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A NEW UNEQUAL CLUSTERING ALGORITHM USING ENERGY-BALANCED AREA PARTITIONING FOR WIRELESS SENSOR NETWORKS

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Abstract - Multi-hop Clustering is more preferred than the single-hop one because the transmission range of the Wireless Sensor Networks (WSN) nodes is not determined by the size of the network area. However, the multi-hop method brings a new problem related to the workload imbalance between the cluster-heads (CHs). Unequal Clustering becomes the most proposed solution of the unbalance load, but the calculation of the radius clusters still become a big challenge to achieve a maximum balancing degree. In this paper, we propose a new unequal clustering algorithm based on the partitioned circles network model, having better accuracy in the energy consumption analysis than the rectangular one. The superiority of the algorithm we propose is cluster parameters, by which the region width and cluster-head probability, are obtained with a complete energy consumption analysis. Through the simulation evaluation, the algorithm brings the better performance than the equal clustering.

Index terms*: WSN, Unequal Clustering, Energy Balancing, Circular Partitioning*

I. INTRODUCTION

As the applications of Wireless Sensor Networks (WSN) get broader and more varied, the protocol supporting the scalability is extremely required, beside WSN's main challenge, associated to the energy efficiency. It has been proven that clustering becomes the best solution to answer the scalability problem and energy efficiency of WSN [1]. LEACH (Low-Energy Adaptive Clustering Hierarchy) [2] is one of the earlier proposed clustering algorithms for WSN. This algorithm is designed based on single-hop communication between the cluster-head and the Base Station (BS). Based on most of recent researches, multi-hop clustering scheme is more preferred than the single-hop one because it is more realistic, especially for networks with broad areas, e.g. HEED [3], [4] and COCA (Constructing Optimal Clustering Architecture) [5]. Using multi-hop clustering, the transmission range of a cluster-head (CH) doesn't depend on the distance increase between a CH and base-station (BS) because the data is not delivered directly from CH to BS, but relayed to CH below it.

However, the multi-hop method brings a new problem related to the workload imbalance between CHs. CH located around BS will consume bigger energy and will die earlier because it is overloaded by heavier relay traffic. The area around BS is commonly called a hotspot area. Thus, the problem is usually called the hotspot problem.

Unequal clustering, by which a cluster close to BS is designed to have a smaller radius to compensate the load in relaying the larger data, becomes the most proposed solution by researchers, e.g. EEUC (Energy-Efficient Unequal Clustering) [6], UCS (Unequal Clustering Size) [7], and UCR (Unequal Cluster-Based Routing) [8]. In those proposals, unequal clustering was claimed was more superior in energy balance than equal clustering. However, they still didn't have accurate analyses in determining the size of the cluster radius. There has been an attempt in Energy Efficient Clustering (EC) algorithm to find solution for this problem [9]. However, the use of rectangular-formed network area assumption is still inaccurate for the varied area dimension, compared to the circular area assumption [10]. Unequal clustering analysis with circular network area model is used in ACT (Arranging Cluster Sizes and Transmission Ranges Protocol) [11]. Yet, this algorithm is hardly realized because the algorithm complexity increases sharply along with the increase of area width.

In this paper, a new complete clustering algorithm is proposed. The new algorithm is designed based on circular partitioning strategy and equipped with a set of energy balancing analysis for determining the cluster parameters. The proposal is split into two stages, *off-line* and *on-line*. The off-line stage is done manually before the WSN nodes are deployed for calculating the width of the region and the probability of CHs. The on-line stage is performed autonomously by nodes after they are deployed, for building the clusters and establishing the routes.

Compared to the previous proposals, below are the main contributions of the algorithm proposed in this paper:

1) The proposed algorithm is completely arranged, including the determination of cluster parameters, the formation of the clusters, and the establishment of the routes.
2) The utilization of circular-based partitioning area strategy, which results in the higher accuracy of energy consumption estimation higher than the rectangular model.
3) The selected width of the region is ones that give data route which has the most minimum energy.
4) The probability of the number of CHs on each region directly correlated to the cluster radius is obtained through complete energy consumption analysis so that it will give a more accurate result.
5) The calculation of region parameter and CH probability is carried out off-line before the network is deployed, thus not overburdening the nodes.

