ANALYSIS OF IEEE 802.15.4-BASED DELAY AND SLOT DURATION ADJUSTMENT COMBINATION METHODS ON WIRELESS SENSOR NETWORKS

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Abstract – IEEE 802.15.4 is one of the standards of the Wireless Sensor Network (WSN) which is at the Medium Access Control (MAC) layer. IEEE 802.15.4 is also technology and protocol within a computer network that can connect all device quickly, has a large capacity and low power consumption. The challenge of Wireless Sensor Network is how to improve the Wireless Sensor Network network performance matrix (goodput, bandwidth utilization, and energy consumption) both in the Contention Access Period (CAP) and in the Contention Free Period (CFP) based on the IEEE 802.15.4 standard. This research is an analysis combination of adjustment delay and slot duration methods to increase goodput, bandwidth utilization and reduce energy consumption in Wireless Sensor Networks in the allocation guaranteed time slots on fixed data simulated using Castalia Simulator software. The problem of this research is whether the combination method can improve the performance matrix of Wireless Sensor Networks on fixed data compared to other methods (SUDAS, ADES, IEEE 802.15.4 Standard). This reserch it aims to determine the performance matrix of combination methods is when compared to other methods (Superframe Duration Adjustment Scheme (SUDAS), Adjustment Delay Scheme (ADES), IEEE 802.15.4 standard) using quantitative approach research methods. Based on the data obtained, the goodput of the combined method increased by 10%, 416%, and 513% respectively compared to the SUDAS method, ADES method, and IEEE 802.15.4 standards. Bandwidth utilization of the combination methods increased by 0.025, 0.223 and 0.232, respectively compared to the SUDAS method, the ADES method, and the IEEE 802.15.4 standard. And the consumption of the combination methods are respectively reduced by 1.02%, 8.72% and 9.08% compared to the SUDAS, ADES and IEEE 802.15.4 standards. With the combination method of delay adjustment and slot duration it is able to optimize the performance of the Wireless Sensor Network compared to other methods.

Keywords: Wireless Sensor Networks (WSN), Goodput, Bandwith Utilization, Energy Consumption .

I. INTRODUCTION

Today's cordless networks are growing rapidly. IEEE 802.15.4 is one of the standards of wireless sensor networks located in the medium access control (MAC) layer. The development of communication technology is now increasingly leading to wireless communication. One of them is Wireless Sensor Network (WSN) technology, which allows remote research through gadgets such as laptops, remote devices, servers and so on with the results of information obtained remains maximal. The challenge of wireless sensor networks is how to increase throughput and bandwidth utilization and reduce overall energy consumption both in contention access period (CAP) and in contention free period (CFP) of a wireless network based on IEEE 802.15.4 standard.

Wireless Sensor Network is a collection of nodes with a compact size, relatively cheap and useful for observing environmental conditions or other parameters. Wireless sensor networks or WSNs can be defined as sets of nodes organized within a network and work together. Each node has processing capabilities, has a radio frequency transceiver, has resources, it also accommodates various sensors (detection systems) and actuators (drive systems) (Pratama & Sinung, 2015).

Wireless Sensor Networks (WSN) consist of hundreds or thousands of low-cost nodes, which can have a designated or random location used to monitor the environment. Due to its small size, the node sensor has some limitations. Sensor nodes usually communicate with each other using a multi hop approach. The data stream ends on a special node called a sink node that is equipped with a gateway to another network commonly called a gateway and is tasked with disseminating the data for further processing. Sink nodes have capabilities above simple node sensors because they have to perform complex data processing so that the sink nodes have enough processor, memory, and energy. (Yona Annissa, 2017).

Personal Area Network (PAN) is one type of computer that is devoted to connecting computers with relatively shorter connection distances and personal connections (for personal use only). For example, the connection between Laptop and Smartphone via bluethooth, Wi-Fi, Infrared and ZigBee. i.e. can be utilized as a WSN but on a smaller scale. WPAN is low rate, where the utilization of WPAN is more than PAN, because it is easier to use and more flexible. The range of signals used is relatively longer and wider than the cable. It can also be said that WSN is a Low-Rate Wireless Personal Area Network (LR-WPAN). (Primary, 2015).

