Journal of Theoretical and Applied Information Technology
20th June 2016. Vol.88. No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

POWER CONSUMPTION OPTIMIZATION ANALYSIS BASED ON BERKELEY-MAC PROTOCOL USING TAGUCHI AND ANOVA METHODS FOR WSN

[1]ALAA KAMAL, [2]M.N. MOHD. WARIP, [3] MOHAMED ELSHAIKH , [4] R.BADLISHAH

[1,2,3,4] Embedded Network and Advanced Computing Research Cluster, School of Computer and Communication engineering, *University Malaysia Perlis, Level 1, Pauh Putra Main Campus, 02600, Arau, Malaysia*

E-mail: [1]kamalyousif@studentmail.unimap.edu.my, [2]nazriwarip@unimap.edu.my , [3]elshaikh@unimap.edu.my , [4] badli@unimap.edu.my

ABSTRACT

Wireless sensor network (WSN) consists of sensor nodes is used to gather information about a physical object or process. On WSN, the sensor nodes deploy in a large region with the harsh environment and limited capacity power. Due to the adhered reason, the energy consumption it is a main critical factor affecting the operational lifetime of individual nodes and the entire network. The energy consumption in medium access control (MAC) for wireless sensor network (WSN) affected by many reasons collision, overhearing, Idle Listening, Control Overhead. The optimizing power consumption is a challenge to prolong lifetime network. In the literature, there are many efforts paid to design and improve the protocols for MAC layer to conserve power consumption. However, few efforts are paid for optimizing the existing protocols. This paper focus in Berkeley – MAC protocol optimizing power consumption and network performance by Taguchi method. Taguchi method is a statistical method to optimize the process and improve the quality. Moreover, Taguchi methods used to optimize the energy consumption for B-MAC. Simulation experiments are carried out on the discrete event simulator OMNET++ for the purposes of this research paper. The obtained results show the effect of the B-MAC parameters protocols toward the energy consumption.
Keywords: *Berkeley MAC Protocol*, *Optimization, Power Consumption, Taguchi Method, WSN*

1. INTRODUCTION

Wireless Sensor Networks (WSN) it has become one of the important technologies in last years. Enabled the evolution in microelectronic mechanical systems (MEMS), smart sensors open broader prospects in the areas of variety military applications, environmental monitoring, and industry process control. A WSN consists of sensor nodes that are deployed in a region of interest in hard environment can't change or replace. These sensor nodes are sensing and data processing and communicating capabilities. They communicate over a short distance via a wireless medium and cooperation to fulfill tasks, Sensors can be used to monitor a sort of physical parameters. Sensor nodes have very limited energy resources, traditional MAC protocols are not suitable for being used in WSN without modification [1]. In B-MAC protocols there many parameters can affect the power consumption and overall performance. Some parameters are listed for B-MAC protocol, slot duration, Check interval, Bit rate, max transmission power, Header Length, Queue length. In literature, there has an amount of researches MAC protocols in WSN network. Recently, there are an amount of research in MAC protocols to summarize the diversity of designs and implantations. In 2015, A. Verma et al. [2] provides a brief analysis of some of the popular MAC layer protocols which could be helpful on energy conservation. M. Bagaa et al., 2014 [3] using data aggregation scheduling solutions. The schedule network nodes in order to make the data aggregation process more efficient against performance criteria such as data latency and accuracy, energy consumption, and collision avoidance. R. C. Carrano et al., 2014 [4] focus on duty cycle scheme in the design of Wireless Sensor Networks to conserve energy . In last year's, there many duty cycle approach achieving ultra-low duty

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

cycles as low as 0.1%. Duty cycling affected by other aspects as topology dependency, network density requirements and increase in end-to-end delay. K. Chen et al. [5] explain Underwater Wireless Sensor Networks (UWSN) has attracted attention. Authors describe the underwater acoustic environment and the challenges to the MAC protocols design in UWSN like (latency, throughput, and energy efficient). In 2012, P. Huang et al. [6] authors concern about MAC protocols designed to evaluate the energy Efficiency, data delivery performance, and overhead. It can find many works in the literature for designing and implementation of MAC protocols that aimed to conserve the energy consumption in WSN MAC layer, however, a few works are dedicated to optimizing and analyzing the impact of the parameters protocols set on the energy consumption. This paper aimed at investigating the impact of B-MAC parameters set on the energy consumption for WSN by Optimization methodology namely (Taguchi method). Simulation experiments are done to optimize and analyze B-MAC protocol parameters set against energy consumption, throughput, and packet delivery ratio. The paper is organized as follow: section 2 gives an overview of Taguchi method. Section 3 describes the Design parameters of this work, and we conclude this paper in Section 4.

