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Fuzzy Transmission Power Control Scheme for Maximizing Lifetime in Wireless Sensor Networks

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Abstract *Energy limitations have become fundamental challenge for designing WSNs. Network lifetime is the most interested and important metric in WSNs. Many works have been developed for prolonging networks lifetime, in which one of the important work is the control of transmission power. This paper proposes a new fuzzy transmission power control technique that operate together with routing protocols for prolonging WSNs lifetime. Dijkstra shortest path routing is considered as the main routing protocol in this work. This paper mainly focuses on transmission power control scheme for prolonging WSNs lifetime. A performance comparison is depicted for maximum and controlled transmission power. Simulation results show an increase in network lifetime equals to 3.4776 for the proposed fuzzy control. The performance of the proposed fuzzy control technique involves a good improvement and contribution in the field of prolonging networks lifetime by using transmission power control.*

***Index Terms*— Fuzzy logic, transmission power control, routing, network lifetime, WSNs**

I. Introduction

Recent years developments show serious progress in wireless networking. The progress and growth in wireless communication technology have made WSNs attractive for multiple application areas, such as medical and health, security surveillance, habitat monitoring, military reconnaissance, disaster management, industrial automation, etc. [1-4]. The development of small and ubiquitous WSNs computing devices is ultimately required. WSNs are comprised of considerable number of limited capabilities sensor nodes with one or more high capability base stations. Each sensor node is a small embedded system, low-power, low-cost, multi-functional [3] Each sensor node performs several functions: sensing, data processing, and communication. Sensor nodes perform wireless communications with each other in order for delivering gathered data to base station. The development of ubiquitous, inexpensive, small and low-power computing devices became available through miniaturization technologies [3]. Due to this, using multi-hop communication help to reduce transmission distance as well as increasing network lifetime. Every node consists of four parts: a processer, sensor, transceiver, and battery. Nodes involve bounded power source with abilities of sensing, datum processing along with communication. The onboard sensors collect datum about the environment through event driven or continuous working mode. The gathered datum may be temperature, pressure, acoustic, pictures, videos, etc. The gathered datum is then transferred across the network in order to form a global monitoring view for objects [5,6].

Since bounded energy source is involved, energy exhaustion is the most important metric for WSNs. In order for prolonging networks lifetime, energy exhaustion must be well managed [7,8].

One of major problems in characterizing WSNs refer to energy saving. The network lifetime may reduce significantly if the energy exhaustion is not well managed and may lead to network partition quickly. Several techniques might be used for maximizing networks lifetime, in which one of them is transmission power control. Since the major of energy exhaustion is related to nodes communication, transmission power control leads to significant improvements for the operation of WSNs. Transmission power control produce several benefits. First, establishment of links with high reliability. Power control would ensure that the communication would established with optimized energy exhaustion along with superior employment of the medium [10-12]. Sensor nodes that communicate using fixed transmission power will spent extra energy with high prospect for successful delivery. Thus, the transmission power control can assists for decreasing transmission power with an appropriate level that ensure high link quality with low energy consumption. Sensor nodes that communicate with a proper transmission level would not cause an interference with other nodes communications. This also leads to reduce the collisions in the network, enhanced network utilization, lower latency, and reduce the retransmission.

This research suggests new fuzzy transmission power control scheme. The main goal of suggested technique refer for selecting the best transmission power level so that the energy exhaustion is minimized along with prolonged overall network lifetime.

The paper is organized as follows. Related work is presented in section II. The proposed transmission power control method is described in section III. Simulation setup and configuration is depicted in section IV. Section V presents simulation results and discussion. Conclusion is depicted in section VI.

II. Related Work

The primary considerations in WSNs is designing energy efficient system. WSNs transmission power control has been used to minimize energy exhaustion and maximize overall network lifetime. Transmission power control is responsible for adjusting transmission power to the appropriate level with the investigating of minimum energy exhaustion and maximizing the network lifetime. Maximizing network lifetime has gained significant interest in recent years.

Neeraj et al. [9] presented a mechanism for transmission power control management. The proposed method saves the battery power of sensor nodes by bringing down transmission power exhaustion of radio during datum transmission depending on LQI. The proposed mechanism uses programming if-then to adjust the transmission power. The proposed method has compared with the system without transmission power control. Simulations demonstrate that suggested mechanism consume energy less than without transmission power control.