IEEE 802.15.4 standard or also called Zigbee Protocol is a technology and protocol in computer network that can connect all devices quickly, has a lot of capacity and save power consumption. IEEE 802.15.4 is also one of the standards of wireless sensor networks located in the medium access control (MAC) layer. Zigbee works at a frequency of 2.4 GHz, with 16 channels in it. (Mausa, 2015)

The MAC sublayer IEEE 802.15.4 can work on two modes of operation: beacon-enabled and non beacon-enabled mode. Where in non beacon-enabled mode, the PAN coordinator does not transmit any beacons, and device communication to the PAN coordinator uses unslotted Carrier Sense Multiple Access with Collision Avoidance(CSMA/CA). As for producing better energy efficiency, the standard provides for beacon-enabled mode through the use of a superframe structure, in beacon-enabled mode, the PAN coordinator transmits beacon packets at periodic Beacon Intervals (BI) to allow devices while working and superframe structure synchronization.

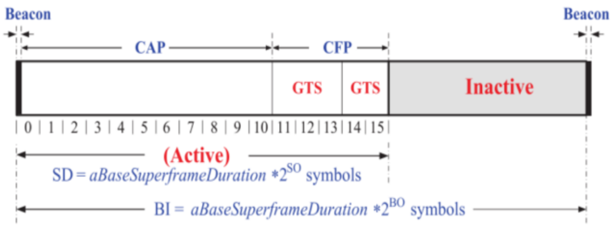

Figure 1. Superframe Structure

The superframe structure is shown in figure 1 which consists of a beacon, an active period and a period of inactivity. Superframe duration (SD) which is an active period consists of Contention Access Period (CAP) and Contention Free Period (CFP) composed of Guaranteed Time Slot (GTS). Where the duration of the active period or so-called superframe duration (SD) can be known using equations (2), while the total duration of active and inactive periods can be known using equations (3). From figure 1 it can be seen that there are 16 time slots divided equally in the active period. The slot is then used to transmit data. To save energy is provided a period of inactivity where all devices are in a state of sleep mode until there are more beacons to transmit data. (Lee et al., 2015).

The superframe structure is composed of two parameters: Beacon Order (BO) and Superframe Order (SO). Where BO and SO values can be determined by equation (1):

$$0 \leq SO \leq BO \leq 14 \tag{1}$$

(Sorce: Lee dkk, 2015)

Formulations of Superframe Duration (SD) and Beacon Interval (BI) can be calculated using equations (2) & equations (3):

$$SD = aBaseSuperframeDuration * 2^{SO} \tag{2}$$

$$BI = aBaseSuperframeDuration * 2^{BO} \tag{3}$$

Information:

aBaseSuperframeDuration = *superframe* minimum duration (symbol)

SO = *Superframe Order*

BO = *Beacon Order*

SD = *Superframe Duration* (symbol)

BI = *Beacon Interval* (symbol)

The length of a superframe is a constant value that is equal to *aBaseSueprframeDuration* when BO=SO=0 or equivalent to 960 symbols. When a device uses a CSMA-CA slot to use a channel and send a packet, the frame beacon from slot 0 will be transmitted by the PAN coordinator for all superframe periods followed by a CAP. In the CSMA slot, the PAN coordinator will align the superframe limiting slots with the backoff period of all devices on the PAN. After CAP, it is followed by a CFP composed of GTS. Devices requesting GTS slots will be allocated bandwidth by pan coordinators to transmit packages without having to complete a channel. The total GTS allocatable devices are limited to seven and the allocation from GTS should not reduce the CAP length to less than the MinCAPLength value. All devices with periodic data can request a GTS slot via the GTS request command. Furthermore, pan coordinators who receive GTS requests will check whether the total number of GTS allocations is less than seven and whether the allocation from the new GTS does not reduce the length of the CAP period less than aMinCAPLength if yes, then the coordinator will receive the request. Otherwise, gts request will be dropped. When the period is off all devices are in sleep mode and are back on when a beacon comes in from the coordinator. (Harsono, 2017)