2 METHODOLOGY

To demonstrate B-MAC parameters and measure the power consumption result, this experiments used Taguchi methods. The Taguchi method is statistical approach developed by Dr. Genichi Taguchi at 1960 .Initially, it was developed for improving the quality of goods manufactured, and later it was extent for other engineering fields. Other approach needed a large number of experiments to reach the optimal result and this so complex to overcome this problem use of the orthogonal array to study the entire parameters with the less number of experiments. Taguchi thus, use of the loss function to calculate an optimal value from parameters. The value of this loss function is signal- to -noise (S/N) ratio. There are three standard types of SN ratios depending on the desired performance response [7] [8]:

- Smaller the better (for making the system response as small as possible):

$$SNs = -10 \log 1/n \sum_{i=1}^{n} y^2 \qquad (1)$$

- Nominal the best (for reducing variability around a target):

$$SN_n = 10 \log \sum_{i=1}^{n} y^2/s^2 \qquad (2)$$

- Larger the better (for making the system response as large as possible):

$$SN_L = -10 \log 1/n \sum_{i=1}^{n} (1/y^{2)} \qquad (3)$$

Where
i= Experiment number
n = Number of trials for experiment i
y= the mean of experiment i
s =Standard deviation of experiment i

2.1 Taguchi Method Design Of Experminet

The general steps involved Taguchi method are as follows:

1- Identify the main process objective it is a target value of the process. Generally, the target of the process could be a minimum or maximum.
2- Define the design factors affecting the process. The factor is variables with the process that impact the performance measure, and the number of levels should be varied for each factor.
3- Create an orthogonal array and construct the matrix for parameters design indicating the number of and conditions for each experiment. Selection orthogonal array depended on a number of Factors and levels of variation for each Factor.
4- Conducting experiments from an orthogonal array to collect data that effect on the performance measure.
5- Data analysis to determine the impact of the different factors on the performance measure.

Below Figure 1 explain all phases for Taguchi methods, depending the complexity of the analysis that was used in this research.

Journal of Theoretical and Applied Information Technology
20th June 2016. Vol.88. No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

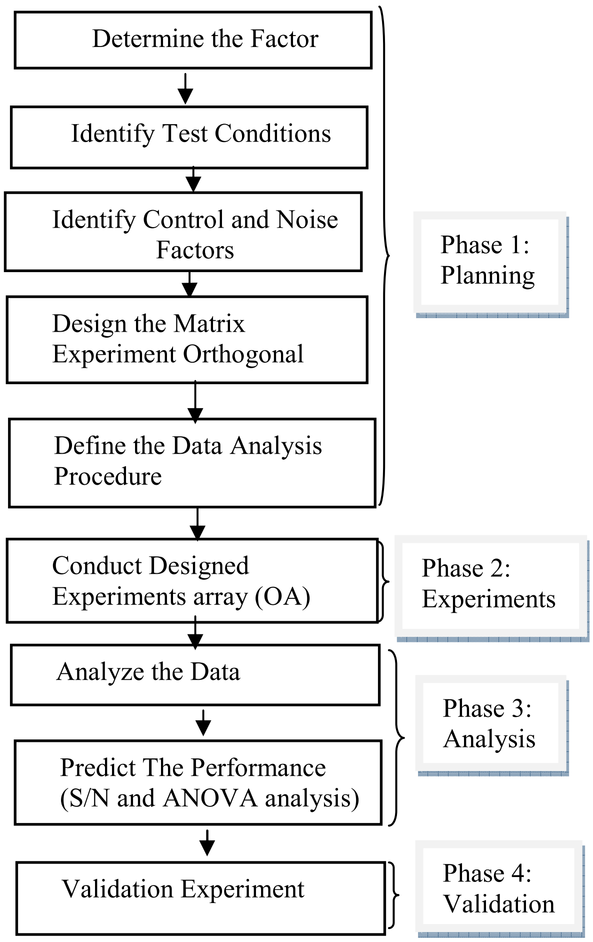

Figure 1: Steps of Taguchi parameter design.

3. EXPERIMENTS DESIGN

In accordance with steps that are involved Taguchi methodology a series of experiments are to be conducted.