The work proposed by Deyun et al. [10] presents a transmission power control method that runs out under routing protocol in MAC layer. The method operates with routing protocol by determining optimum transmission power predicated on distance between neighbor nodes. The proposed method find the optimum transmission power level using mapping table in the routing protocol. They realize their scheme by setup a test-bed for depicting performance. Experiments show a decrease in packet collisions, energy exhaustion and significant improvement in the network performance.

Jang-Ping et al. [11] suggested a distributed algorithm for transmission power control. For this algorithm, each node utilizes radio RSSI with LQI values for determining appropriate broadcasting power for its neighbors. Experimental results, in comparison with AMTP, demonstrate that the proposed algorithm can retain energy of about 20% - 30% and undertaking adequate link quality for any two nodes communications.

The work proposed by Jianhui et al. [12] suggests a method for transmission power adjustment based on fuzzy control theory. Simulation of the suggested method involves two forms of deployment, regular and random. Results has compared with LMA and LMN methods. Simulation results demonstrate that this technique is powerful for tolerate accidental interfere, rapid convergence, and more energy efficient, which leads to prolonging the network lifetime.

Kritchai et al. [13] proposed a practical approach to control the transmission power. The proposed method achieved by implementing a closed-loop model predictive control mechanism within a nominal state-space tracking error based dynamic model that uses the RSSI related to SINR as state feedback signal. The resulting controller has compared with other strategies and has experimentally validated for different test scenarios.

The work proposed by Junseok et al. [14] presented an ODTPC algorithm. In this algorithm, each node calibrate the optimum level for broadcasting power fastly with no starting period besides the ability for dynamical maintaining broadcasting level along time with no increment in datum. In addition, this algorithm has combined with AODV routing protocol and results have evaluated. Experimental results demonstrate the suggested algorithm has reduced the broadcasting energy exhaustion along with maintaining good quality links.

Jaein et al. [15] presented an experimental dynamic transmission power control algorithm based on model predictive control. The proposed algorithm has evaluated on realistic WSN workloads and a large Mica2dot based test bed. The proposed method is compared with fixed transmission power. Experimental results demonstrate that suggested technique has reduced power exhaustion to 16% minimum.

The work proposed by Shan et al. [16] presented an adaptive transmission power control for WSNs. They introduced a lightweight algorithm for adaptive power broadcasting control in a pairwise manner for WSNs. For the proposed method, nodes involve building models for their neighbors and specifying correlation among broadcasting energy along with link quality. Depending on this, the suggested technique controls the system besides preserving adequate links quality. Experimental results demonstrate that suggested method has reduced energy exhaustion in the network along with making the impact of collision and interference less serious.

III. The Proposed Transmission Power Control Technique

The suggested transmission power control scheme involves Fuzzy logic system control. This section deals with the design of fuzzy control scheme based routing that adjusts the output transmission power level of the wireless sensor node. The main objective of the suggested control scheme is determining transmission power level to reserve more energy as much as possible so that every node adjusts its transmission power level with environmental changes quickly and maintains good link quality.

The controller is suggested to be work in each sensor node. The closed-loop control structure is depicted in figure 1. In each sensor node, the input to the controller is the error between the estimated distance and the current distance and the output is the adjusted transmission power level that is used to send data from current node (source node) to next node (destination node). The controller adjust the power level to be used for transmitting data, so that energy exhaustion is minimum, and lifetime is increased.

A. Design of Fuzzy Controller

Fuzzy logic was first suggested by Zadeh in 1965 [17]. Fuzzy systems implementation was expanded for wide applications like systems identification and control. Fuzzy systems are robust, easy to implement and has the advantage of processing non-linear systems. Fuzzy logic performs information analysis using fuzzy sets. Fuzzy rules combines the fuzzy sets using logical operations. Fuzzy sets are defined by the used membership function shape. Selecting MF is substantial in FL because the choice of right MF provides proper interpretation.

For proposed transmission power control scheme, the purpose of the fuzzy controller has assigned for determining optimum level value for transmission power. Figure 2 depicts the proposed fuzzy controller with couple of inputs, error (E) together with change of error (EC). In this paper, the parameters of MICA2 MPR400CB wireless sensor mote is considered [18], whose involves high efficiency Atmel ATmega 128L microcontroller as well as tunable frequency radio. Also it involves couple operating band ranges: 868–870MHz plus 902–928MHz. This device involve adjustable transmission power between −20dBm and 5dBm in centric frequency 915MHz.