CSMA/CA is a contention protocol on the network that uses carrier sensing mechanisms to avoid collisions. The CSMA/CA algorithm is based on a unit backoff period (UBP), one backoff period has a Value of aUnitBackoffPeriod or equivalent to 20 symbols. This is a basic unit of time for the MAC protocol and access to the channel can only occur at the backoff period limit. (IEEE Standard 802.15.4, 2015)

Superframe Duration Adjustment Scheme (SUDAS) is a schema of adjustment to gts size. This method aims to accurately determine the value of gts slots based on the length of the package size and the arrival rate of the package. The

SUDAS method also aims to increase the probability of transmission success, network throughput, average utilization bandwidth, and energy consumption by managing GTS allocations for the requested device nodes. (Lee et al, 2015)

Adjustment Delay Scheme (ADES) is a delay time adjustment scheme when the device node detects a channel in a busy state. The ADES method aims to reduce collisions and blind of-backoff-processes that require more energy consumption for random backoffs. This ADES method is a modification of the CSMA/CA method that aims to regulate data transmission traffic. When the channel is busy, the device will detect how much the Contention Window (CW) value is and will delay with the provisions on the ADES algorithm with the delay can avoid collisions or collisions and the probability of sending a larger package because the Contention Window (CW) slot is provided in the number of 3. (Yundra & Lee, 2017)

For analysis of performance assessment of WSN network performance can be seen from the performance of WSN network using goodput parameters and bandwidth utilization and energy consumption.

Goodput is the amount of information successfully delivered to the application layer between nodes that communicate with each other for a unit of time without taking into account the large size of the header and the possibility of a transmitting package. (Yundra & Lee, 2017)

Goodput can be written in equation (4):

$$S = \frac{N_{received} \times L_{data}}{T_{sim}} \tag{4}$$

(Source : Yundra & Lee, 2017)

Information:

S = *Goodput* (bps)
$N_{received}$ = Number of packages received
L_{data} = Data *payload* (bit)
T_{sim} = Duration of simulation time (second)

Bandwidth utilization is a comparison between the number of SD occupied and the total available superframes (bandwidth). (Lee et al., 2015)

Calculations to find out the T_f and T_{SD} values can be seen in the equations (5) and (6):

$$T_f = T_{data} + T_{ack} + T_{Lack} + T_{LIFS} \tag{5}$$

$$T_{SD} = \frac{aBaseSuperfameDuration \times 2^{SO}}{Rs} \tag{6}$$

To find out the SD values occupied and total SD can be seen in the equation (7) and (8):

$$\text{Total } SD = \frac{T_{sim}}{T_{SD}} \tag{7}$$

$$SD \text{ yang ditempati} = \frac{N_{received} \times T_f}{T_{SD}} \tag{8}$$

(Source : Yundra & Lee, 2017)

As for the calculation of bandwidth utilization can be seen in the equation (9):

$$BU = \frac{SD \text{ yang ditempati}}{\text{Total } SD} \tag{9}$$

(Source : Yundra & Lee, 2017)

Information:

T_f = Time for sending one data package and receiving an ACK package (second)
T_{data} = Time to send a data packet (second)
T_{ack} = Durasi waiting for ACK packet (second)
T_{Lack} = Delivery duration of one package (second)
T_{LIFS} = Duration of time from interfrasa (second)
T_{SD} = Duration of simulation time (second)
T_{sim} = Duration of simulation time (second)
$N_{received}$ = Number of packages received
aBaseSuperframeDuration = superframe minimum duration (symbol)
SO = *Superframe Order*
Rs = data symbol rate (symbol/second)
BU = *Bandwidth* utilization