3.1 Phase 1: Planning

Before proceeding on further steps, it necessary to define list down all the factors that are going to affect. The factors that affect B-MAC protocol are listed in the Table 1.

Table 1: Factor that affect B-MAC protocol

Control factors	Nosie factors
Slot duration	useMacAcks
Bit rate	maxTxAttempt
Check interval	Nil
Max power transmission	Nil
Header Length	Nil
animation	Nil
Queue length	Nil

After listing the factor affect the B-MAC control and the noise factors, decide on the factors that have an important effect on the performance and only those factors must be taken into consideration in constructing the matrix for experimentation. All other factors look like Noise Factors. The object from optimizing B-MAC it minimizes the energy consumption, in Taguchi method using Smaller the better Equation 1 to do optimize. The factors and their levels were decided for conducting the experiment. The factors and their levels are shown in Table 2.

Table 2: Factors and Levels for B-MAC protocol

Control factors	levels		
	1	2	3
Slot duration (s)	0.0025	0.00125	0.0006
Bit rate (bps)	4915200	9830400	19660800
Check interval (s)	0.001	0.002	0.004
Max power transmission (mw)	1	2	4

After identify the objective function and control factors, must select the appropriate the orthogonal array for conduction the experiment .the most suitable orthogonal array for experimentation is L9 (3^4) array as shown in Table 3.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 3: L9 (3^4) Orthogonal Array

Experiment NO	Control factors			
	Slot duration	Bit rate	Check interval	T_X power
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

According to the orthogonal array L9 (3^4), the experiments were conducted with the factors and their levels as mentioned in Table.2. The experimental layout with the selected values of factors nine experiments is carried out as shown in Table 4.

Table 4: Measure Values for B-MAC protocol

Experiment NO	Control factors			
	Slot duration	Bit rate	Check interval	Tx power
1	0.0025	4915200	0.001	1
2	0.0025	9830400	0.002	2
3	0.0025	19660800	0.004	4
4	0.00125	4915200	0.002	4
5	0.00125	9830400	0.004	1
6	0.00125	19660800	0.001	2
7	0.0006	4915200	0.004	2
8	0.0006	9830400	0.001	4
9	0.0006	19660800	0.002	1

3.2 Phase 2: Expermients

According to the Measure Values for B-MAC protocol as mention in Table 4. The experiments for this paper carried out in the OMNET++ simulator. The parameters used in WSN simulation shown in Table 5.

Table 5: Simulation parameters in OMNET++

Attribute	Value
Network	WSN
Simulation area	200×200 m^2
Simulation time	250 s
Transport layer	UDP
MAC layer	B-MAC
Message length	512-768-1024-1280 bps
Random seed generation	8 times

3.3 Phase 3: Analysis

The main objective of this research is to reduce the energy consumption for B-MAC protocols at WSN by using Taguchi method. When to minimize power consumption this effect to network performance, so the first experiment minimizing the power consumption, the second maximizing the throughput, and the last one maximize the packet delivery ratio (PDR). The Taguchi method has three equations each one of them is designated for a certain category of targets, to minimize the power consumption used Equation 1 (Smaller - the - better) and maximize the throughput and PDR used Equation 3 (Larger - the - better) . Typically, each of the nine experiments was conducted 8 times to account for the variations that may occur due to the noise factors for every experiment.

3.3.1 ANALYSIS RESULT

In this paper, three performance parameters are optimized power consumption, throughput and packet delivery ratio.

3.3.1.1 Power Consumption

Power consumption is the total power consume by all hosts in the network. In Figure 2. The graphs showing the mean S/N smaller the better (Equation 1) power consumption response against control factors. The obtained results show that the optimized B-MAC protocol for minimum power consumption could be achieved by implementing the slot duration 0.0006 S this result the best value for decrease power consumption. The adhered results explain the effect of the slot duration values on the power consumption. The second factor is the bit rate, three values are chosen, typically, 4915200bps, 9830400bps, 19660800pbs; and the results explain that the optimum bit rate it is19660800pbs. The third factor is Check Interval and the results explain that the value gives the minimum the power consumed 0.002 S. The last

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

parameter is the transmission power, where three levels of transmission power are used (1, 2, 4 mW) and the optimization results come in the favor of high transmission power.