This paper is organized as follows: Section II describes the related works of the previous researchers. Section III contains explanations about network model and problem description. Proposed algorithm and the explanation are presented in Section IV. Then, Section V contains explanations about performance evaluation. The last Section contains the conclusion and our future works.

II. RELATED WORKS

Numbers of clustering algorithms have been proposed by researchers. LEACH [2] is one of the earliest clustering algorithm proposed and often used as the comparator for the later proposals. The purpose of this algorithm is to increase the *lifetime* of the network by using signal strength as a parameter in the formation determining. The nature of LEACH is distributed, which means that the algorithm is executed autonomously on each node. LEACH algorithm is really suitable for WSN due to its algorithm's simplicity. However, the use of direct link between CH and BS is unrealistic, especially for the network with broad area.

Multi-hop communication is offered by HEED [3] as a solution for the CH-to-BS distance problem. Although has been successful in solving such problem, the multi-hop strategy brings a new problem, related to the load balance between CHs. In the WSN system, all data is routed between CHs toward one point, that is BS, so the CH that closer the distance from CH to BS will be burdened heavier data load that has to be relayed. This problem then is known as hotspot problem.

Many researchers believe that unequal clustering becomes the solution to solve the hotspot problem. This strategy is firstly presented in EEUC algorithm [6], which is then fixed through UCS [7] and UCR [8]. Although claimed to have been successful in solving the hotspot problem in determining the quantity of cluster parameters, such algorithms are not supported by a comprehensive energy balance analysis.

A comprehensive analysis of energy balance in producing cluster parameter has been proposed in EC [9]. In EC, network area that is assumed to be of a rectangular form, is partitioned into regions with horizontal division pattern. The energy consumption analysis is done comprehensively so that the probability of CH in each region is obtained, having a direct correlation with the cluster radius. Although it looks superior, there is some inaccuracy in energy balance analysis in EC algorithm, related to the network area model assumed in rectangular shape, as has been proven in [10].

The new algorithm related to unequal clustering is ACT [11], using a circular network pattern that is not less comprehensive than EC. Network area in ACT is divided into cluster layers; each of them has different thickness. The layer thickness, the representation of cluster diameter, is obtained all at once by completing one energy balance equation of all layers. Although very accurate, the complexity of the energy equation, which acts as the tool to decrease the value of the cluster diameter, is highly complex and growing more and more complex with the growth of the number of the layers.

On a multi - hop network, routing strategy is required for obtaining a most efficient delivering data. There were many routing algorithms that have been proposed, and therefore, our proposed algorithm does not specifically determine the routing mechanism. There are many routing algorithms designed specifically for WSN, e.g. GeRaF [12], NHRPA [13], and LEACH-DE [14].

III. NETWORK MODEL AND DESCRIPTION OF PROBLEM

In this paper, we use the following assumptions:

1) Area of the network assumed as a circle with BS as the center. The area partitioned into some regions with a specific shape and dimensions that will be explained in the next chapter.
2) The nodes are deployed randomly in the area using a uniform distribution. The position of the node is unknown but the any node is assumed has knowledge about its region where it is located. The density of the nodes is also assumed known.
3) The main parameter that be exposed by the algorithm is energy consumption. Other parameters that probably affected by the algorithm, e.g. time delay and reliability, will not be included in the optimization problem. The time delay will be analysis in the performance evaluation as an addition discussion. The reliability problem is assumed has been solved by the lower layer of the network, i.e. the link and physical layers. To ensure that the reliability is maintained, we set the distance of any link is not exceed the maximum below the maximum transmission range of the nodes (e.g. 100 m for Imote2 outdoor).

In WSN analysis, energy consumption formulations widely used by researchers are the three part model which proposed by Heinzelmann et.al [2] :

1. Energy to transmit a *l*-bit message a distance d, the radio expends:

$$E_{TX} = \begin{cases} lE_{elec} + l\varepsilon_{fs} d^2 & for \quad d < d_0 \\ lE_{elec} + l\varepsilon_{mp} d^4 & for \quad d \geq d_0 \end{cases} \quad (1)$$

2. Energy for receiving this message, the radio expends:

$$E_{RX} = lE_{elec} \quad (2)$$

3. Energy that needed by the CH to run the data aggregation process is E_{DA}

The electronics energy, E_{elec}, is the energy dissipated per bit to run the transmitter or the receiver circuit that depends on factors such as the digital coding, modulation, filtering, and spreading of the signal. The amplifier energy, $\epsilon_{fs} d^2$ or $\epsilon_{mp} d^4$, depends on the distance to the receiver and the acceptable bit-error rate [2].

