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A Novel Fuzzy Based Method to Improve the Network Lifetime in Internet of Things

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Abstract— Internet of Things (IoT) opens the way for many of the research areas out of which Network lifetime extension is one of the craziest research areas. Proposing a design for any sensor network routing protocol needs to concentrate on extending the network's existence. Minimizing energy consumption leads to an extension of the life of the network. Routing Protocol for Low power and Lossy Networks (RPL) is the routing protocol designed by IETF especially which meets the necessities of the constrained environments in IoT. This research article attempts improve performance of the RPL protocol by incorporating the soft-computing techniques. Here, a fuzzy logic-based approach is used which considers DIO_MIN as the essential factor/metric to improve the performance of RPL (i.e., reducing the energy consumption). The COOJA simulator is used for performing the simulations and assessment purpose. Results obtained from this research prove that fuzzy logic can be exercised to improving routing protocol quality (i.e., RPL) in terms of energy consumption.

Keywords: Internet of Things (IoT), Routing Protocol for Low-Power and Lossy Networks (RPL), Fuzzy Logic, Cooja Simulator, Energy Conservation.

I. INTRODUCTION

Wireless Sensor Network (WSNs) is envisioned to turn out to be the most noteworthy technology in many fields like they're extensively used in a wide number of civil, military and industrial applications [1]. In a WSN, sensor nodes form the network on their own when they are spread out in the sensing field. Sensors collect different data from the environment and send the information to the Base Station (BS) which is otherwise called as a sink node. This activity of the sensor nodes/sensor network is based on the principal topology of the network that is established. The sink node takes the responsibility of gathering and processing of information. Above all, the sink node is responsible for connection of network of the sensors to the internet through gateways. The sink node does not have any constraints on computing capabilities, power resources, and data storage. Sensors are resource-constrained devices which have restricted battery capacity, low memory and restricted processing capabilities. The sensor nodes are also constrained by their radio range [2].

The introduction of open standards and IP-based protocols guide to the inception of IPv6 over Low Power Wireless Personal Area Networks (6LoWPAN) and IPv6 Routing Protocol for Low Power and Lossy Networks namely RPL. This protocol being harmonized by Internet Engineering Task Force (IETF). The routing protocol is a key function of any communication system and must facilitate the efficient transmission of data in the network from one point to another. A various number of metrics is accounted by the protocol during the topology building stage. Such metrics are used as an objective function (OF) in order to set different performance targets for the network, which satisfies the requirements of the target application. To date, hardly two objective functions were listed and standardized for RPL: The first utilizes hop-count as a routing metric and is stated as OF0 and the other utilizes the Expected Transmission Count (ETX) which is needed to send a packet to its target competently[3].

Parallel to WSNs, the IoT concept was created. The term IoT was given by Kevin Ashton in 1999 and it refers to the unique identification of objects in the internet [4]. Machines, large building, cars, industrial plans, planes, plants, and animals or any kind of goods can be used as objects in IoT. Wireless communication technologies compete with other communication technologies and play a crucial role in communications in IoT. IoT sensors can be setup on any kind of objects ranging from smallest to huge size at reasonable pricing. The availability of low powered, cheap and rugged sensors in IoT can be treated as a main advancement of WSNs.

In a Low Power and Loss Network (LLN), routing plays a vital role in energy conservation. LLN is indeed a network consisting of resource constrained machines that are connected by wireless connections. The routing protocol in LLN has the limitations such as low capacity for data processing, limited storage, and power. In addition, the LLN routing process needs the network nodes to be self-organized; i.e., healing itself without manual intervention. The standard routing protocol is therefore not suitable for LLN. IETF standardized IPv6 routing protocol for low power and Lossy networks (RPL) for LLN [5]. If the participant node decides to join the DODAG in LLN, specific routing metrics should be considered in order to switch the data to the best route.

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RPL is a proactive routing protocol which follows the Destination oriented Acyclic Graph (DODAG). In DODAG, the member node transfers the data to the root of DODAG. The root node which in turn forwards the data to the destination node through the parent node. The up route indicates the edge to the root and the down route indicates the position of the edge away from the root. In a network, the RPL protocol creates more than one RPL instance and that each instance includes more than one DODAG. RPL ranks how long is the distance from root to parent of DODAG. The DODAG node has storing and non-storing mode. The root node has storage mode by definition and manages the entire network routing table. Within DODAG, the root node gives another node the privilege to maintain routing knowledge of the network. The node will store and transmit the data to another node in the storage mode. The node may simply forward the data to another node in non-storing mode.