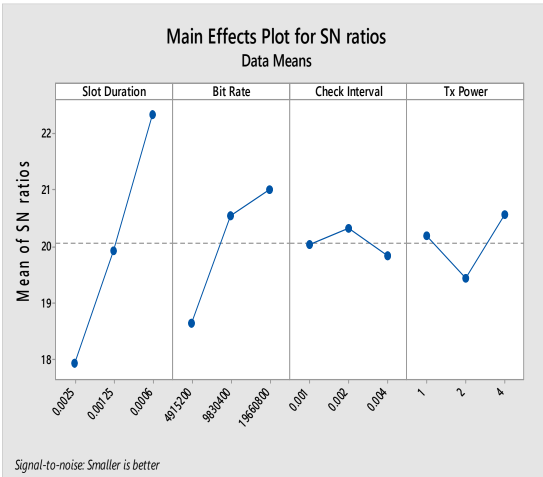

Figure 2: Parameters levels vs. B-MAC factors for power consumption

Table 6: Power consumption S/N response

level	Slot duration	Bit rate	Check interval	Tx power
1	17.93	18.63	20.03	20.19
2	19.91	20.54	20.32	19.43
3	22.33	21.00	19.82	20.55
delta	4.40	2.37	0.49	1.13
rank	1	2	4	3

Table 6 shows the S/N response, the Slot duration has the biggest impact on the power consumption, While the Check interval has the least effect on the power consumption. For calculating the B-MAC protocol the objective function, "smaller-the-better" type was used. The factor levels corresponding to the highest S/N ratio were chosen to optimize the condition. From linear graphs, it is clear that the optimum values of the factors and their levels are as given in Table 7.

Table 7: Optimum Values For Minimum Power Consumption

Parameters	Optimum Value
Slot Duration	0.0006 s
Bit Rate	19660800 bps
Check interval	0.002s
Tx power	4 mw

3.3.1.2 Throughput

Throughput is the total amount of data received (bytes) per time unit (seconds). To calculate the throughput, the traffic generated at each host is dedicated to a single server, and UDP protocol is used. Figure 3 Presents graphs of the means S/N larger is better Equation 3 throughput against the control factors.

Throughput (bit) = ∑ Number of packet receive* 8 / time simulation

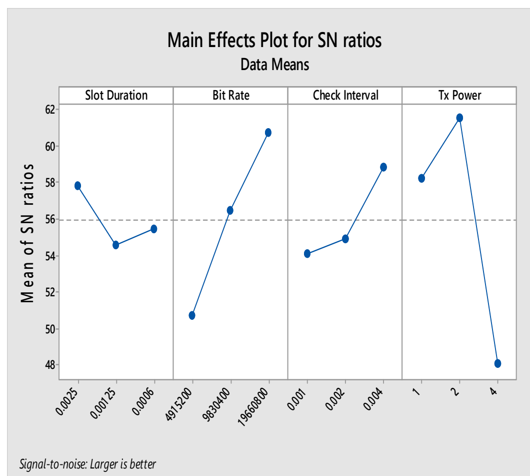

Figure 3: Parameters Levels Vs. B-MAC Factors For Throughput

From Figure 3, we can conclude that the optimum value of factors in terms of Throughput are, slot duration 0.0025 s bit rate 19660800 bps, check interval 0.004 s, transmission power 2 mw.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 8: Throughput S/N response

level	Slot duration	Bit rate	Check interval	T_x power
1	- 6.106	-13.057	-9.683	-5.504
2	-9.156	-7.790	-9.301	-2.729
3	- 8.274	-2.697	-4.560	-15.311
delta	3.059	10.361	5.123	12.582
rank	4	2	3	1

As for the effect of the control factors, Table 8 explain the response for the control factors and their variances. The response table results show that the transmission power (Tx power) is the major factor in the Throughput, and slot duration factor has the lowest effect on the Throughput.

3.3.1.3 Packet Delivery Ratio (Pdr)

Packet delivery ratio: the ratio of the number of delivered data packet to the destination. This illustrates the level of delivered data to the destination. Figure 4 presents graph of the means S/N larger is better Equation 3 packet delivery ratio against the control factors.

PDR= ∑ Number of packet receive / ∑ Number of packet send.