Energy consumption of a CH related to the cluster radius is illustrated as a simple model as shown in Figure 1. The CH A (the head of cluster A) receives and aggregate data from cluster members and sends them to BS via CH B. The CH B, beside relaying data from CH A, also receives and aggregate data from its members.

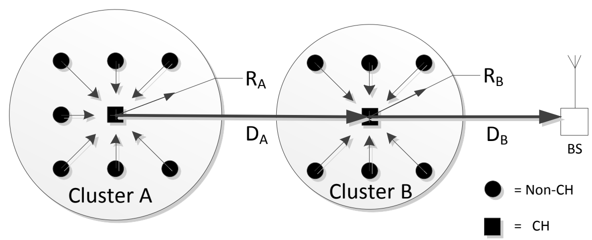

Figure 1. Simple Multi-hop Clustering Model

The energy consumed by a CH, E_{tot}^{CH} , generally is composed of two components: 1) energy needed for handling the data of internal cluster E_{own} and 2) energy for relaying data from outer CHs, E_{relay} , so

$$E_{tot}^{CH} = E_{own} + E_{relay} \tag{3}$$

In Figure 1, There is no data that must be relayed by CH A, therefore the energy component of CH A is only E_{own} . For one sensing cycle, the energy consumed by CH A for sending 1 bit data is

$$E_{tot}^{CH\_A} = E_{own}^{A} = \left(N_{mbr}^{A} - 1\right) E_{rx}^{CH\_A} + \gamma N_{mbr}^{A} E_{tx}^{CH\_A} \tag{4}$$

with N_{mbr}^{A} is the number of member nodes in cluster A, and $E_{rx}^{CH\_A}$ and $E_{tx}^{CH\_A}$ are energy for receiving and transmitting 1 bit data, respectively. The parameter γ is compression factor whose value ranges from 0 to 1. Given node density of σ node/m2 and radius of cluster radius A being R_A , the total energy of CH A is

$$E_{tot}^{CH\_A} = \left(\sigma \pi R_A^2 - 1\right) E_{elec} + \gamma \sigma \pi R_A^2 \left(E_{elec} + \varepsilon_{fs} D_A^2\right) \tag{5}$$

For CH B, the total energy is the sum of internal data processing energy and external data relaying energy :

$$E_{tot}^{CH\_B} = E_{own}^{B} + E_{relay}^{B} \tag{6}$$

By using the energy model as in eq. (1) and eq. (2), so that

$$E_{own}^{B}=\left(N_{mbr}^{B}-1\right)E_{rx}^{CH\_B}+\gamma N_{mbr}^{B}E_{tx}^{CH\_B}=\left(N_{mbr}^{B}-1\right)E_{elec}+\gamma N_{mbr}^{B}\left(E_{elec}+\varepsilon_{mp}D_{B}^{2}\right) \quad (7)$$

and

$$E_{relay}^{B}=\gamma N_{mbr}^{A}E_{elec}+\gamma N_{mbr}^{A}\left(E_{elec}+\varepsilon_{mp}D_{B}^{2}\right) \quad (8)$$

Therefore, the total energy for CH B is

$$E_{tot}^{CH\_B}=\left(\gamma N_{mbr}^{A}+N_{mbr}^{B}-1\right)E_{elec}+\gamma\left(N_{mbr}^{A}+N_{mbr}^{B}\right)\left(E_{elec}+\varepsilon_{mp}D_{B}^{2}\right) \quad (9)$$

Given node density of σ , we obtain

$$E_{tot}^{CH\_B}=\left(\gamma\sigma\pi R_{A}^{2}+\sigma\pi R_{B}^{2}-1\right)E_{elec}+\gamma\sigma\pi\left(R_{A}^{2}+R_{B}^{2}\right)\left(E_{elec}+\varepsilon_{fs}D_{B}^{2}\right) \quad (10)$$

