THE IMPACT OF INNER-PARAMETERS B-MAC PROTOCOL BY TAGUCHI METHOD FOR WSN

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ABSTRACT

The MAC protocols play an important role in the performance of wireless sensor network (WSN). MAC protocols are controlled with set of parameters from being dragged to undesired situation such as reduce the power consumption, listening idle, and overhead. This inner- parameters have direct impact on the efficiency of a MAC protocols and overall network performances. The impacts of theses parameters on reduce the power consumption are less considered. In the literature, a lot of studies concentrates on introducing a new protocols to reduce the power consumption for WSN. This paper aims to analysis the inner- parameters of MAC protocols for WSN power consumption by using Taguchi Delta Analysis (TDA). Moreover, the measure of inner - parameters is very important to find the optimal values to reduce the power consumption. This paper utilized Taguchi method to analysis the impact of B-MAC protocol parameters in WSN scenarios by exploits Taguchi delta analysis. Further, four inner - parameters are investigated in a simulation platform. Moreover, simulation experiments are carried out by OMNET++5 to prove the work in this paper. The obtained results show that inner- parameters B-MAC inner- protocol reduce the power consumption of WSN for two different scenarios.

Keywords: *B-MAC, Taguchi Delta analysis (TDA), Power consumption, Taguchi method, WSN*

1. INTRODUCTION

Wireless sensor network (WSN) attracts the attention in last years. Moreover, WSN exploits in many applications such as industrial sensing, environmental monitoring, home automation, process monitoring, healthcare applications, intelligent transportation systems, and military surveillance. WSN network contains sensor nodes collecting the information from the environment to perform a task. The sensing information forwarded to sink node. WSN deployed large amounts of sensor nodes in the harsh environment driven by a battery. However, the critical issue faced the WSN is limited battery capacity. Further, the sensor nodes need to work for a maximum time without depletion battery. MAC protocols for wireless sensor networks is challenging because the sensor nodes depend on limited capacity. Additionally, the lifetime of sensor nodes effects of entire lifetime network and the performance. In the literature, many MAC protocols are proposed based on prior energy efficient mechanisms[1][2] [3][4][5].

The work in this paper is aimed effects of the B-MAC inner- parameters for WSN by Taguchi method. Moreover, defined which one of the parameters have large effects of reducing the power consumption by delta analysis and find the optimum values for a set of defined B-MAC protocol parameters. Further, the framework for this paper is carried out through OMNET++5 and INET3.5 simulation experiments. The obtained set of optimal values is compared against the original parameters set defined in the B-MAC protocol.

The rest of the paper is organized as follow: Section two highlights some previous work in the same direction of this paper. Section three gives an overview of the Taguchi method and description of the proposed work. Section four reviews and discusses the obtained results of this work. Finally, the work in this paper is concluded in the last section.

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

2. RELATED WORK

Energy consumption is considered as major design challenge for WSN. The energy-efficient MAC protocols for WSN had been reviewed and introduced in many previous works by introducing a new protocol.

Corbellini et al. (2012) presented a low-latency asynchronous access method (LA-MAC) for efficient forwarding, in wireless sensor networks. Moreover, the uniqueness of the design of LA-MAC is that there is no existing MAC access method that can be compared to its characteristic behavior (throughput, power efficient, and an end-to-end delay) for different network parameters. LA-MAC works similar to X-MAC, in that when the source needs to send data packet active, it checks the shared medium, and forwards preambles. However, after the early acknowledgment is received, the source returns to sleep again and waits for the SCHEDULE message to be forwarded. When the destination receives one preamble, it clears it and completes check on the channel (polling period) to detect additional possible preambles to clear. After finished checking the channel, the destination processes requests and broadcasts the SCHEDULE message. The result of simulation shows that LA-MAC provides the best performance in the case of high bitrate networks under traffic congestion [6].

Han et al. (2013) proposed a power efficient asynchronous MAC protocol (WX-MAC) for the wireless sensor network. WX-MAC shortens the preamble and ensures the sensor nodes remains in an active mode as short as possible. WX-MAC minimizes the power consumed by the sources and receivers as well as reduces the chances of overheating on the surrounding sensor nodes, which provides more efficiency on the power preservation. WX-MAC shortens the preamble by keeping sensor nodes awake for a short period as possible. Further, WX-MAC enables sensor nodes to interchange the sampling schedules. Then, the sensor node uses the sampling schedules to define the beginning of its preamble based on estimating its target's sampling schedules. Also, the strobe preamble approach stops the preamble, begins the transmission process, and backs to sleep mode, at appropriate times. The simulations result indicates that WX-MAC outperforms, regarding power consumption, compared with B-MAC, Wise- MAC, and X-MAC [7].