RPL provides four command messages, namely DODAG Information Solicitation (DIS), DODAG Information Object (DIO), DODAG Advertisement Object (DAO) and DODAG Advertisement Object -Acknowledgement (DAO-ACK). Originally, the request process for DODAG was performed in two ways.

• The DIS query is sent to DODAG by the participant node.

• DODAG sends information to all participant nodes through the DIO request.

The DODAG activates the trickle timer; within the interval of time, the participant node must transmit the DAO control messages to DODAG. The DODAG then transfers control messages from the DAO-ACK to all member nodes.

Fuzzy logic is a generalization of well-known crisp logic. Through the fuzzy logic, real-world problems are intelligently articulated than with the crisp logic. It works for reasoning even in uncertain situations. Human knowledge and its interactions can be well applied through the roles of Fuzzy Logic Membership and Fuzzy Rules. It is a highly effective mechanism for the formulation of solutions to the problems containing vague information. Fuzzy Logic can be applied to the routing protocols where many routing measurements focused on the fuzzy logic rules can be combined to augment the performance of the routing protocols.

The majority of the paper is structured as follows. In section II overview of RPL, DODAG construction in RPL and fuzzy interference mechanism are explained. Section III focuses on an overview of fuzzy logic. In section IV, a description on the proposed system with metrics of interest and the fuzzy logic controller is given and finally section V details about the results and discussions. In the end, the conclusion and future scope were discussed as section VI and section VII respectively.

II. RPL OVERVIEW

RPL is an IPv6 routing protocol intended for networks with low power and loss networks. RPL's main objective is to facilitate the connection of restricted devices via the Internet. The nature of RPL is that it might create a link between nodes based on Directed Acyclic Graph(DAG). The DAG specifies a tree structure in which the default route between nodes can be constructed. RPL describes a set of parameters for ICMPv6 control messages that facilitates the sharing of related information with DODAG. The four types of RPL control messages are:

• DODAG Information Object (DIO): LBR (LowPAN Border Router) initiated and retransmitted to its neighbors in a multicast fashion.

• Destination Advertisement Object (DAO): Used to distribute information in the upward direction about the destination along the DODAG.

• DODAG Information Solicitation (DIS): Used to propagate destination information in the upward direction. A node can request a DODAG information Object (DIO) from an accessible neighbor.

• Destination Advertisement Object Acknowledgement (DAO-ACK):

It was in response to a DAO message by a DAO recipient.

A. Objective Function (OF):

The RPL is dependent on the OF to generate paths.

The OF characterizes how one or several metrics are translated into a Rank value by a node. A node is chosen as the best parent, which offers the minimum rank from a collection of member nodes. A node is chosen as the best parent, which offers the minimum rank from a collection of member nodes. In addition, the OF is configured explicitly in the context of the RPL specification, allowing RPL to adapt to new configuration based on specific requirements. Such parameters make it possible to select the best parent based on a set of metrics for routing. Such metrics can be hop count node metrics and energy metrics or connection metrics such as bandwidth, latency, Link Quality Level (LQL) or amount of Expected Transmission Count (ETX) or may be both when used in a combination. Two objective functions have been specified by the ROLL working group so far. One of these is the objective function zero (OF0), which utilizes the minimum hop count to pick the best parent [6]. The other one is the Minimum Rank with Hysteresis objective Function (MRHOF) with ETX metric to pick the optimum path to the sink node.

B. RPL support for IoT

Three important elements constitute the IoT and they are identification, sensing, and communication. The widespread IoT applications have tailored to IETF protocol stack [7]. IETF protocol stack is shown in Table I which consists of IEEE 802.15.4 PHY-MAC, IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) and RPL. MAC layer defines a multi-hop routing protocol and IEEE 802.15.4 standard defines the PHY layer that operates at 2.4 – 2.485 GHz frequency. 6LoWPAN gets fit in between the intermediate layers of IEEE 802.15.4 MAC and IPv6. Due to frequent changes in the topology and due to energy constrained nodes, the routing in 6LoWPAN is a major concern. Topological redundancy can be avoided by cluster-tree that is proposed in IEEE 802.15.4 MAC. IEEE 802.15.4 is supported by the following three network topologies: peer-to-peer, cluster and star tree. Peer-to-Peer topology supports multi-hop data transmission at the MAC layer.