The optimization problem can be expressed as follows: To achieve the load-balancing between both CHs, we must find the value of R_A and R_B such that the energy consumed by CH A is equal to one for CH B". Energy consumed by CH A is equal to one for CH B. Mathematically, the problems can be formulated as

$$\begin{aligned} &\min_{R_A,R_B} \quad E_{tot}^{CH} \\ &s.t. \\ &\quad E_{tot}^{CH}=E_{tot}^{CH\_A}=E_{tot}^{CH\_B} \end{aligned} \quad (11)$$

For more complex model with N levels of cluster, the formulation eq. (11) can be extended into:

$$\begin{aligned} &\min_{R_1,R_2,\ldots,R_N} \quad E_{tot}^{CH} \\ &s.t. \\ &\quad E_{tot}^{CH}=E_{tot}^{CH\_1}=E_{tot}^{CH\_2}=\ldots=E_{tot}^{CH\_N} \end{aligned} \quad (12)$$

In the process of clusters establishment, with the assumption that the nodes are uniformly distributed in the area, the target value of cluster radius can be approached by determining the probability becoming a CH on a particular region, as proposed in [9]. By the approach, the network area partitioned into some regions based on the distance to BS where any node on a region is set to have the same probability. To achieve optimum value of probability, we have proposed a new area partitioning scheme that gives more accurate analysis on estimating the energy [10]. Our proposed scheme is based on a circular form as shown in Figure 2.

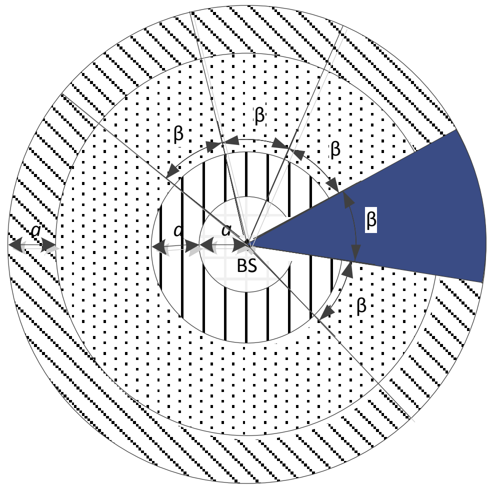

Figure 2. Proposed circular partitioning

In the scheme, the sink or BS is assumed to be located at the center of the circle. The network area is partitioned into several segments with same angle β that we called *super-regions*. And then, each super-region is partitioned into some *regions* as shown in Figure 3.

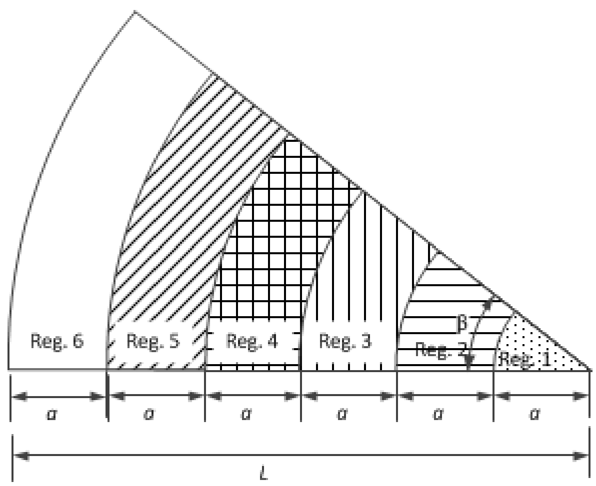

Figure 3. A *super-region* partitioned into some *regions*.