Zhang et al. (2013) introduced scheduled channel polling-MAC (SCP) protocol for energy efficiency in a wireless sensor network. Scheduled Channel Polling (SCP) reduces the preamble by combining preamble sampling and scheduling techniques; this process provides more efficiency for power con and low duty cycles. Scheduled channel polling (SCP) inherits significant characteristics from SCP-MAC and takes into consideration minimization of delay and contention in the context of remote monitoring and data gathering applications. Furthermore, it strives to extend the network lifetime and curtails the delay limitations [8].

Min et al. (2015) presented an Energy and Latency-Aware MAC (ELA-MAC) protocol that provides high energy-efficiency and reduces the delay for data collection applications, in wireless sensor networks. ELA-MAC protocol spreads collection-request without using an early ACK and delivers collection response using an early ACK, with due consideration on the traffic types. In this way, power consumption on both downlink and uplink can be minimized. Besides, the time for collecting data can be shortened on the up- link as well [9].

Morshed et al. (2016) introduced the Traffic-adaptive duty cycle adaptation. TR-MAC is a WSN protocol for energy efficiency by using the preamble sampling protocol, to provide maximum sleeping time for sensor nodes and active periodically separate from other nodes to sample the shared medium for any activity. The protocol works in two states: firstly, unsynchronized sender; begins to send preamble with the small data packet and waits for ACK from the destination; the source iterates the process until it receives the ACK. After receiving the preamble-data packet, the destination node forwards an ACK back to the source. Secondly, synchronized link states; after this unsynchronized communication link state, each node could remember the others next active time and move to the synchronized link state. If the source remembers the destination's next active state, called receiver-driven synchronization, the source holds its packet transmission till the destination's next active time. Thus, the source node successfully ignores much extra iteration of the data and acknowledges listen cycles to save energy. The simulation result shows that there is an improvement in terms of an end-to-end delay and power consumption for stable traffic [10].

Chen et al. (2017) introduced Light-Weight Opportunistic Forwarding (LWOF) protocol for energy efficiency in WSN. LWOF protocol tune the preamble length for specific forwarding probability to node density and sleep duration. LPL-MAC used two scheme firstly, light-weight opportunistic forwarding scheme (LWOF) to provide reliable and timely data delivery for WSN with asynchronous duty cycles. Secondly, preamble length of LPL MAC protocol is optimized by using the non-deterministic characteristic of opportunistic forwarding, according to forwarding probability, node density, and sleep duration [11].

Alahmadi & Bouabdallah (2019) a multichannel preamble sampling MAC protocol, (MCPS) for WSN. MCPS is a low-power MAC protocol operating on multichannel using carrier sensing for collision avoidance. Specifically, MCPS uses all the non-overlapping channels provided by IEEE 802.15.4 physical layer. MCPS uses one dedicated common control channel to wake up an intended receiver using a preamble sampling technique [12].

3. TAGUCHI METHOD(TM)

Genichi Taguchi is a Japanese researcher, who developed an optimization concept that depends on quality management, dated back to the late 1940s. The concept embodied a set of statistical methods and equations to find the optimum point. Taguchi method is one of the branches of the design of experiments (DOE) methods, introduced in many works in different scientific applications. Generally, DOE methods share a common objective to determine the relationship between the control factors and the response. TM utilizes orthogonal arrays and statistical equations to evaluate measuring system. The most important part of the Taguchi technique is quality loss function. Taguchi has recognized signal to noise ratio (S/N) as performance statistics. Figure 1 explains the block diagram of a product as specified by TM. Also it could be utilized to explain a manufacturing process or even a business system. The output is represented by y. The parameters which affect the output are classified into three as follows [13] [14] [15]:

a) Signal factors refer to the input factors, which are determined by the user to gain more performance or to accurate the specific output. Further, the input factors chosen by the engineer depended on the engineering knowledge.

b) Control factors refer to system values to signal factors. The control factor values are the responsibility of the designer. Further, the control factor can determine more than single value called level. This process is performed to find the best level of these factor for objective design.

c) Noise factors indicate uncontrollable factors. The uncontrollable factors affect the response and their levels change on the unit of the product, environment, and time.