Peer-to-Peer topology follows the construction of DODAG for discovering routing paths through the exchange of control messages [8]. Home automation, Industrial automation, smart grid, smart metering system, smart retail etc., are various applications of IoT.

Table I. IPv6 Protocol Stack

Application Layer	COAP
Transport Layer	TCP/UDP
Network Layer	RPL
Adaptation Layer	6LoWPAN
MAC Layer	IEEE 802.15.4 MAC
PHY Layer	IEEE 802.15.4 PHY

The major challenges of RPL protocol are achieving higher throughput, credible and effective routing with energy conservation, and mobility support. Improvement in Network throughput is achieved by the design of Backpressure RPL (BRPL), which manages load and traffic using Quick Theta and Quick Beta.

In QuickTheta, a smooth queue length is used along with Exponential Weighted Moving Average (EWMA) that produces a congestion level. QuickBeta computes the mobility status by using the state changes that occur in side by side nodes and which are at a distance of one-hop. Performance of the RPL is evaluated with two diverse topologies (Grid and Random) [9]. The performances of IoT applications are analyzed with respect to consumption of power by the nodes, reception ratio, Packet Delivery Ratio (PDR) etc., to name a few.

C. DODAG construction in RPL

In RPL, DODAG is constructed which is a tree-oriented routing design. Dissemination of data is done by the exchange of ICMPv6 control messages. The objective function in RPL is achieved based on the path selection by considering various constraints into account. Control messages in RPL are divided into four types which are mentioned as follows [10]:

(i) DIO message: DIO is DODAG Information Object message is the message that is distributed by the root node to start the DODAG construction. This message reaches all the nodes in the network and that too within the root nodes contact array. The receiver nodes, upon receipt of the DIO message decides whether to be added into the network or not.

(ii) DIS message: It is used to access the DODAG network. Unicasting of DIS messages is done to search for its neighboring nodes.

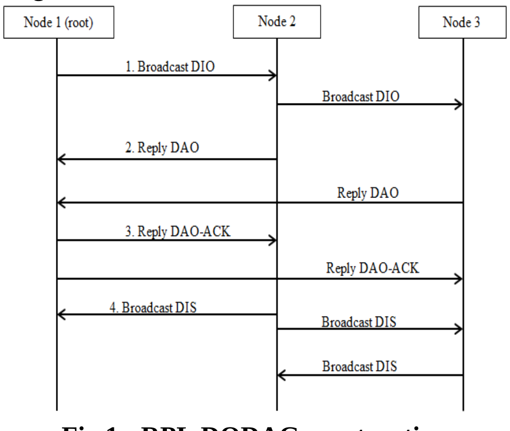

Fig 1 : RPL DODAG construction

(iii) DAO message: It is also a multicast message (i.e.) point-to-multipoint. Here, the node transmits information to the constructed DODAG about the destination in an upward direction.

(iv) DAO-ACK message: DAO-ACK is the message received from the recipient node that transmitted messages from the DAO.

Exchange of the control messages leads to the construction of DODAG and each node is provided with a rank [11]. The number of nodes from the root node is the node rank in the DODAG. Communication takes place in the built DODAG so that the packets move up to the root node. Fig 1 illustrates the RPL DODAG formation.

D. Fuzzy Interference Mechanism

Fuzzy logic reasoning helps in convertion of multiple input variables/parameters (delay, ETX, and energy) into one parameter. There were several phases to the fuzzy inference system.

• Fuzzification: Take a crisp value information and discern the membership level (fuzziness) for the appropriate fuzzy sets.

• Fuzzy inference: Apply the rules of combination to fuzzy inputs and determine a fuzzy output.

• Aggregation: When an output relies on more than one principle, all values are unified in this stage.

•Defuzzification: Simply transfer into a crisp value from the fuzzy output produced at the previous step.

III. OVERVIEW OF FUZZY LOGIC

Fuzzification is a system in which the crisp input value is transformed into the fuzzy array/set. Fuzzy Logic can be applied to the routing protocols for improving their performance. Linguistic variable and membership functions are the two important terms in Fuzzy logic.

A. Linguistic Parameter

A linguistic parameter/variable is a language structure and is categorized into several areas of study. It's part is setting the values among true and false. The linguistic parameter includes routing metrics of both the input and the output. This portrays the value in the form of words instead of numerical.

B. Energy Consumption (EC)

It is the power of the nodes expended in the information exchange in the network. It is the power of the nodes expended in the information exchange in the network. The energy expended by the node in transmission is called " all transmit" while it is called as "all listen" in the reception. Additionally, other energy calculation parameters are considered as CPUs power representing the power consumption during maximum power/full power mode and LPM representing the power consumption during silent mode/low power mode.