Energy consumption in the WSN is one of the parameters that need to be considered, because on the WSN network where the sensor node uses energy consumption from the battery for the operation of the sensor node in order to be used portableally. Meanwhile, in its application data retrieval is not done only once that can drain the power from the battery. Total energy consumption in WSN (Etotal) network is the total amount of energy used in coordinators (ECoord) and devices (Edev) as described in the equation (10)

$$E_{\text{total}} = E_{\text{dev}} + E_{\text{Coord}} \tag{10}$$

(Source : Yundra & Lee, 2017)

Information:

E_{total} = Total energy consumption in the network (Joule)
E_{dev} = Energy consumption of device nodes (Joule)
E_{Coord} = Energy consumption from coordinator nodes (Joule)

Various studies have been conducted on IEEE 802.15.4. However, research on IEEE 802.15.4 still does not discuss about the combination method of ADES and SUDAS which is a combination of GTS slot allocation or called Superframe Duration Adjustment Scheme (SUDAS) method and transmission delay delay method or called Adjustment Delay Scheme (ADES) method. In addition, nodes that send data to the coordinator will always be the same size of the payload data that it transmits, but each node has its own specifications. With data that is always the same or called fixed data.

Based on the background writing, the research was conducted with the title "Analysis of Delay Adjustment Combination Method and IEEE 802.15.4 Based Superframe Duration Adjustment method to Improve Performance on Wireless Sensor Networks". By applying a combination method of SUDAS method and ADES method on fixed data that is expected to be a reference for both lecturers and students to be a reference for further development related to WSN.

The problem in this study is whether the combination method of adjusting delay and superframe duration adjustment can improve the matrix of goodput performance, bandwidth utilization, and and can reduce energy consumption in the WSN network in fixed data compared to other standards and algorithms (ADES and SUDAS).

Where the goal is to find out the new method of delay adjustment and superframe duration adjustment can increase goodput and bandwidth utilization as well as decrease energy consumption in wireless sensor networks on fixed data compared to standard algorithms and algorithms (ADES and SUDAS).

In this study using Castalia Simulator software operated on Ubuntu OS 18.04 LTS along with its analysis for data retrieval. The limitation of the problem in this study is the IEEE 802.15.4 ZigBee standard only on the medium access control (MAC) layer. Matrix analysis of WSN network performance will use goodput, bandwidth utilization and energy consumption. Payloads are fixed data, one node to another sending the same payload size.

II. METHODS

In this study the method used was a combination method of delay adjustment and duration slot adjustment with reference to SUDAS method and ADES method, SUDAS method algorithm and ADES method combined to obtain Wireless Sensor Networks performance optimization.

Research Approach

The data in quantitative research is in the form of statistical figures or quantified coding. The data is in the form of variables and operationalism with a certain size scale. (Sarwono, 2006:261).

The data in this study is a matrix of goodput performance, bandwidth utilization and energy consumption of the combination method of adjustment of delay and slot duration with reference to SUDAS method and ADES method as well as from other methods (SUDAS, ADES, IEEE Standard 802.15.4). In this study, a simulation test will be conducted to determine the matrix of system performance using Castalia Simulator software and its analysis.

Data Collection Instruments

Sugiyono (2014:92) stated that "Research instrument is a data collection tool used to measure observed natural and social phenomena". The data collection instruments used in this study are laptops (PCs) with Linux OS Ubuntu 18.04 LTS and installed Omnet++ software and Castalia Simulator used to simulate the method of delay adjustment and slot duration combination with reference to sudas fan ADES method on WSN network, and also Microsoft Excel as analysis data processor generates research data in the form of WSN performance matrix which is then analyzed using Microsoft Excel.