The relation between cluster radius of a cluster, R_i and the CH probability, p_i , with node density σ is [9]

$$p_i = \frac{1}{\pi R_i^2 \sigma} \Rightarrow R_i = \sqrt{\frac{1}{\sigma \pi p_i}} \tag{13}$$

Therefore eq. (5) can be reformulated as

$$E_{tot}^{CH\_A} = \left(\frac{1}{p_A} - 1\right)E_{elec} + \frac{\gamma}{p_A}\left(E_{elec} + \varepsilon_{fs} D_A^2\right) \tag{14}$$

Eq. (10) becomes

$$E_{tot}^{CH\_B} = \left(\frac{\gamma}{p_A} + \frac{1}{p_B} - 1\right)E_{elec} + \left(\frac{\gamma}{p_A} + \frac{\gamma}{p_B}\right)\left(E_{elec} + \varepsilon_{fs} D_B^2\right) \tag{15}$$

And eq. (11) and (12) respectively are replaced as

$$\begin{aligned} &\min_{p_A, p_B} \quad E_{tot}^{CH} \\ &s.t. \\ &\quad E_{tot}^{CH} = E_{tot}^{CH\_A} = E_{tot}^{CH\_B} \\ &\quad 0 < p_A, p_B \le 1 \end{aligned} \tag{16}$$

And

$$\begin{aligned} &\min_{p_1, p_2, \ldots, p_N} \quad E_{tot}^{CH} \\ &s.t. \\ &\quad E_{tot}^{CH} = E_{tot}^{CH\_1} = E_{tot}^{CH\_2} = \ldots = E_{tot}^{CH\_N} \\ &\quad 0 < p_1, p_2, \ldots, p_N \le 1 \end{aligned} \tag{17}$$

The components of each energy on eq. (17) can be formulated in association with value of CH probability, p_i, by using the following analysis. Consider a network partitioned into K regions, the average of CH energy of a region i refering to eq. (3) is

$$E_{tot}^{CH\_i} = E_{own}^{i} + E_{relay}^{i} \tag{18}$$

with

$$E_{own}^{i} = \left(N_{mbr\_ch}^{i} - 1\right)E_{rx}^{CH\_i} + \gamma N_{mbr\_ch}^{i} E_{tx}^{CH\_i} \tag{19}$$

With the average of cluster radius in region i being R_i then the cluster area is πR_i^2. Using eq. (13), the number of nodes in the cluster is

$$N_{mbr\_CH}^{i} = \sigma\pi R_i^2 = \sigma\pi\left(\sqrt{\frac{1}{\sigma\pi p_i}}\right)^2 = \frac{1}{p_i} \tag{20}$$

Therefore, by using eq. (1) and (2) so that

$$E_{own}^{i} = \left(\frac{1}{p_i} - 1\right)E_{elec} + \frac{\gamma}{p_i}\left(E_{elec} + \varepsilon_{fs}\left(d_{outer}^{i}\right)^{x}\right) \tag{21}$$

where d^i_{outer} is the longest distance that must be reached by a CH in region i. The variable x is equal to 2 in a free-space channel and 4 in multipath channel.

Energy for relaying data, E^i_{relay}, is

$$E^i_{relay} = N^{CH\_i}_{relay}\left(E^{CH\_i}_{rx} + E^{CH\_i}_{tx}\right) \tag{22}$$

The number of incoming data accumulation, N_{relay_i} is calculated as

$$N^i_{relay} = \frac{N^i_{outer}}{N^i_{CH}} = \frac{\gamma \sum_{j=i+1}^{L} N_{tot_j}}{A_i \sigma p_i} = \frac{\gamma \sum_{j=i+1}^{L} \sigma A_j}{A_i \sigma p_i} = \frac{\gamma}{A_i p_i} \sum_{j=i+1}^{L} A_j \tag{23}$$

where

$$A(j) = \beta a^2 (j - 0.5) \tag{24}$$

so that

$$E^i_{relay} = \left(\frac{\gamma}{p_i} \sum_{j=i+1}^{L} \frac{A_j}{A_i}\right)\left(2E_{elec} + \varepsilon_{fs}\left(D^i_{outer}\right)^x\right) \tag{25}$$

where

$$D^i_{outer} = a\sqrt{2i^2 - 4i + 4 - \left(2i^2 - 4i\right)\cos\beta} \tag{26}$$

IV. PROPOSED ALGORITHM

The proposed algorithm is split into two stages: *on-line* and *off-line*. The off-line stage contains the processes of calculating the network parameters, including region width and CHs probability, that are done manually before the network is deployed. The on-line stage, done autonomously by the nodes after deployed, contains cluster formation and route establishment.

a. *Off-line* Stage

The output of the *off-line* stage is the region width a and the CH probability of each region, $p_1, p_2, ..., p_K$. The the region width a is obtained by solving the optimization problem in eq. (27).

$$\begin{aligned} &\min_{a} \quad E_{path} \\ &s.t. \\ &0 \le a \le \frac{L}{2} \end{aligned} \tag{27}$$

E_{path} is the energy for transmitting one bit data from the farthest point from BS with the longest distance and L is radius of circle (length of the super region). The longest route is illustrated as the bold lines in Figure 4.