Power (mJ) = (Transmit ⁄ 19.5 mA + Listen ⁄ 21.5 mA + CPU_ time ⁄ 1.8 mA + LPM ⁄ 0.0545 mA) ⁄ 3V/(32768)

C. Membership Functions

The function that is used to specify the level to which the given input fits a set. These are used in Fuzzy Logic System (FLS) during Fuzzification and Defuzzification steps. The non-fuzzy input parameters are mapped to fuzzy linguistic terms and vice versa.

Membership function determines the linguistic parameter and it is used to support correct input and output factor calculation. Based on the application requirements, the threshold values and the membership functions can also be fine-tuned. Below are various forms of membership functions:

- Triangular
- Trapezoidal
- Singleton
- Gaussian
- Piecewise linear

The choice of Membership Function depends on the application. The user is free to choose any membership function which suites his application.

IV. PROPOSED SYSTEM

A. Metrics of Interest

This article focuses on two input parameters namely Network Size and Mobility Speed along with only one output parameter Imin.

Network Size

The number of nodes / devices hooked up to the network is known to be the network's size. In IoT, the nodes can be any device like simple sensor devices, smart phones, palmtop, laptop, and any high-end system. This research article considered the skymotes as a node and the number of skymotes in the simulations is considered as the network size which varied from 20, 30, and 40.

Mobility Speed

In the present-day scenario, dealing with dynamic networks involves the movement of nodes/devices. Hence, mobility in the network is considered a common phenomenon. This research work has taken Random Way Point (RWP) mobility model for nodes. Each node is set to have a specific mobility speed and is based on the mobility model which is chosen (RWP in this research article).

Imin

Imin is defined in terms of units of time (i.e., millisecond, microseconds, seconds, etc.) and it represents minimum interval size. The choice of the minimum interval is protocol independent and the user has a choice to select any value.

Fuzzy Logic Controller

The development of the Fuzzy Logic Controller requires two important measures.

- Member functions should always be defined for each parameter of input and output.
- Fuzzy rules should be defined.
- Fuzzy logic employs specified parameters which often express the effect of their interaction with different values a d units in defined ranges. The graphical interpretation of each input's degree of participation is defined by the membership function [12]. Each of the inputs is associated with a weight that describes the efficient overlie between inputs and based on the results, it will determine the output response. Fuzzy rules utilize input membership values to ascertain the influence of inputs on output sets.

The membership functions should be designed such that the following two conditions are met:

- There has to be a overlie between the membership function and the overlie with the nearest neighboring membership functions.
- The membership values should amount to 1(or nearly) in all the relevant fuzzy sets, for any input variable.

This paper considered triangular membership function for all the input as well as the output parameters. Equation (1) gives the formula for the triangular membership function that is defined by a lower limit a, an upper limit a and b value m where a <m<b

$$\mu A(X) = \begin{cases} 0, & x \le a \\ \frac{x-a}{m-a}, & a < x \le m \\ \frac{b-x}{b-m}, & m < x < b \\ 0, & x \ge b \end{cases} \quad (1)$$

Fig 2 depicts the Fuzzy Logic Designer used in this research article. It clearly depicts that the Sugeno model is used and it also represents two input values "Network Size" and "Mobility Speed" and one output value "Imin".

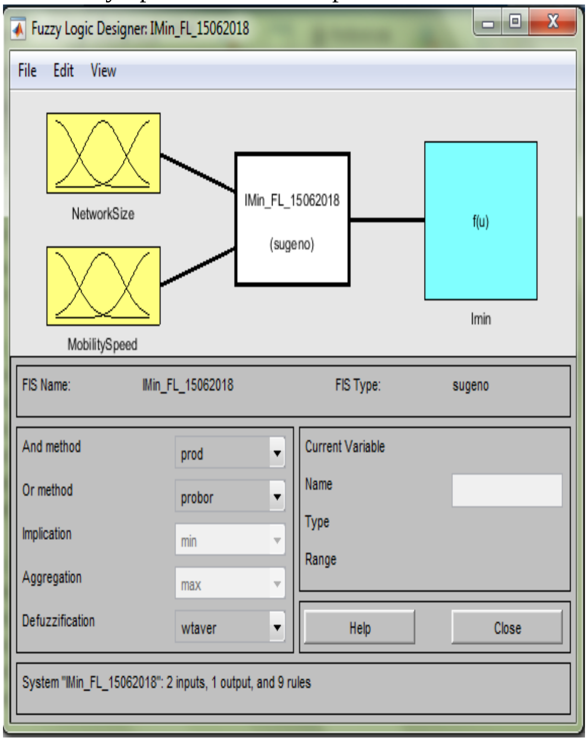

Fig 2. Fuzzy Logic Designer

The membership functions used in this research work are as follows:

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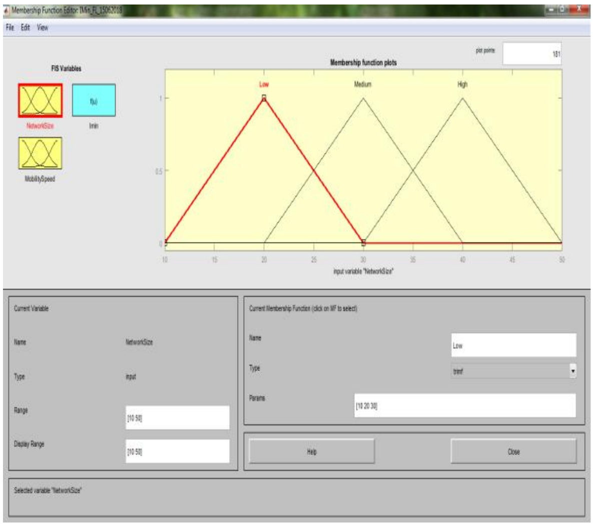

Fig 3 .Triangular Membership function for Network Size

Network

Size: Three triangular membership functions reflect the network size as shown in Fig 3.

The x-axis is the network size value (NS).Low, medium and high are the three triangular membership features of the NS. The y-axis represents the membership values and the sum of the membership values as described above is equal to 1

Mobility Speed: Three triangular membership functions represent Mobility Speed as shown in Fig 4.

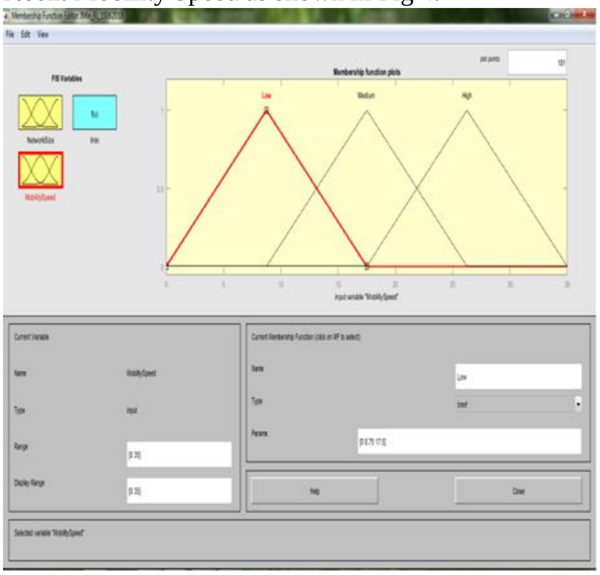

Fig 4.Triangular Membership for Mobility Speed

The x-axis represents the value of Mobility Speed (MS). The three triangular membership functions representing the MS are marked as low, medium, and high. The y-axis represents the membership values and as described earlier the sum of the membership values is equal to 1.

Imin:

For this research article, the three values of Imin are chosen and they are portrayed in Fig 5.

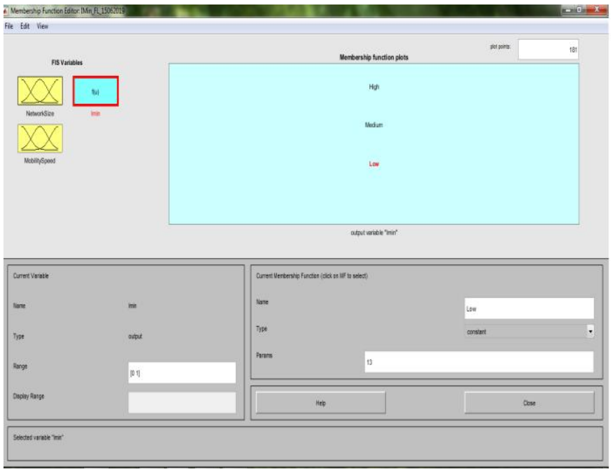

Fig 5. Membership function for Imin

Table II describes the nine fuzzy rules that are used in this research article.