Research Design

The steps of designing this research are outlined in figure 2,

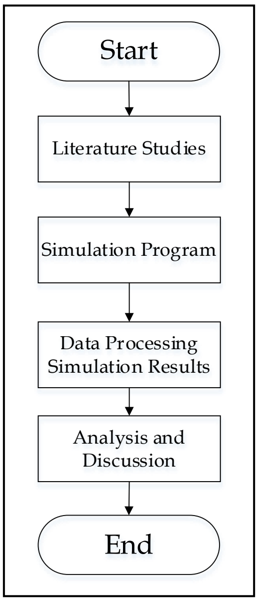

Figure 2. Research steps

In general, the first steps of research conducted literature studies then conducted research using several methods such as combination methods, sudas methods sudas methods as well as standard methods and collected data on all four simulations in castalia simulator software, simulation steps can be seen in figure 3:

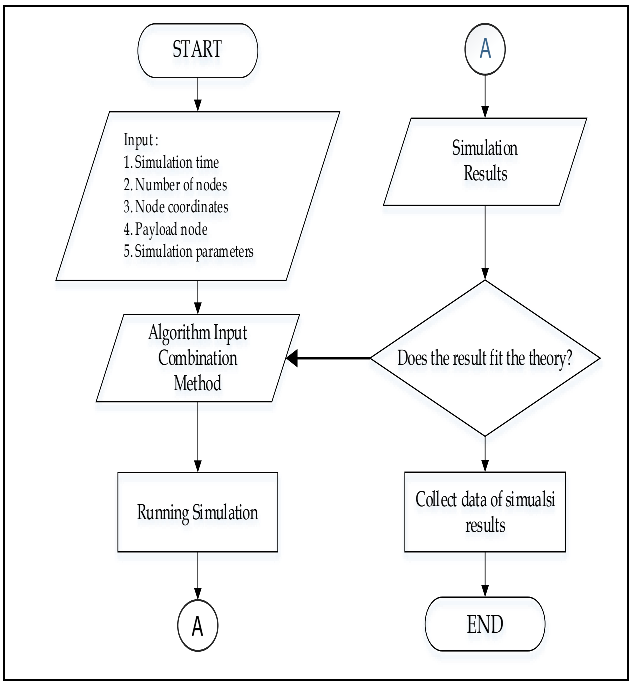

Figure 3. Simulation steps on Castalia software

From the results of the simulation of wireless sensor networks network performance obtained data from Castalia

Software in the form of package data received by each node and energy consumpt1ion of each node, which can be seen in ubuntu terminals, examples of data obtained from Ubuntu terminals are found in figure 4:

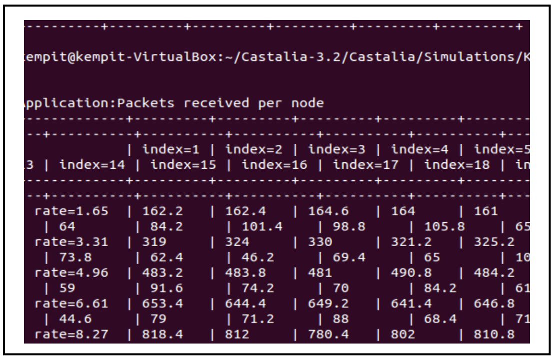

Table 4. Results of bandwidth utilization analysis

From the results of the simulation of wireless sensor networks network performance will be obtained data available in the form of notepad files, the results of compare data that can also be seen through the terminal. Then processed in Microsoft excel to get matrk value of goodput performance, bandwidth utilization, as well as energy consumption. Further analysis and discussion was conducted by comparing the performance matrix of the combination method with other methods (SUDAS, ADES, and IEEE 802.15.4 standard).

III. RESULT AND DISCUSSION

Simulation Parameters

Table 1 is the parameter value that will be used in the simulation of the program using the algorithm of the combination method of SUDAS and ADES in Castalia software.

