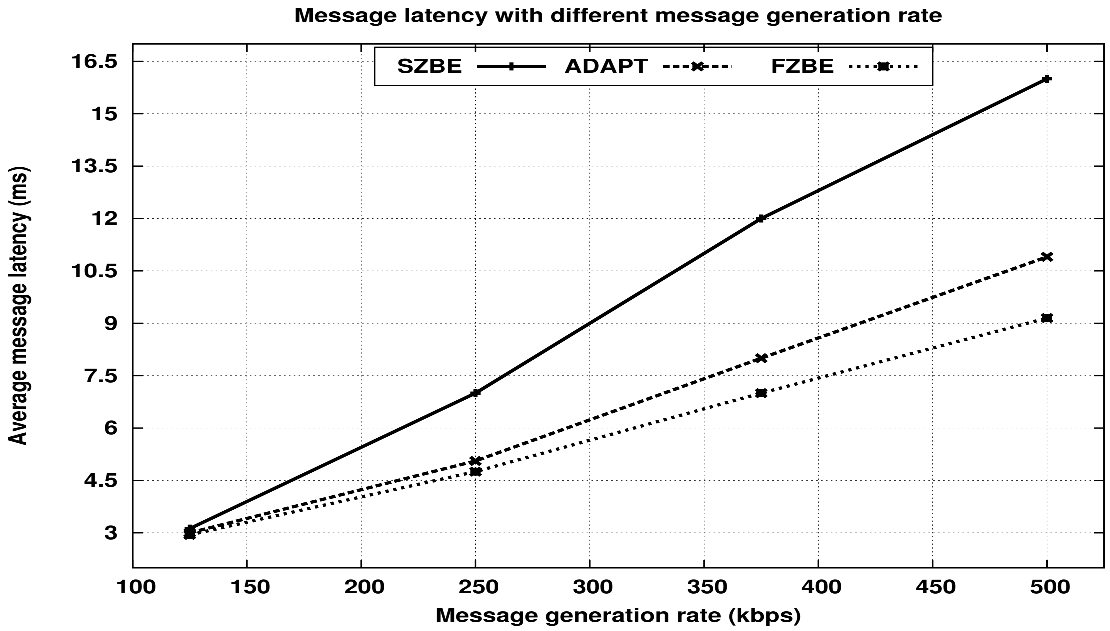

Figure 6.15: Latency as a function of message generation rate

loss rate. FZBE is up to 20% energy efficient compared to ADAPT. Figure 6.18 shows that latency increases linearly with message loss rate. This is mainly because an increase in message loss rate initiates the retransmission mechanism, which in turn increases the channel access time. Due to this, messages may not be forwarded to the next hop during a single active period and the nodes will have to wait for the next active period to transmit those messages. This in turn, results in an additional delay. However FZBE has up to 6% less latency compared to ADAPT. This is because FZBE manages the nodes retransmission time based on the suggestion given by fuzzy logic. Fuzzy logic uses number of messages queued (PDR), data delivery and channel assesment records in nodes to suggest increase or decrease in retransmission time.