Table II. Fuzzy Rules

Input 1 (Network Size (NS))	Input 2 (Mobility Speed (MS))	Output (Imin)
Low	Low	High
Low	Medium	Medium
Low	High	Low
Medium	Low	High
Medium	Medium	Medium
Medium	High	Low
High	Low	High
High	Medium	Medium
High	High	High

1. if NS is Low and MS is Low, Output Imin is High
2. if NS is Low and MS is Medium, Output Imin is Medium
3. if NS is Low and MS is High, Output Imin is Low
4. if NS is Medium and MS is Low, Output Imin is High
5. if NS is Medium and MS is Medium, Output Imin is Medium
6. if NS is Medium and MS is High, Output Imin is Low
7. if NS is High and MS is Low, Output Imin is High
8. if NS is High and MS is Medium, Output Imin is Medium
9. if NS is High and MS is High, Output Imin is High

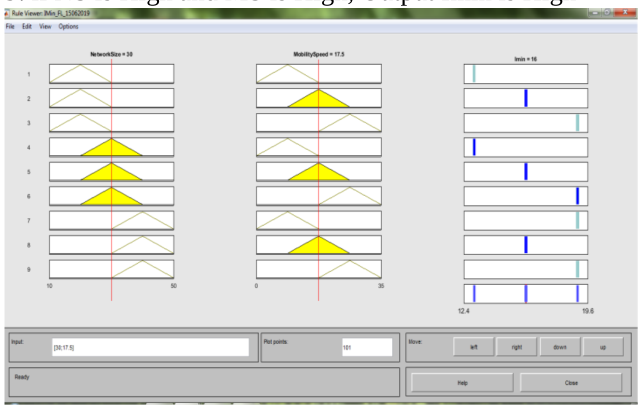

Fig 6. Rule Viewer

Fig 6 depicts the rule viewer which helps in finding out how the output values vary at each of the different combinations of the Input values. The above rules summarize the Imin properties. Each node in the network passes its parameters (NS and MS) to the fuzzy logic controller and returns a weight representing these parameters. The simulations using Cooja simulator were carried out with the values outputted from the fuzzy logic controller and the detailed discussion is presented in the results section.

V. RESULTS AND DISCUSSIONS

A. Simulation Setup

The research finding in this paper were the results from COOJA emulator runs on the operating system of Contiki. It is an open source emulator designed for IoT applications. Table III shows the simulation configuration for this experiment.

The purpose of the simulation is to reveal how DIO_MIN_INTERVAL effects the power consumption of the RPL protocol. Different values of Imin for various combinations of network size and mobility speed are suggested by the fuzzy logic controller based on the fuzzy rules that are explicitly defined. Simulations were carried out in Cooja simulator to identify the significance of Imin value on power consumption. The simulations were repeated 5 times for the same set of parameters with a simulation time of 1.2e+6 ms for each simulation. The network density varies takes the values of 20, 30 and 40 out of which one node is considered as a sink and the remaining are treated as receiver nodes over a square environment (100m × 100m). The experimental nodes in the LLN are randomly located and linked. Mobility is also introduced to nodes as a part of the evaluation process. This simulation considered only TmoteSky.

Table III. Simulation Configuration Table

Parameter	Value
Network simulator	COOJA under Contiki OS
Number of nodes	20, 30 and 40
Simulated nodes	Tmote Sky
Routing Protocol	RPL
Deployment type	Random position
Radio environment	DGRM (Directed Graph Radio Medium)
Interference range	100m
Transmit and Received ratio	TX=100%, RX=100%
Total simulation time	1.2e+6 ms

The results of the simulations conducted during the research work are depicted below using five different types of power (i.e., Transmit Power, Listen Power, CPU Power, and Total Power). Fig 7 illustrates the comparison between transmit power when Defacto values of Imin are taken and the transmit power when Imin values are taken from the Fuzzy Logic. It clearly shows that the value of Imin generated using Fuzzy Logic will definitely lead to low transmit power whatever may be values of network size and mobility speed.