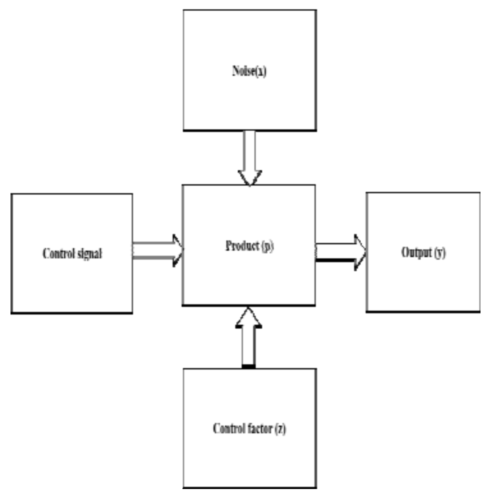

Figure 1: Taguchi Process Diagram (P-Diagram).

Recently, Taguchi method is utilized in various technique to improve the quality [16] [17]. Taguchi method works through four phases: planning phase, experimental phase, Delta analysis phase, and validation experiment as illustrated in Figure 2. The following subsection explains the implementation of Taguchi methods in the work of this paper.

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

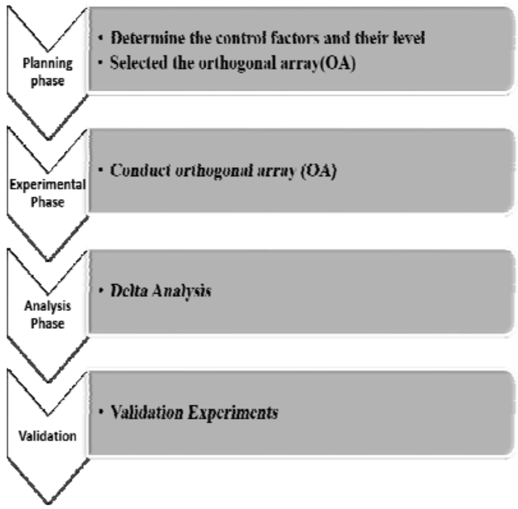

Figure 2. Taguchi method phases.

3.1 Planning phase

The first phase in TM aims to define the parameters that need optimization process. Further, the determining process for the parameters depend on whose have effectiveness to provide better quality, the output or response of these parameters must be observed. Four B-MAC inner- parameters selected for this work as explained in Table 1. Further, the parameters exploit to reduce the power consumption for two WSN scenarios (Farm, Part of farm).

Table 1. Inner- parameters B-MAC protocol (ZigBee standard).

Control factors	level 1	level2	level 3
Slot duration (ms)	1	2	4
Bit rate (kbps)	20	40	250
Check interval (µs)	128	800	1600
Max power transmission (mW)	1	5	10

Subsequently, select the convenient orthogonal array for the control factors and the number of levels. The suitable orthogonal array is selected to design the experiments table and the data analysis procedure. Orthogonal array is standard for experimental design that performs the optimization process with only a small number of experimental trials

The choice orthogonal array is L9 (3^4). Moreover, the objective of this process is finding the optimal values for inner- parameters and large impact of inner-parameters by Delta analysis.

Table 2. L9 (3^4) orthogonal array.

experiment No	Slot duration	Bit rate	Check interval	Tx power
1	level1	level 1	level 1	level 1
2	level 1	level 2	level 2	level 2
3	level 1	level 3	level 3	level 3
4	level 2	level 1	level 2	level 3
5	level 2	level 2	level 3	level 1
6	level 2	level 3	level 1	level 2
7	level 3	level 1	level 3	level 2
8	level 3	level 2	level 1	level 3
9	level 3	level 3	level 2	level 1

3.2 Experimental Phase

The second phase in TM, according to the orthogonal array is achieved by conducting the experiments table and recording the results. Experiments design in TM is expected to produce a measure of the output targets (Power consumption) which are to be used in the analysis phase. Outputs are presented according to trails for further calculate the objective functions. Experimental layout with the selected value of parameters for nine experiments carried out is illustrated in Table 3.

Table 3. Measure values for inner- parameters B-MAC protocol.

Experiment No	Slot duration	Bit rate	Check interval	Tx power
1	1	20	128	1
2	1	40	800	5
3	1	250	1600	10
4	2	20	800	10
5	2	40	1600	1
6	2	250	128	5
7	4	20	1600	5
8	4	40	128	10
9	4	250	800	1

The simulation experiments are conducted on OMNET++5 simulator and INET3.5 framework. Moreover, the farm and part of farm scenarios are designed based on the INET3.5 framework. The part of farm scenario contains 43 sensor nodes and low bit rate traffic. On the other hand, farm scenario contains 16 nodes with high bit rate traffic. Further, the experiments will be repeated with different random seed for two scenarios. The obtained results of orthogonal array experiments exploits in the analysis phase.