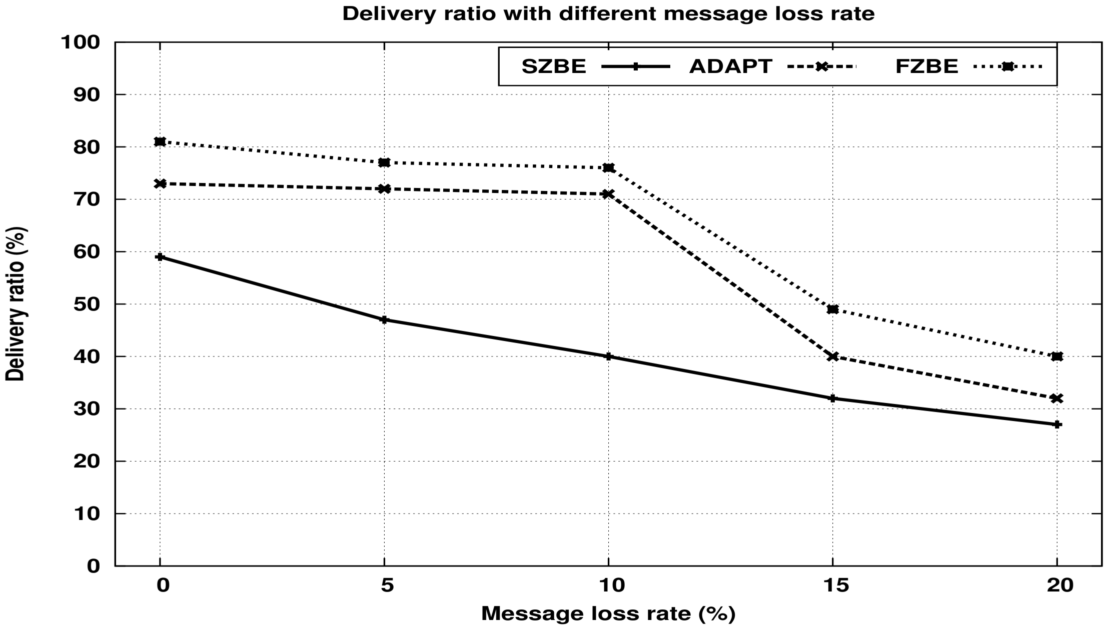

Figure 6.16: Delivery ratio as a function of message loss rate

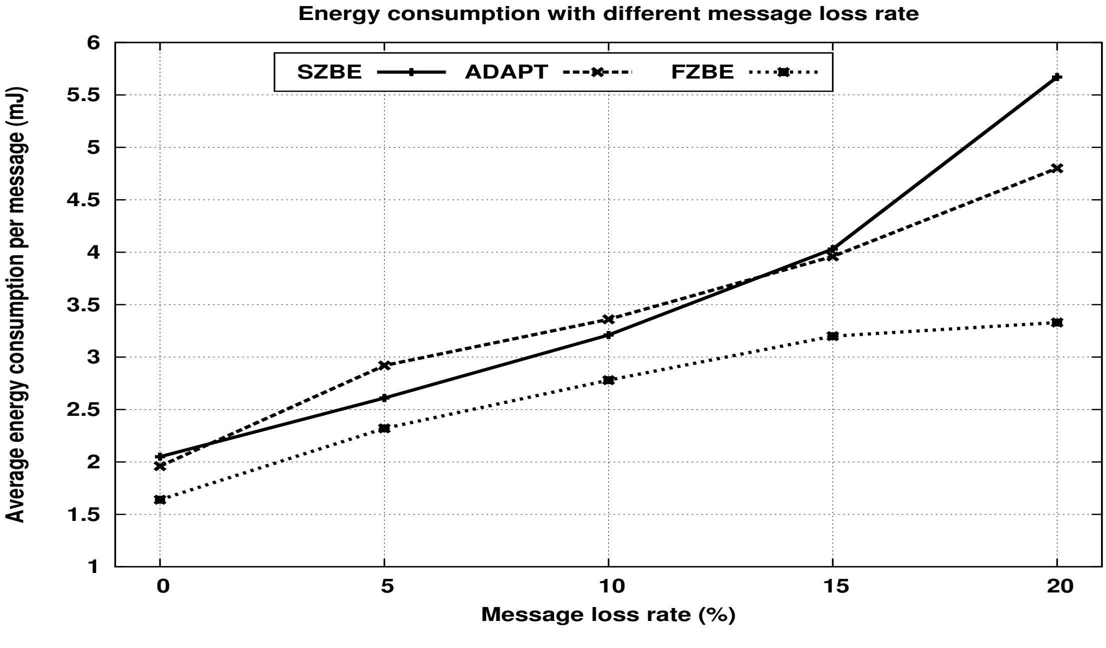

Figure 6.17: Energy consumption as a function of message loss rate

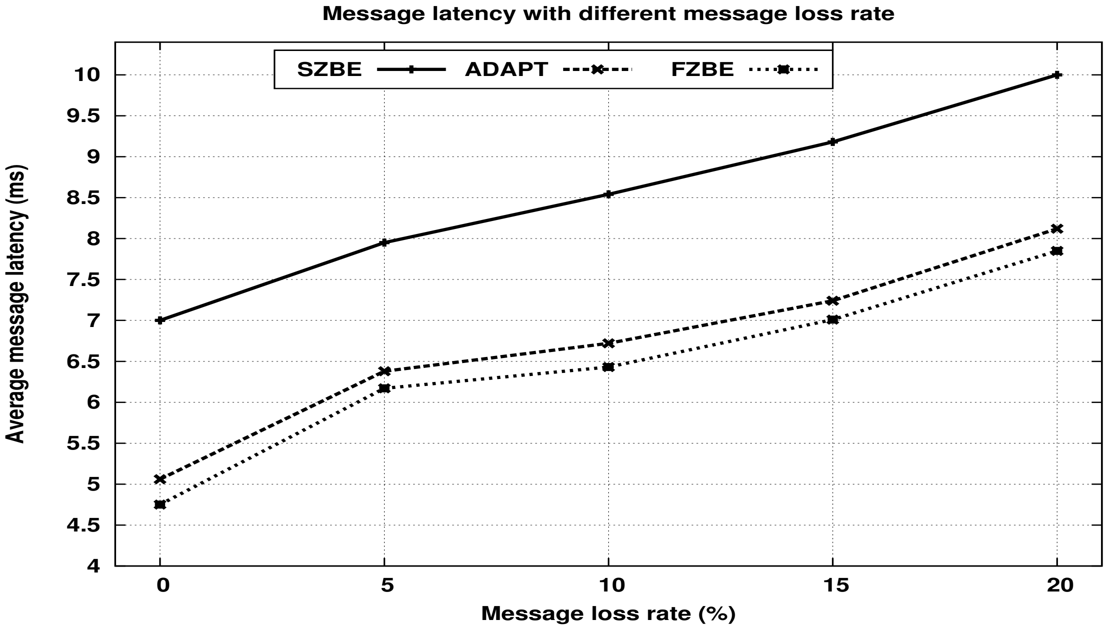

Figure 6.18: Latency as a function of message loss rate

6.3.4 Fairness

In many applications, particularly when bandwidth is scarce, it is important to ensure that MS receives information from all sources in a fair manner. Hence, fairness of all the architectures in terms of how delivery ratio and energy consumption are distributed among the nodes with different hop distances from the MS is presented Figure 6.19, 6.20 and 6.21. Figure 6.19 shows that FZBE has a very low variation of delivery ratio around the average value (depicted as a dashed line). Figure 6.20 shows energy consumed per message from different levels in the routing tree with no message loss rate. One-hop neighbors of the MS are the most loaded nodes in the network because in a multi-hop network the traffic sources for non-leaf nodes consist of data generated by its sensing unit and transit data received from its children as a part of its relay duty. The latter traffic is maximum for the nodes at one-hop distance from the MS. However, energy consumption for one-hop neighbors of the MS is less in case of FZBE compared to ADAPT. Same trend is seen for the lower levels of the tree. Figure 6.21 again shows FZBE consumes less energy per message compared to ADAPT when the message loss rate is 20%. This is due to appropriate settings of duty cycle, retransmission time out and back off time in FZBE.