According to the MICA2 MPR400CB parameters, The universal of discourse for inputs error (E) with change of error (EC) beside fuzzy control output (u_f), are specified as [-6,30], [-

20,20], [-25,25], respectively. When the error (E) between estimated distance and current distance exceeds higher or lower limits, it resets to these specified limits. The same case is applied for change of error (EC). The proposed design of our fuzzy controller uses eight MFs for error (E) input with nine MFs for change of error (EC) and nine membership functions for fuzzy control output (u_f). The shape of the MFs for inputs error with change of error besides fuzzy control output (u_f) with lingual variable meaning are depicted in figure 3. FL system decision surface is depicted in figure 4.

For fuzzy logic system, inference engine composed of the rule base along with processing the fuzzified values. The rule base involves groups concerning IF-THEN rules, which related to fuzzy input with fuzzy output variables, and by involving lingual variables, everyone will qualified depending on sets specified with logical operators. We have used a total 72 fuzzy rules in our design. Table I shows the rules that are considered in the proposed fuzzy based transmission power control technique. Any rule that fire will share out in the final fuzzy solution calculation. By involving area center technique with reference to defuzzification, the final crisp value is calculated which represent the fuzzy controller output (u_f). Equation (1) describe area center defuzzification method.

$$fuzzy\ control\ output\ (u_f) = \frac{\sum_{i=1}^{n} R_i * c_i}{\sum_{i=1}^{n} R_i} \quad (1)$$

where, R_i represents output of rule base i, and c_i represents center of output membership function.

IV. Simulation Setup and Configuration

Simulation is carried out in MATLAB. A topological areas of (500mx500m) is considered in this paper. A 100 sensor nodes are randomly scattered for the topological area. One base station "Sink" has been used for the topological area. The position of the sink is (450m,450m). According to MICA2 MPR400CB [18], every node operates with maximum transmission range equals to 150m. Receiving sensitivity for mentioned sensor mote has minimum value equal to −98dBm. Every node has initial energy equals to 5J. Datum rate has set to 19.2Kbaud. Network involve broadcasting messages with one packet per time epoch rating for each node. A 200 bit packet length is used for simulation. The transmission power exhaustion depend on transmission power level, and is computed by involving Table II. Table II detailed the output power level and its corresponding current exhaustion. Dijkstra shortest path routing is considered for this simulation. This paper mainly focuses on transmission power control scheme along with routing techniques. The proposed routing technique utilized with first order radio model proposed by Heinzelman [19]. This model is shown in the following equations.

$$E_{Tx}(pkt_{length}) = E_{elec} * pkt_{length} + E_{amp} * pkt_{length} * d^2 \quad (2)$$

$$E_{Rx}(pkt_{length}) = E_{elec} * pkt_{legth} \quad (3)$$

where, E_{Tx} and E_{Rx} are energy exhaustion related to transmitting and receiving, respectively. pkt_{length} represent number of bits per packet. d represents distance between two communicating nodes. E_{elec} represents per bit energy exhaustion for broadcasting or receiving for electrical hardware. E_{amp} is the per bit per meter square energy exhaustion. The value of E_{elec} is equals to 50nJ/bit [19].

The proposed controller suggested operating as follows. First, the source node finds all of its neighbor nodes, and selects a node to send it the data packets. The routing protocol is responsible for choosing this node from all neighbor nodes. After the routing protocol selects the optimal node to send data (the destination node), the controller start sending Hello message towards destination node and receives an Acknowledge message from it. From the received Acknowledge message, the controller measures the received signal strength indicator (RSSI) magnitude then estimates the distance between the two nodes. Depending on estimated distance, suggested controller adjusts transmission power value. This operation is repeated for each node like to send data packets to another neighbor node.