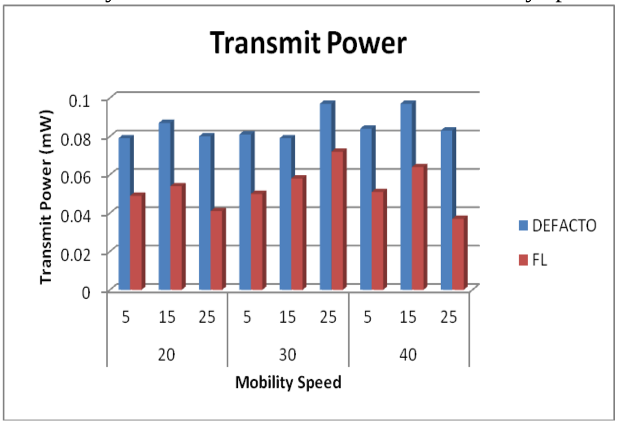

Fig 7. Defacto Transmit Power vs FuzzyLogic Transmit Power

As an example let us consider the transmit power at a network size of 30 and mobility speed of 15. The defacto transmit power is 0.079mW and for the same parameters of NS and MS, the fuzzy logic based transmit power is 0.058 mW.

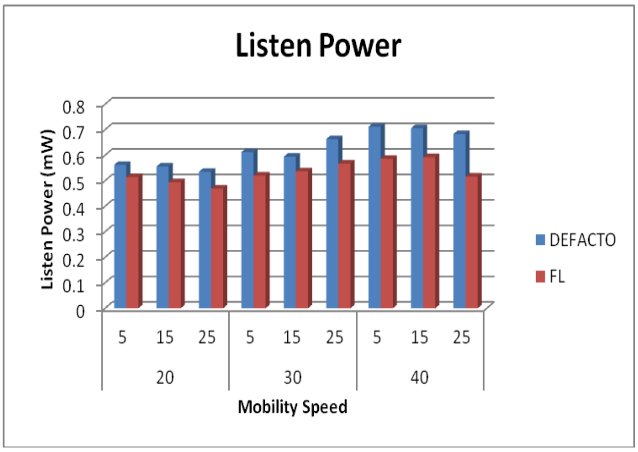

Fig 8. Defacto Listen Power vs FuzzyLogic Listen Power

Similarly, Fig 8 illustrates the comparison between listen power when Defacto values of Imin are taken and the listen power when Imin values are taken from the Fuzzy Logic.

For example, consider the listen power at a network size of 40 and mobility speed of 5. The defacto listen power is 0.712 mW and for the same parameters of NS and MS, the fuzzy logic based transmit power is 0.586 mW. It has a significant reduction in listen power when fuzzy logic values of Imin is utilized.

CPU power refers to the power consumption when the skymote is operating in full power mode. Fig 9 describes the comparison between CPU power when Defacto values of Imin are taken and the CPU power when Imin values are taken from the Fuzzy Logic.

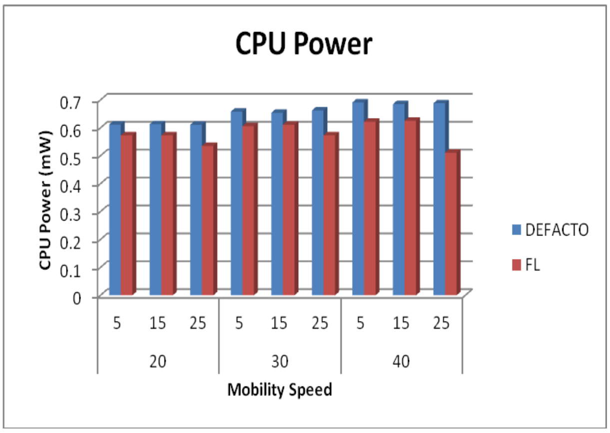

Fig 9 .Defacto CPU Power vs FuzzyLogic CPU Power

For example, consider the CPU power at a network size of 30 and mobility speed of 25. The defacto CPU power is 0.662 mW and for the same parameters of NS and MS, the fuzzy logic based transmit power is 0.573 mW. One can observe a noteworthy fall in CPU power when the fuzzy logic values of Imin is exploited.

The total power consumption is given by the sum of transmit power, listen power and CPU power. Comparison of defacto total power with fuzzy logic based total power is illustrated in Fig 10.