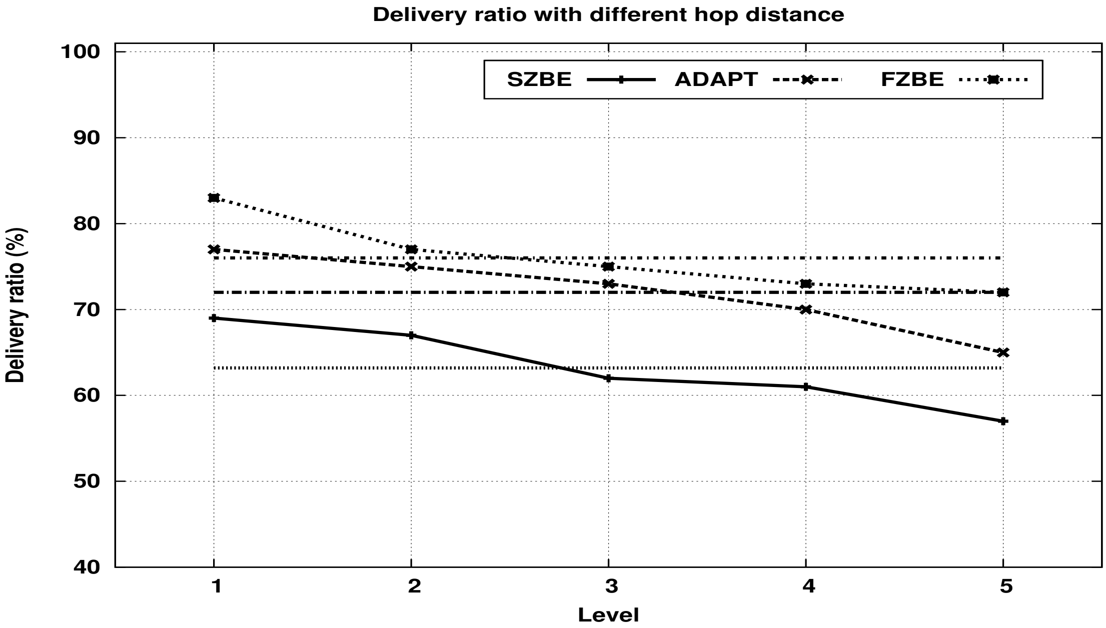

Figure 6.19: Delivery ratio as a function of hop distance

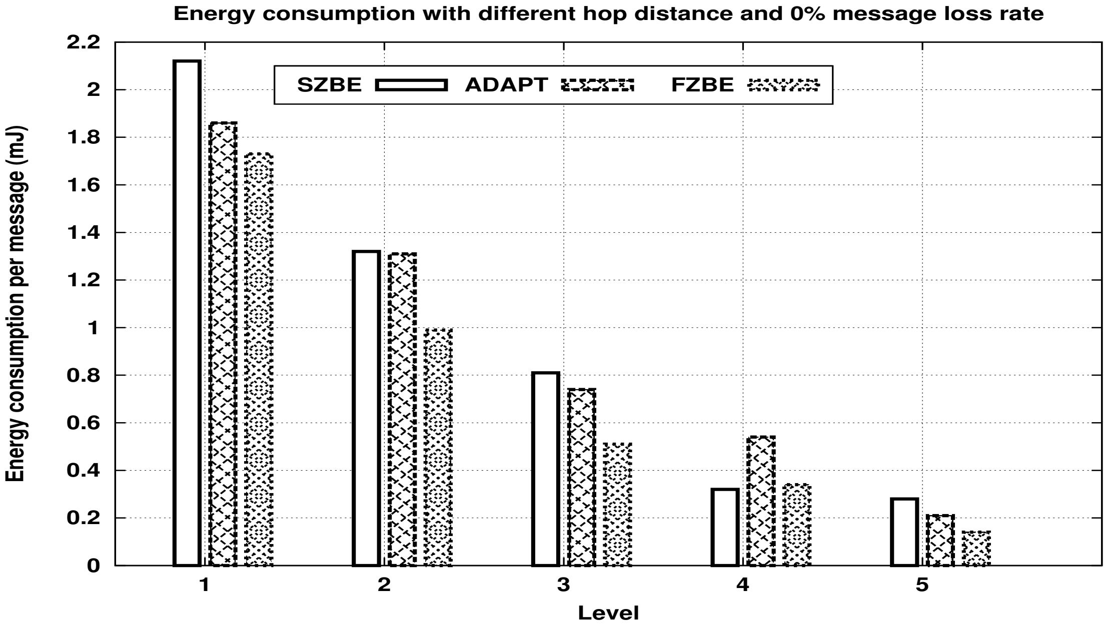

Figure 6.20: Energy consumption with 0% loss rate as a function of hop distance

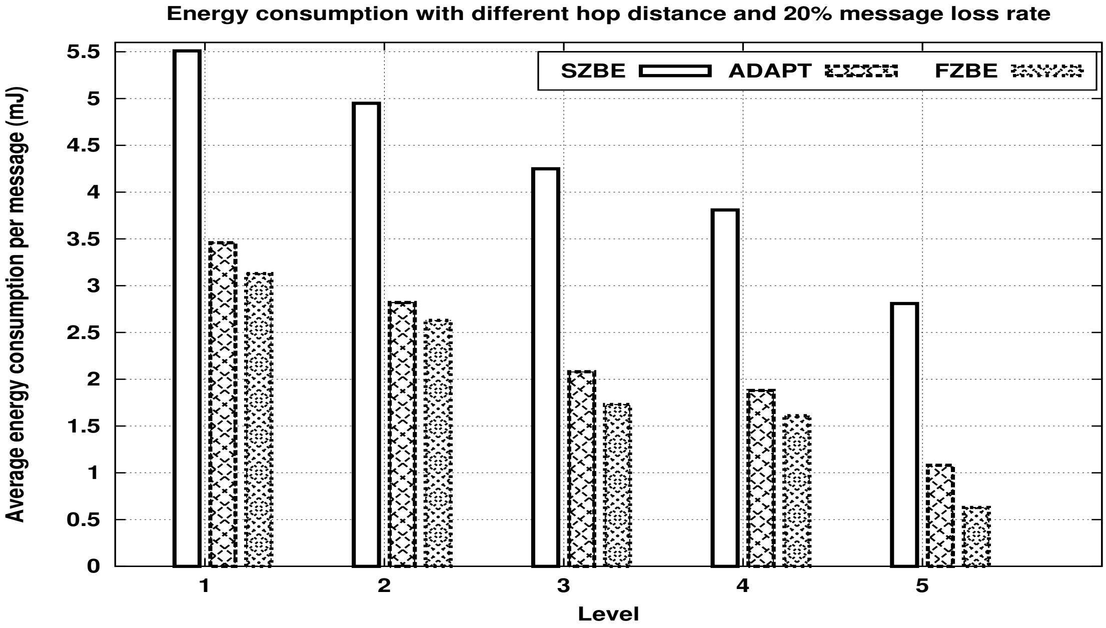

Figure 6.21: Energy consumption with 20% loss rate as a function of hop distance

Chapter 7

Conclusion and future scope

7.1 Conclusion

This work improves the performance of Zigbee using fuzzy logic. Four parameters such as residual energy, data delivery ratio and channel accessment ratio, packet dispatch rate and sensitivity are used as input to FIS engine. Performance metrics like packet delivery ratio, average message latency, average energy consumed per message for the AODV routing protocol for the ZigBee network has been analyzed for both singlehop and multihop scenaio. From the observation it is concluded that delivery ratio with increase in number of nodes while average energy consumption and average message latency increases as number of nodes increases. Also as message rate increases delivery ratio and average energy consumption decreases whereas average message latency increases. Im multihop scenario delivery ratio and energy consumption per node decreases with increase in hop distance.

Further comparing simulation results of Fuzzy based Zigbee(FZBE) with Standard Zigbee(SZBE), ADAPT with Zigbee it can be concluded that delivery ratio of FZBE is 9-13% better than ADAPT and SZBE for both singlehop and multihop scenario. Also FZBE is almost 12% more energy efficient as compared to ADAPT. The increase in delivery ratio and energy efficiency in FZBE is because nodes data link layer adjusts retransmission timer, back off time and duty cycle using fuzzy logic with input from physical (residual energy), data link (data delivery ratio, channel assessment ratio). This reduces number of collisions and hence the energy waste and packet loss arising due to it.

7.2 Future scope