V. Simulation Results and Discussion

Simulation is carried out for the specified topological area. The dijkstra routing protocol is considered for this simulation as the base routing protocol. Two scenarios are used for simulation, which are Dijkstra routing with (1) maximum transmission power, and (2) fuzzy transmission power control. A comparison has been made for these two scenarios in term of overall network lifetime, average remaining energy, average consumed energy, simulation time, and output transmission power. The number of alive nodes has been used to give indication about the lifetime of the WSNs. Network lifetime considered is period from starting work of network till first sensor node dies or exhausts its energy. A network partition feature has been activated for the simulation. Network partition is working out when any of the 100 deployed sensor nodes has not finds neighbor nodes to send data packet. This is due to the dyed sensor nodes. Hence, simulation is stopped when network partition is occurred.

Figure 5 depicts simulation results of the topological area, for network lifetime (number of still alive nodes till network partition). From this figure, obviously that FL transmission power controller is better choice for transmission power control against maximum transmission power. It shows an increase in the overall network lifetime equals to 3.4776. The fuzzy transmission power control show less energy consumption and as result, the lifetime is maximized. A summary of the lifetime and the improvements is detailed in table III. Results reflect the significant improvements of the control of the transmission power, so that energy exhaustion has decreased and network lifetime has increased.

Figure 6 illustrates the average remaining energy for the two scenarios. From this figure, the average remaining energy for fuzzy transmission power control is higher than the max transmission power. This figure shows the significant decrease in energy consumption by applying the proposed scheme, so that the overall lifetime of the network is increased significantly.

Figure 7 illustrates average consumed energy for illustrated topological area. From this figure, average consumed energy for proposed fuzzy controller is less than maximum transmission power. The key effect of proposed transmission power control is reducing energy consumption by adjusting a proper transmission power level depending on distance between nodes, which leads to minimize total energy exhaustion along with maximize network lifetime. This reflect efficiency of proposed fuzzy controller for decreasing energy exhaustion besides prolonging network lifetime.

Figure 8 illustrates the packet delivery ratio for the illustrated topological area. It shows a unity value for this area. This value is related to the routing protocol under consideration, which is the Dijkstra routing.

Figure 9 depicts the maximum number of hops used by the Dijkstra routing protocol. As mentioned before, Dijkstra routing uses fixed paths for delivering packets to the sink. Therefore, no significant change in the route path as shown in this figure, and this is a drawback of Dijkstra routing method.

Figure 10 depicts average simulation time “end-to-end delay” for illustrated topological area. Average simulation time refers to average time of complete rounds for transmitting datum packets from source nodes towards the base station. From this figure, simulation time for proposed fuzzy controller is higher than maximum transmission power due to more computations required by the control system.

Figure 11 illustrate the average output transmission power for the proposed topological area. This figure show the effectiveness of fuzzy controller as it shows a significant downgrade in output transmission power.

All results reflect the significant improvement and contribution of the fuzzy based transmission power control.

VI. CONCLUSION

WSNs available with limited source power through their life cycle. Since the battery of the sensor node is difficult to be replaced or recharged, energy preservation involves crucial issue for designing the WSN infrastructure. In this paper, a new technique for maximizing WSNs lifetime and minimizing energy exhaustion is proposed. This new technique involves the fuzzy transmission power control scheme. Simulations demonstrate that proposed fuzzy transmission power control technique has good performance than the max transmission power and a contribution to the control problem of transmission power. Simulation results show an increase in network lifetime equals to 3.4776 for the proposed fuzzy control. Average remaining energy for the proposed technique is higher than the system without control. This reflects the well optimization for energy consumption. The proposed fuzzy controller has reduced the level of output transmission power significantly.

Simulation results show that the lifetime is maximized and the energy exhaustion is reduced. The performance of the proposed fuzzy control technique involves a good improvement and a good contribution in the field of maximizing WSNs lifetime by using transmission power control techniques.