Table 1. Simulation parameters

Parameter	Value
Physical data rate	250 kbps
UBP	80 bits
NumSuperframeSlots	16
MacPacketOverhead	112 bits
ACK length (L_{ack})	88 bits
D_{node}	10 m
PWR_{tx}	31.32 mW
PWR_{rx}	35.28 mW
PWR_{idle}	712 µW
BO=SO	6
BE_{min}	3
BE_{max}	5

Parameters of Each Node

In this study using fixed data, where there are 7 kinds of nodes with all nodes have the same payload size. The following parameters used for all nodes in the simulation method combination of delay adjustment and duration slot adjustment are presented in table 2.

Table 2. Parameters of each node

Node	Lack (bit)	ACK (bit)	LIFS (bit)	L_{data} (Byte)
1&2	88	32	160	90
3,4,5	88	32	160	90
6,7,8	88	32	160	90
9,10,11	88	32	160	90
12,13,14	88	32	160	90
15,16,17	88	32	160	90
18,19,20	88	32	160	90

Based on the data in table 2, there are 7 kinds of nodes with a fixed /equal payload, which is 90, in Byte units. Or if in bits it becomes 720.

Goodput Performance Matrix Results

Goodput itself on wireless sensor networks is the speed of data transfer in the network by ignoring the header size, the data generated from the simulation process in the Castalia Simulator software is the packet received by each node. Here is the data of the simulation results obtained. With fewer data packets received in the Sudas method, when compared to the Combination method the difference between ±3-500 packets. As for the data packets received in the Ades method has a lesser comparison than the combination method with the difference ±14-1990 package. And for the Standard method receives fewer data packets than the combination method with the difference between ±35-2000 packages.

Where each node has a fixed payload value and is calculated according to the equation (3) so that the result is obtained as presented in table 3:

Table 3. Goodput analysis results

Traffic Load	Method			
	Combination	SUDAS	ADES	Standard
0.1	14575.68	13425.48	3240.36	2459.88
0.2	20691.36	19210.39	4538.23	2424.31
0.3	26174.88	23969.95	3219.55	3946.75
0.4	31046.4	28909.51	3361.03	2571.91
0.5	36662.4	32406.26	5243.54	4177.94
0.6	38966.4	31208.54	5608.22	2430.14
0.7	41182.56	32630.18	3380.90	2482.34
0.8	41464.8	35166.45	3296.37	2276.85
0.9	42399.36	33283.29	3561.69	2625.69

Traffic Load	Method			
	Combination	SUDAS	ADES	Standard
1	43472.16	35724.45	3747.81	4316.61

In figure 5 is a comparison chart of goodput with combination method, sudas method, ades method and standard method:

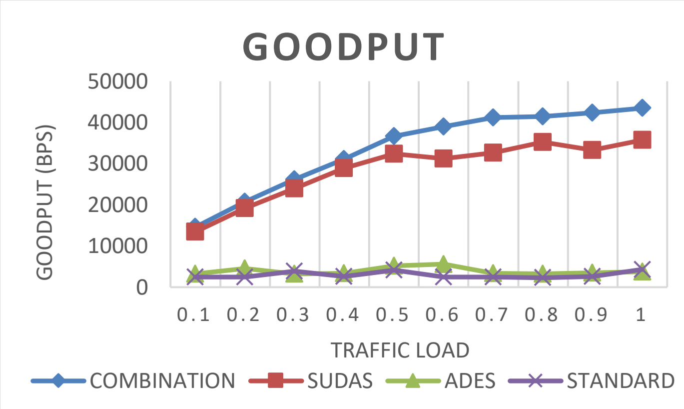

Figure 5. Goodput comparison graph

Based on figure 5 shows that the goodput value of traffic load in the combination method of delay adjustment and slot duration refers to the combination method has the highest value compared to other methods (SUDAS, ADES, IEEE Standard 802.15.4). The average goodput value of sudas and ADES combination methods increased by 5%, 29.7%, and 30.7% respectively compared to SUDAS methods, ADES methods, and IEEE 802.15.4 standards.