Current work evaluates performance of Zigbee under simulation environment only. This work can be extended and can be implemented on hardware also using IRIS modes. Also this protocol is for a static sensor network only in which nodes remain at the same location i.e. they are static. Wireless sensor networks consisting of both mobile and static nodes. So same logic can be applied to network consisting of mobile nodes.

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Appendix

TCL script to introduce error module

```
$ns_ node-config -IncomingErrProc losses_module -OutgoingErrProc losses_module
proc losses_module {}
{
set loss_module [new ErrorModel] ;        #Error Model Introduced
$loss_module set rate_ 0.0 ;                  #Change 0-30% i.e (0.05 - 0.30)
return $loss_module
}
```

TCL script to adjust parameters

```
Phy/WirelessPhy set CSThresh_ $dist(30m);        # To adjust carrier sensing range
Phy/WirelessPhy set RXThresh_ $dist(15m);        # To adjust receiving threshold
hy/WirelessPhy set Pt_ 1.0;          # Pt_ To adjust transmit power
Phy/WirelessPhy set X_ 1.0;          # X_ Variable linkage with back-off timer BoT
Phy/WirelessPhy set Y_ 1.0;          # Y_ Variable linkage with retransmission timeout RTo
Phy/WirelessPhy set A_ 0.866;          # A_ Variable linkage with beacom order BO (BO=13)
Phy/WirelessPhy set B_ 0.53;          # B_ Variable linkage with superframe order SO (SO=8)
```

MATLAB code for Fuzzy output

```
A=load(’Residual_Energy.txt’,’-ascii’);
B=load(’DDR_CAR.txt’,’-ascii’);
C=load(’Sensitivity.txt’,’-ascii’);
D=load(’packet_dispatch_rate.txt’,’-ascii’);
chns_ip=[A,B,C,D];
fis=readfis(’Fis_modified1.fis’);
out = evalfis([chns_ip(:,1) chns_ip(:,2) chns_ip(:,3) chns_ip(:,4)],fis);
```

NS2 variables for FUCR parameter calculation

FUCR parameter	Variable used in calculation of the value of FUCR parameter	File of the variable
REN	column number 14	Trace file
DDR	column 1 (send, receive)	Trace file
CAR	column 1 (send), packet interval total simulation time	Trace file, Tcl file
PDR	column 1 (dropped), column 5 (IFQ, packet drop due to queue length)	Trace file
TXP	Pt	Tcl file
RTO	macAckWaitDuration	p802_15_4mac.cc
BOT	aUnitBackoffPeriod	p802_15_4csmaca.cc
DTC	SO	p802_15_4sscs.cc