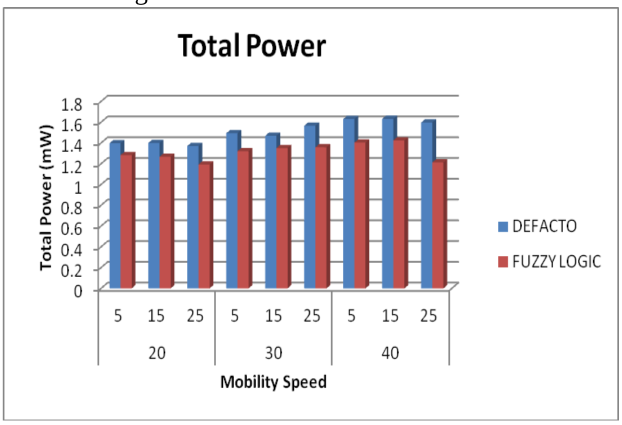

Fig 10. Defacto Total Power vs FuzzyLogic Total Power

Consider the total power at a network size of 20 and mobility speed of 5. The defacto total power is 1.397 mW and for the same parameters of NS and MS, the fuzzy logic based transmit power is 1.283 mW which has a considerable decrease in power consumption.

VI .CONCLUSION

This paper proposes a fuzzy-based energy efficient design approach that protracts the lifetime of a highly resource-constrained IoT network. This is achieved by reducing the power consumed by all the nodes in the network. A fuzzy logic controller was developed to combine the important parameters like Network Size, Mobility Speed and Imin that characterize a Skymote/node. Simulation results show that fuzzy logic based networks (i.e., Imin values) have around 50% less power consumption than their counter defacto networks (i.e., default Imin values). In this research article, on an average 55% power consumption was minimized by applying soft computing techniques like fuzzy logic.

VII .FUTURE SCOPE

Current simulations for extended durations were aimed for assessing the influence of only one parameter (namely Imin) value on the network lifetime. In the future, a combination of metrics (Lexicographic and Additive methods) can be used to assess their impact on the network lifetime as well as on the routing. A comparative analysis can be made to analyze the behavior of the motes in the constrained IoT environment. Similarly, it is also proposed that a multi-staged fuzzy model can be designed and implemented for making the RPL routing more and more efficient.

REFERENCES

1. R. Biradar, V. Patil, S. Sawant, and R. Mudholkar, “Classification and Comparison of Routing Protocols in Wireless Sensor Networks,” Special Issue on Computing Security Systems, UbiCC Journal, Vol. 4, pp. 704-711, 2009.
2. J. Al-Karaki and A. Kamal, “Routing Techniques in Wireless Sensor Networks: A Survey”, IEEE Wireless Communications, Vol. 11, No. 6, pp. 6-28, 2004.
3. O. Gnawali and P. Levis, “The Minimum Rank with Hysteresis Objective Function”, RFC 6719, Internet Engineering Task Force, Sep 2012.
4. Kevin Ashton, "Internet of Things", "RFID Journal", pp.97- 114, 2009.
5. H. Lamaazi, N. Benamar, M. I. Imaduddin, and A. J. Jara, “Mobility Support for the Routing Protocol in Low Power and Lossy Networks”, IEEE International Conference on Advanced Information Networking and Applications (AINA-2016), Le Régent Congress Centre, Crans-Montana, Switzerland, 2016.
6. P. Thubert, “Objective Function Zero for the Routing Protocol for Low-Power and Lossy Networks (RPL)”, RFC 6552, pp. 1–14, 2012.
7. Sharwari Satish Solapure, Harish Kenchannavar, “Internet of Things: A survey related to various recent architectures and platforms available”, IEEE International Conference on Advances in Computing, Communications and Informatics, Jaipur, India, pp. 2296 – 2301, 2016.
8. Chun-ming Tang, Ying Zhang, Yu-ping Wu, “The P2P-RPL Routing Protocol Research and Implementation in Contiki operating system”, IEEE International Conference on Instrumentation & Measurement, Computer, Communication and Control, Harbin, China, pp. 1472 – 1475, 2012.
9. Qusai Q.Abuein et al., “Performance Evaluation of Routing Protocol (RPL) for the Internet of Things”, International Journal of Advanced Computer Science and Applications, Vol. 7, No. 7, pp. 17 – 20, 2016.
10. Belghachi Mohamed, Feham Mohamed, “QoS Routing RPL for Low Power and Lossy Networks”, International Journal of Distributed Sensor Networks, USA, 2015.
11. Hanane Lamaazi, Nabil Benamar, Antonio J. Jara, “RPL-Based Networks in a static and mobile environment: a performance assessment analysis”, Elsevier Journal of King Saud University - Computer and Information, 2017
12. El-Hajj, W., Kountanis, D., Al-Fuqaha, A., & Guizani, M, "A fuzzy-based hierarchical energy-efficient routing protocol for large-scale mobile Ad Hoc networks (FEER)", IEEE International Conference on Communications, 8, 3585–3590, 2006