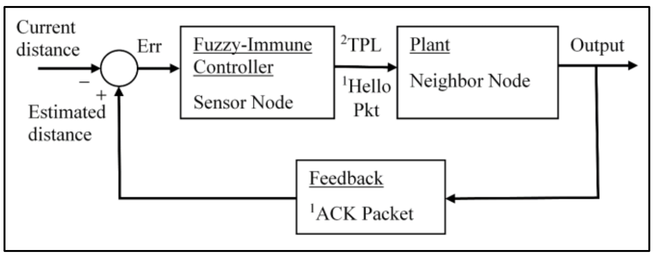

Fig. 1. The proposed node control architecture

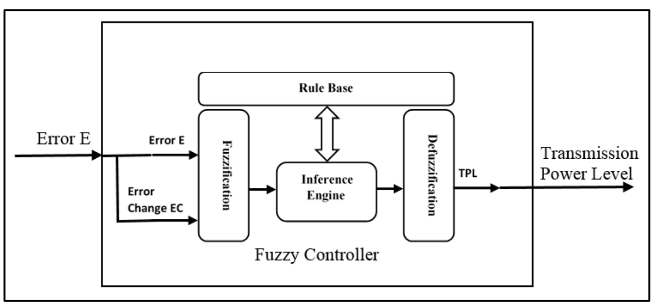

Fig. 2. The proposed fuzzy logic control scheme

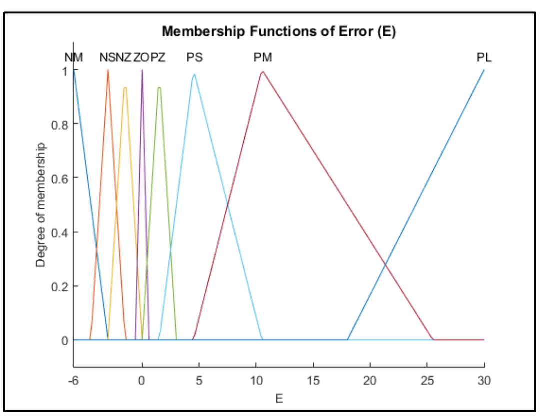

Fig.3(a). The memberships of the error (e)

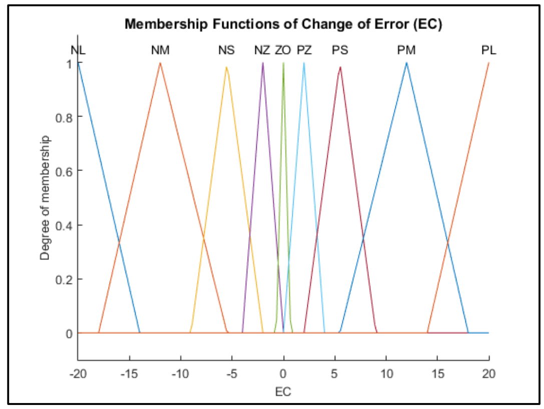

Fig.3(b). The MFs of the change of error (ec)

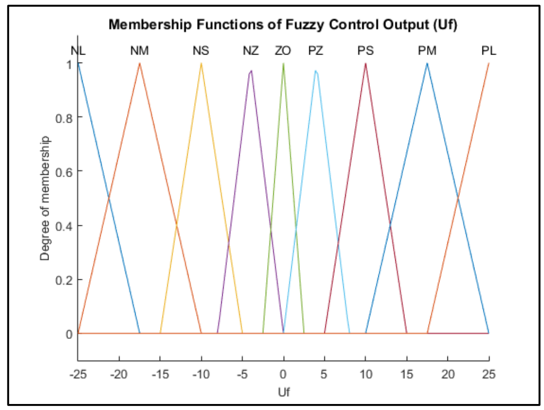

Fig.3(c). The MFs of the fuzzy control output (u_f)

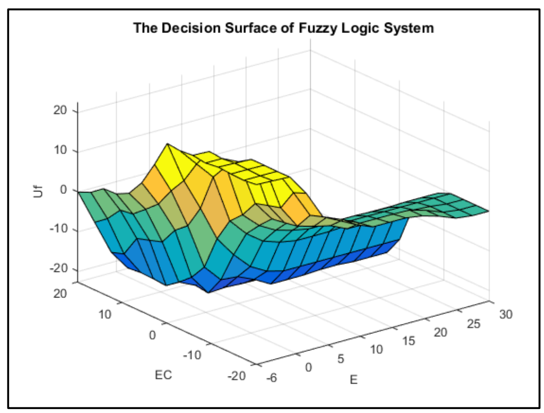

Fig.4. The decision surface of fuzzy logic system

TABLE I
FUZZY IF-THEN RULES

E/EC	NL	NM	NS	NZ	ZO	PZ	PS	PM	PL
NM	PL	PL	PL	PL	PL	PM	PS	PZ	ZO
NS	PL	PL	PL	PM	PS	PZ	ZO	NZ	NS
NZ	PL	PL	PM	PS	PZ	ZO	NZ	NS	NM
ZO	ZO	ZO	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PZ	PM	PS	PZ	ZO	NZ	NS	NM	NL	NL
PS	PS	PZ	ZO	NZ	NS	NM	NL	NL	NL
PM	PZ	ZO	NZ	NS	NM	NL	NL	NL	NL
PL	ZO	ZO	NZ	NS	NM	NL	NL	NL	NL