Based on the graph image of the goodput performance matrix test results on the combination method of delay adjustment and slot duration can be concluded that the combination method is a better method in determining goodput or packet delivery speed on Nerworks Wireless Sensor network especially on IEEE 802.15.4 when compared to other methods, SUDAS, ADES, and IEEE standard 802.15.4.

Utilization Bandwidth Performance Matrix Results

Bandwidth utilization on wireless sensor networks is data obtained from the simulation results in Castalia Simulator software is also a package received by occupying superframe duration (SD) that can be shown in figure 4 which will then be calculated as equation (5). With the data can calculate the number of SD occupied as the equation (8), and to get the total value of SD using the equation (6) so that the results are obtained as presented in table 4.

Table 4. Results of bandwidth utilization analysis

Traffic Load	Method			
	Combination	SUDAS	ADES	Standard
0.1	0.08097	0.07458	0.01800	0.01366
0.2	0.11495	0.10672	0.02521	0.01346
0.3	0.14541	0.13316	0.01788	0.02192
0.4	0.17248	0.16060	0.01867	0.01428
0.5	0.20368	0.18003	0.02913	0.02321
0.6	0.21648	0.17338	0.03115	0.01350
0.7	0.228792	0.18127	0.01878	0.01379
0.8	0.23036	0.19536	0.01831	0.01264
0.9	0.23555	0.18490	0.01978	0.01458
1	0.24151	0.19846	0.02082	0.02398

In picture 6 is a comparison graph bandwidth utilization with combination method method, sudas method, ades method and standard method:

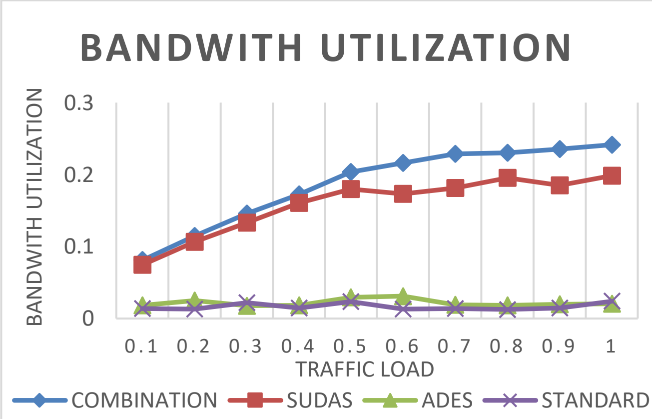

Figure 6. Graph of comparison bandwidth utilization

In the equation (4) and (3) it can be seen that the BU and goodput values are influenced by the received packet value $(N_{received})$ and the simulation time (T_{sim}) which distinguishes is the time to send the data packet (T_f) and the payload value (L_{data}) on the goodput. While in T_f and L_{data} the value does not change when the *traffic load* value changes. So the working matrix graph is obtained with the same shape between goodput and BU, but has a different value.

Based on the above utilization bandwidth test obtained the result that the value of badwith utilization against traffic load in the combination method of adjustment delay and slot duration occurs increased bandwidth utilization or has the highest value compared to other methods (SUDAS, ADES, Standard IEEE 802.15.4). The bandwidth utilization value of combination methods increased by 0.0282, 0.1652, and 0.1705 respectively compared to sudas methods, ADES methods, and IEEE 802.15.4 standards. Based on the graph image of the bandwidth performance matrix test results utilization on the combination method of delay adjustment and slot duration adjustment can be concluded that the combination method is a more efficient method of managing the large slots available on the Nerworks Wireless Sensor network especially on IEEE 802.15.4 when compared to other methods.

Energy Consumption Performance Matrix Results

Energy consumption on Nerworks Wireless Sensors is one of the parameters that need to be considered, because on the

Nerworks Wireless Sensor network where the sensor node uses energy only from the battery for its operation. To measure energy consumption on wireless sensor networks can be calculated using equations (9), data obtained from simulation results in Castalia Simulator software is energy consumption from per node. Here is the data of the simulation results obtained. With the data can calculate the total energy consumption by summing the overall energy consumption on the coordinator node (node 0) and energy consumption on the device node (nodes 1 to 20), so that the results are obtained as presented in table 5.