3.3 Analysis Phase

The third phase comes after the experiments are carried out. TM results analysis uses the signal- to –noise equations to measure the performance (Equation 1, 2, and 3). Then, TM output for power consumption illustrated in Table 3.4 achieves delta analysis. The measures the impact of the control factors on the output, and this result is obtained by the delta analysis of loss function. [18] [19].

A- Smaller the better refers to the system response will be as small as possible:

$$S/N_{smaller\text{-}the\text{-}better} = -10 \times \log \sum_{i=1}^{n} \frac{Y^2}{n} \quad (1)$$

B- Nominal the best refers to reducing variability around a target:

$$S/N_{Nominal\text{-}the\text{-}best} = -10 \times \log \sum_{i=1}^{n} \frac{Y^2}{S^2} \quad (2)$$

C- Larger the better refers to the system response will be as large as possible:

$$S/N_{larger\text{-}the\text{-}better} = -10 \times \log \sum_{i=1}^{n} \frac{1/Y^2}{n} \quad (3)$$

Where

i= Experiment number

n = Number of trials for experiment i

y= the mean of experiment i

s =Standard deviation of experiment i

Outputs are presented according to Measure values illustrated in Table. To accomplish this goal exploited OMNET++5 simulator and INET3.5 framework. The experimental results is illustrated in Table 4 and Table 5.

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

Table 4. Power consumption result from OMNET++ by OA experiments for part of farm scenario.

Experiment NO	R1*	R2*	R3*	R4*
1	0.463562	0.475720	0.484948	0.494180
2	0.403319	0.401987	0.401719	0.400956
3	0.355728	0.355870	0.355063	0.355133
4	0.351708	0.370141	0.603170	0.355223
5	0.310796	0.309466	0.309520	0.308640
6	0.317712	0.319477	0.322532	0.325009
7	0.313291	0.312927	0.312386	0.339914
8	0.227533	0.227287	0.227206	0.228098
9	0.216054	0.217697	0.221815	0.223825

Table 5. Power consumption result from OMNET++ by TOA experiments for farm scenario.

Experiment NO	R1*	R2*	R3*	R4*
1	0.143002	0.146192	0.149272	0.151943
2	0.125974	0.125229	0.125343	0.283092
3	0.110651	0.110662	0.110546	0.110192
4	0.106960	0.112299	0.109191	0.108489
5	0.096792	0.096675	0.096625	0.096221
6	0.096676	0.097361	0.098274	0.098931
7	0.098052	0.097740	0.097703	0.106113
8	0.068416	0.068695	0.068573	0.068686
9	0.064819	0.065419	0.066243	0.066691

The objective of this research optimizes the power consumption for B-MAC protocol by using TM. TM has three equations each one of them is designated for a specific category of targets, to minimize the power consumption used smaller the better Equation 1. S/N ratios for the power consumption of all the experiments were calculated and tabulated as shown in Table 6 and Table 7.

Table 6. Tabulated S/N ratios power consumption for part of farm scenario.

Experiment NO	S/N
1	6.380385674
2	7.915562028
3	8.984461953
4	7.265933986
5	10.18379974
6	9.864631872
7	9.901232005
8	12.85917828
9	13.15669008

Table 7. Tabulated S/N ratios power consumption for farm scenario.

Experiment NO	S/N
1	16.61590932
2	14.96877953
3	19.13173936
4	19.23140784
5	20.30239185
6	20.19195456
7	20.00291648
8	23.27445564
9	23.63588015

After tabulated the S/N ratio for each experiment, calculate the average S/N value for each factor and level. The results of this process for all parameters illustrated in Table 8 and Table 9.

Table 8. S/N for part of farm power consumption.

experiment No	Slot duration	Bit rate	Check interval	Tx power	S/N
1	level1	level 1	level 1	level 1	6.380385674
2	level 1	level 2	level 2	level 2	7.915562028
3	level 1	level 3	level 3	level 3	8.984461953
4	level 2	level 1	level 2	level 3	7.265933986
5	level 2	level 2	level 3	level 1	10.18379974
6	level 2	level 3	level 1	level 2	9.864631872
7	level 3	level 1	level 3	level 2	9.901232005
8	level 3	level 2	level 1	level 3	12.85917828
9	level 3	level 3	level 2	level 1	13.15669008

Table 9. S/N for farm power consumption.