TABLE II

OUTPUT POWER AND CURRENT EXHAUSTION

P_{out} (dBm)	-20	-19	-18	-17	-16	-15	-14
Current (mA)	8.6	8.8	9.0	9.0	9.1	9.3	9.3
P_{out} (dBm)	-13	-12	-11	-10	-9	-8	-7
Current (mA)	9.5	9.7	9.9	10.1	10.4	10.6	10.8
P_{out} (dBm)	-6	-5	-4	-3	-2	-1	0
Current (mA)	11.1	13.8	14.5	14.5	15.1	15.8	16.8
P_{out} (dBm)	1	2	3	4	5		
Current (mA)	17.2	18.5	19.2	21.3	25.4		

TABLE III

NETWORK LIFETIME AND PARTITION TIME

Technique	Lifetime	Partition Time	PDR
Dijkstra Routing with Max Transmission Power (No Power Control)	201	1198	1
Dijkstra Routing with Fuzzy Controller	900	3862	1

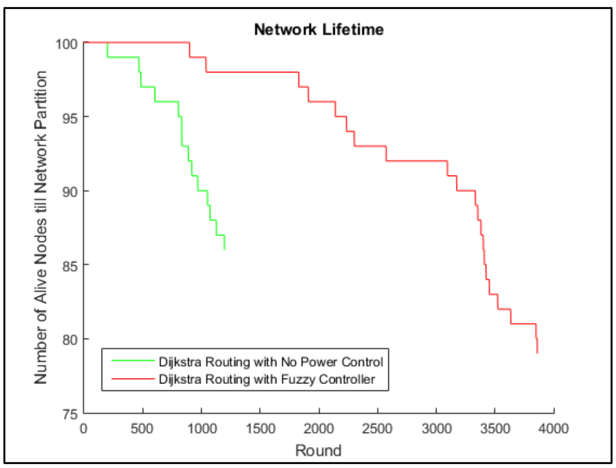

Fig.5. Network Lifetime (No. of Alive Nodes)