Table 5. Energy consumption analysis results

Traffic Load	Method			
	Combination (*j*)	SUDAS (*j*)	ADES (*j*)	Standard (*j*)
0.1	4.348	4.42	4.769	4.764
0.2	4.313	4.437	4.791	4.863
0.3	4.359	4.384	4.748	4.703
0.4	4.395	4.376	4.769	4.827
0.5	4.4	4.405	4.71	4.742
0.6	4.347	4.345	4.693	4.823
0.7	4.36	4.456	4.788	4.811
0.8	4.368	4.417	4.749	4.779
0.9	4.388	4.363	4.78	4.815
1	4.41	4.397	4.787	4.786

In figure 7 is a graph comparing energy consumption with combination method, sudas method, ades method and standard method:

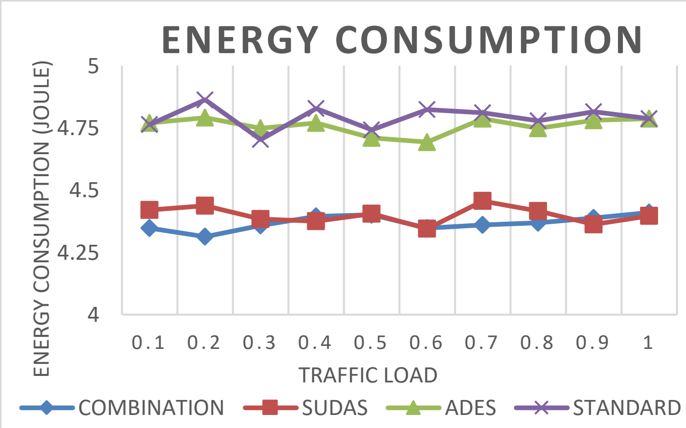

Figure 7. Energy consumption comparison graph

Based on figure 7 shows that the value of energy consumption against traffic load in the combination method has the lowest value compared to other methods such as (SUDAS, ADES, IEEE Standard 802.15.4). In light traffic loads (values 0.1 to 0.2), the energy consumption values of combination methods decreased by 3.1%, 38.9%, and 42.2% respectively compared to SUDAS methods, ADES methods, and the IEEE 802.15.4 standard.

Based on the graph image of the results of the matrix test of energy consumption performance on the combination method of delay adjustment and slot duration occurs the following energy saving can be concluded that the combination method is the optimal method in energy saving on the Nerworks Wireless Sensor network especially on IEEE 802.15.4 when compared to other methods, such as combination, SUDAS, ADES, and IEEE standard 802.15.4.

IV. CONCLUSION

From the results of the study analysis of the combination method of delay adjustment and slot duration based on IEEE 802.15.4 can be concluded, i.e. the results of matrix analysis of goodput performance, bandwidth utilization and energy consumption, where the average goodput results of combination methods increased by 5%, 29.7%, and 30.7% respectively compared to SUDAS methods, ADES methods, and IEEE 802.15.4 standard methods. For bandwidth performance matrix the utilization of combination methods increased by 0.0282, 0.1652, and 0.1705 respectively compared to SUDAS method, ADES method, and IEEE standard method 802.15.4. And in the matrix of energy consumption performance of combination methods decreased by 3.1%, 38.9%, and 42.2%, respectively compared to sudas, ADES, and IEEE 802.15.4 standard methods.

Based on the results of the performance matrix in this study the advantages possessed by the combination method of delay adjustment and slot duration can be concluded that, the combination method has faster performance in data transmission, is more efficient in allocating bandwidth, and has a more efficient energy consumption compared to other methods, such as combination, SUDAS, ADES, and IEEE standard 802.15.4.

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