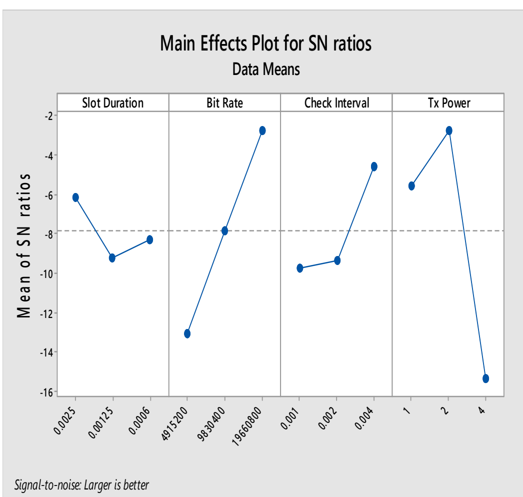

Figure 4: Parameters Levels Vs. B-MAC Factors For PDR

From the Figure 4, we can conclude that the slot duration value 0.0025 is the optimum choice for increasing PDR network, the values for Bit rate, check interval and transmission power keep it as already explained in the Throughput.

Table 9: PDR vs. S/N response

level	Slot duration	Bit rate	Check interval	T_x power
1	57.76	50.67	54.05	58.23
2	54.56	56.43	54.92	61.49
3	55.46	60.68	58.81	48.06
delta	3.19	10.00	13.43	13.43
rank	4	2	3	1

As for the response table analysis, Table 9 explain the response table results. Moreover, the response table analysis concludes that, the transmission power (T_x power) has the most impact on the PDR, and the Slot duration is the least affecting factor on the PDR.

3.3.1.4 Analysis Of Varince (Anova)

ANOVA is a collection of statistical based objective decision-making tool for detecting any differences in the average performance of groups of items tested, it is a quick and easy method to analyze results of parameter Design. ANOVA is used to determine the response magnitude in percent of individual factors in the orthogonal array experiments. It is used to identify the sources of different trial results from different trial runs. The basic property of ANOVA is that the total sums of the squares (total variation) is equal to the sum of the SS (sums of the squares of the deviations) of all the condition parameters and the error components [9].

$$SS_t = \sum_{1}^{n} y^2 - (G^2/n) \tag{4}$$

$$SS_K = \sum_{1}^{t} (sy_j^2/t) - (G^2/n) \tag{5}$$

Where

G is the sum of the resulting data of all trial runs
N is the total number of the trial runs
K is one of the tested parameters
j is level number of this parameter
Sy_j is sum of all trial results involving this parameter k at level j
n is the total number of trial runs

The following Table 10, Table11, Table 12 respectively shows the results of the ANOVA for

Journal of Theoretical and Applied Information Technology
20th June 2016. Vol.88. No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

power consumption, Throughput, and packet delivery ratio (PDR).

Table 10: Sum Of All Squares Of All Deviations For Power Consumption

source	DOF	SS	Contribution (SS %)
Slot duration	2	0.003749	71.14928%
Bit rate	2	0.001275	24.19095%
Check interval	2	3.83E-05	0.726013%
Tx power	2	0.000207	3.933757%
total	8	0.005269	100%

It can be seen from this Table 10 that for power consumption, the contribution of slot duration (71.14928%) is more significant than bit rate which is (24.19095%).These factors are more significant than the T_X power (3.933757%) and Check interval is very low as compared to the control factors. (0.726013%). This agrees with the result obtained by Taguchi method.

Table 11: Sum Of All Squares Of All Deviations For Throughput

source	DOF	SS	Contribution (SS %)
Slot duration	2	5260097	21.51994%
Bit rate	2	5836474	23.878%
Check interval	2	5627257	23.02205%
Tx power	2	7719069	31.58001%
total	8	24442897	100%

It can be seen from this Table 11 that for throughput, the contribution of T_X power (31.58001%) is more significant than bit rate which is (23.878%). These factors are more significant than the check interval (23.02205%) and slot durations very low as compared to the control factors. (21.51994%). This agrees with the result obtained by Taguchi method.

Table 12: Sum Of All Squares Of All Deviations For PDR

source	DOF	SS	Contribution (SS %)
Slot duration	2	0.016077	2.855568%
Bit rate	2	0.212997	37.83337%
Check interval	2	0.035939	6.383576%
Tx power	2	0.297975	52.92748%
total	8	0.562988	100%

It can be seen from this Table 12 that for packet delivery ratio, the contribution of T_x power (52.92748%) is more significant than bit rate which is (37.83337%).These factors are more significant than the check interval (6.383576%) and slot durations very low as compared to the control factors. (2.855568%). This agrees with the result obtained by Taguchi method.

3.4 PHASE 4: VALDATION

The main goal of the previous analysis is minimized power consumption for Wireless Sensor Network (WSN) based on the Berkeley- MAC protocol. After analysis, we take the optimal values have been found by using Taguchi method in Table 7 and carried out at OMNET++ simulator. To verify the validation of the result are comparing between Taguchi B-MAC with the B-MAC result. The comparing Taguchi B-MAC with the B-MAC result in Figure 5, we can observe the Taguchi B-MAC have minimum power consumption compared with B-MAC protocol. Taguchi B-MAC achieved reducing power consumption for WSN.