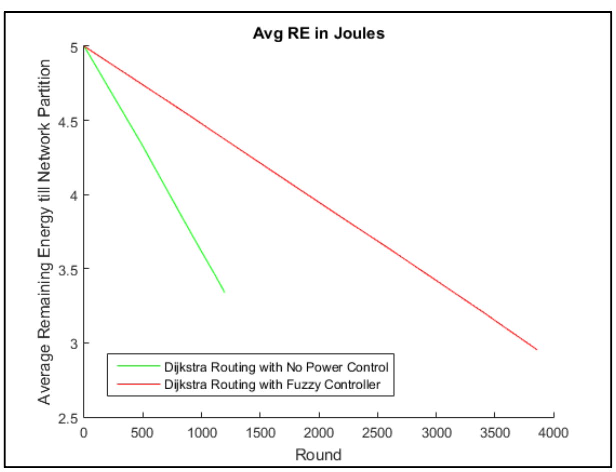

Fig.6. Average Remaining Energy

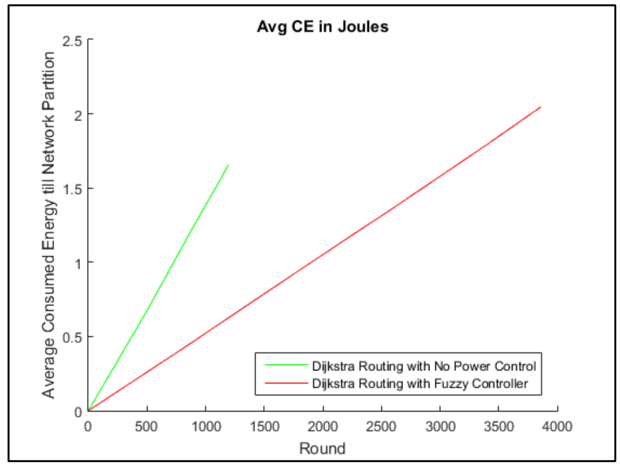

Fig.7. Average Consumed Energy

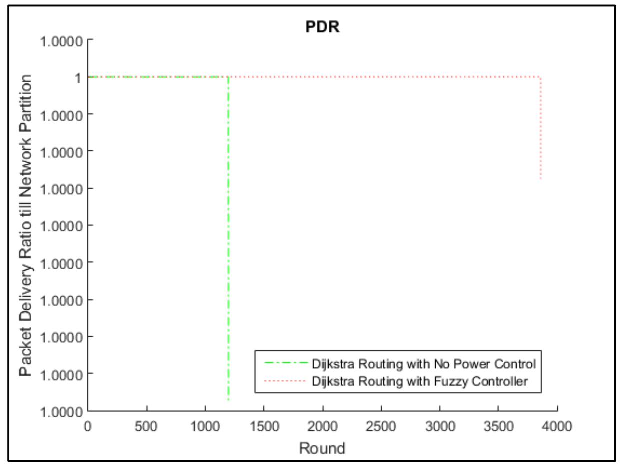

Fig.8. Packet Delivery Ratio

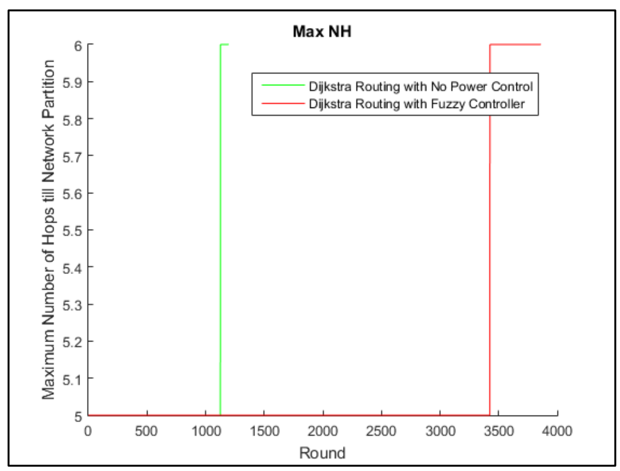

Fig.9. Maximum Number of Hops

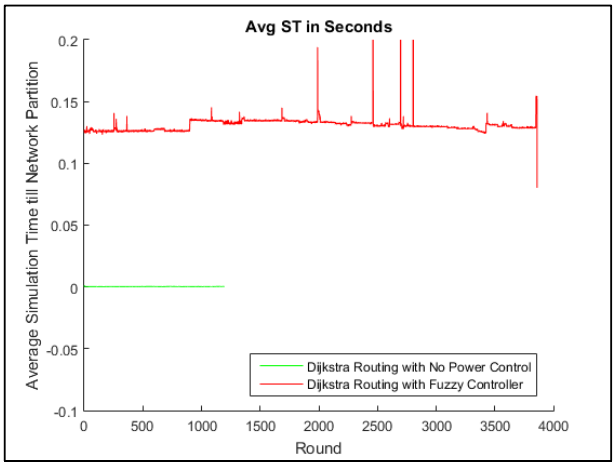

Fig.10. Average Simulation Time

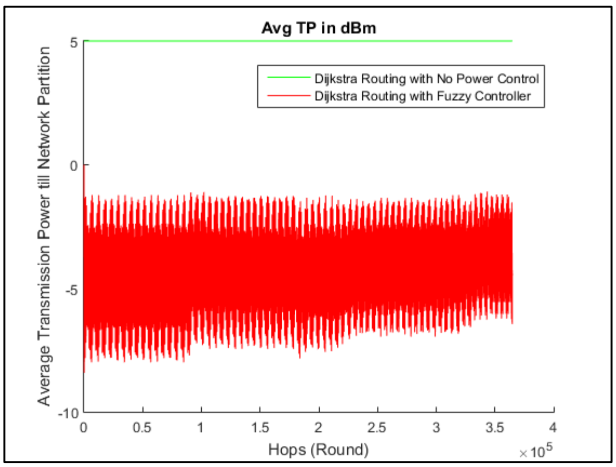

Fig.11. Average Output Transmission Power

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