experiment No	Slot duration	Bit rate	Check interval	Tx power	S/N
1	level1	level 1	level 1	level 1	16.61590932
2	level 1	level 2	level 2	level 2	14.96877953
3	level 1	level 3	level 3	level 3	19.13173936
4	level 2	level 1	level 2	level 3	19.23140784
5	level 2	level 2	level 3	level 1	20.30239185
6	level 2	level 3	level 1	level 2	20.19195456
7	level 3	level 1	level 3	level 2	20.00291648
8	level 3	level 2	level 1	level 3	23.27445564
9	level 3	level 3	level 2	level 1	23.63588015

Delta analysis is utilizing to measuring the impact of the inner parameters on the output. Further, the optimum values are obtained by comparing the averages S/N for all inner-parameters levels. Moreover, Delta is the difference between S/N of factors (**Delta = high S/N – Low S/N**).

Journal of Theoretical and Applied Information Technology
15th March 2020. Vol.98. No 05

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

Table 10. Delta analysis of the S/N power consumption value for part of farm scenario.

level	Slot duration	Bit rate	Check interval	Tx power
1	7.760	7.849	9.701	9.907
2	9.105	10.320	9.446	9.227
3	11.972	10.669	9.690	9.703
Delta	4.212	2.819	0.255	0.680
Rank	1	2	4	3

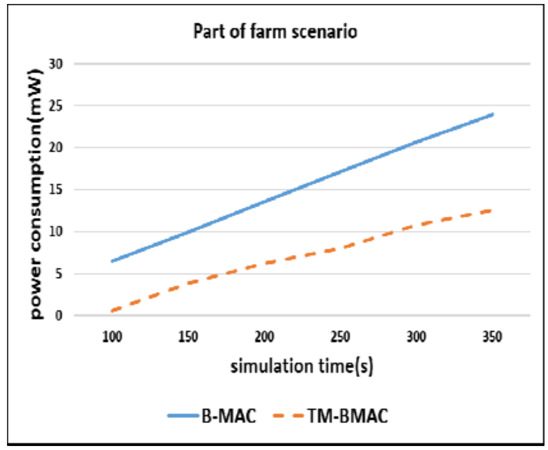

Figure 3. Comparison between TM- BMAC and B-MAC for part of farm Scenarios.

Table 11. Delta analysis of the S/N power consumption value for farm scenario.

level	Slot duration	Bit rate	Check interval	Tx power
1	16.91	18.62	20.03	20.18
2	19.91	19.52	19.28	18.39
3	22.30	20.99	19.81	20.55
Delta	5.40	2.37	0.75	2.16
Rank	1	2	4	3

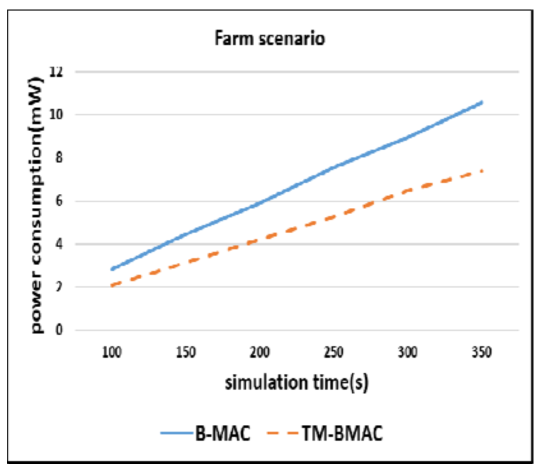

Figure 4. Comparison between TM- BMAC and B-MAC for farm Scenarios.

Table 10 and Table 11 explained the slot duration has the largest effects on the reduce power consumption, while the transmission power has the least for part of farm and farm scenarios.

3.4 Validation Experiments

The validation phase carried out the optimal values defined in analysis phase by OMNET++5 simulator. On the other hand, validation experiments are comparing between Taguchi B-MAC with the B-MAC result. Figure 3 and Figure 4 shows the comparison between Taguchi B-MAC protocol and B-MAC protocol for farm and part of farm. Finally, Taguchi B-MAC reducing the power consumption for farm scenario about 71.07% and for part of farm about 45.71%.

4. CONCLUSION

The objective of this paper is studying the impacts of inner parameters B-MAC protocol by Taguchi Delta Analysis (TDA). Further, two WSN scenarios are considered for the purposes of this work namely farm and part of farm. TDA explained inner- parameters B-MAC protocol can effect on reducing the power consumption. Further, the bit rate has the largest effects on the reduce power consumption for farm scenario. While the check interval has the largest effects on the reduce power consumption. Furthermore, Taguchi B-MAC it

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

outperforms of B-MAC protocol in terms of power consumption.

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