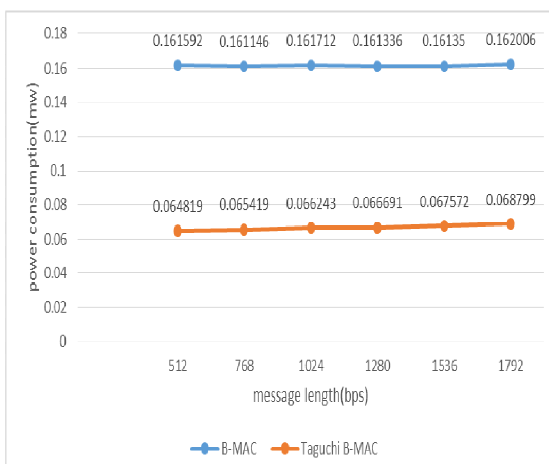

Figure 5: Compare Between B-MAC And Taguchi B-MAC

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

4 CONCLUSION

There are varied factors that affected on the performances of WSN MAC protocols. In this paper, the Taguchi optimization method is proposed, the Experiments are set for optimizing four factors to Berkeley- MAC (B-MAC) protocol at wireless sensor network (slot duration, bit rate, check interval, transmission power). The adhered factors are optimized for energy consumption, throughput, and packet delivery ratio (PDR). The optimization results conclude that increasing the transmission power reduces the energy consumption. Slot duration has the highest impact for optimizing the power consumption, still other factors are important for improving network throughput and PDR performances. For future work, more parameters can be involved in the optimization.

REFRENCES:

[1] W. Ye and J. Heidemann, "An energy-efficient MAC protocol for wireless sensor networks," *Proc. IEEE Infocom*, vol. 00, no. c, pp. 1567–1576, 2002.

[2] A. Verma, M. P. Singh, J. P. Singh, and P. Kumar, "Survey of MAC Protocol for Wireless Sensor Networks," *2015 Second Int. Conf. Adv. Comput. Commun. Eng.*, pp. 92–97, 2015.

[3] M. Bagaa, Y. Challal, a Ksentini, a Derhab, and N. Badache, "Data Aggregation Scheduling Algorithms in Wireless Sensor Networks: Solutions and Challenges," *IEEE Commun. Surv. Tutorials*, vol. 16, no. 3, pp. 1339–1368, 2014.

[4] R. C. Carrano, D. Passos, L. C. S. Magalhaes, and C. V. N. Albuquerque, "Survey and taxonomy of duty cycling mechanisms in wireless sensor networks," *IEEE Commun. Surv. Tutorials*, vol. 16, no. 1, pp. 181–194, 2014.

[5] K. Chen, M. Ma, E. Cheng, F. Yuan, and W. Su, "A Survey on MAC Protocols for Underwater Wireless Sensor Networks," *IEEE Commun. Surv. Tutorials*, vol. 16, no. 3, pp. 1433–1447, 2014.

[6] P. Huang, L. Xiao, S. Soltani, M. W. Mutka, and N. Xi, "The Evolution of MAC Protocols in Wireless Sensor Networks: A Survey," *IEEE Commun. Surv. Tutorials*, vol. 15, no. 1, pp. 1–20, 2012.

[7] Y.-Y. Hong, F.-J. Lin, and T.-H. Yu, "Taguchi method-based probabilistic load flow studies considering uncertain renewables and loads," *IET Renew. Power Gener.*, vol. 10, no. 2, pp. 221–227, 2016.

[8] Mohamed Elshaikh, Mohd Nazri Mohd Warip, Ong Bi Lynn, R. Badlishah Ahmad, Phaklen Ehkan, Fazrul Faiz Zakaria, and Fairul Afzal Ahmad Fuad, "Energy Consumption Optimization with Ichi Taguchi Method for Wireless Sensor Networks," *2014 2nd Int. Conf. Electron. Des.*, pp. 554–559, 2014.

[9] S. Athreya and Y. D. Venkatesh, "Application Of Taguchi Method For Optimization Of Process Parameters In Improving The Surface Roughness Of Lathe Facing Operation," *Int. Ref. J. Eng. Sci.*, vol. 1, no. 3, pp. 13–19, 2012.