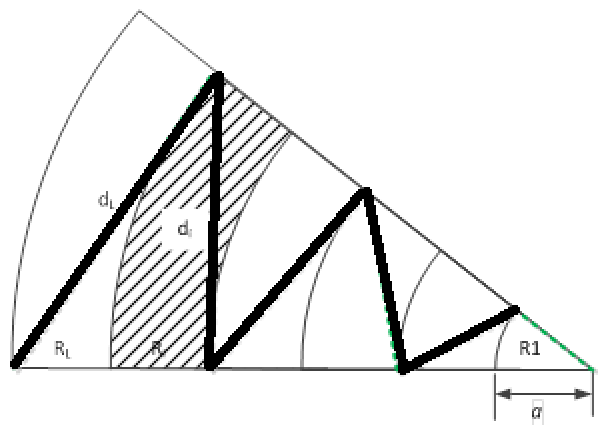

Figure 4. The longest route on a super region

Using energy model eq. (1) and eq. (2), amount of energy needed for delivering a bit data via the route can be calculated as

$$E_{path} = \sum_{i=1}^{L} le_{elec} + l\varepsilon_{fs} d_i^x \tag{28}$$

where

$$x = \begin{cases} 2 & for \quad d < d_0 \\ 4 & for \quad d \geq d_0 \end{cases} \tag{29}$$

The diagonal d_i can be obtained using a triangle formulation as illustrated in Figure 5.

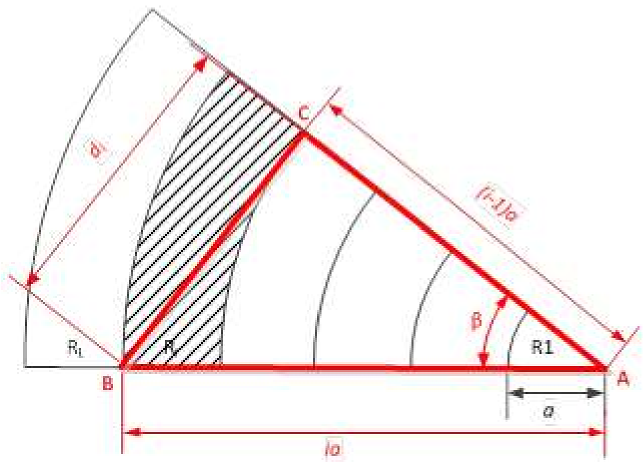

Figure 5. Region diagonal calculation

From Figure 5, the value of d_i is illustrated as edge BC of triangle ABC and can be obtained as:

$$\begin{aligned} d_i &= \sqrt{AB^2 + AC^2 - 2AB.AC.\cos\beta} \\ &= \sqrt{(ai)^2 + \left(a(i-1)\right)^2 - 2ai\left(a(i-1)\right)\cos\beta} \end{aligned} \quad (30)$$

After a is obtained, the next step in off-line stage is finding the CH probability of each region ($p_1, p_2, ..., p_K$) that can be obtained by solving the optimization problem eq. (17). With unlimited resources and energy on off-line stage, the high complexity optimization problem eq. (17) can be solved heuristically by using the algorithm in Figure 6.

Algorithm for Solving The Optimization Problem (17)

for $p_1 = 0$ to 1
    calculate $E_{tot}^1(p_1)$; // start from region 1 (the closest to CH)
end for
find $\left(E_{tot}^1\right)_{\min}$ = minimum value of $E_{tot}^1(p_1)$;
find $(p_1)_{opt} = p_1$ that give $\left(E_{tot}^1\right)_{\min}$;
for i=2 to K // for 2nd to Kth region
    $\left(E_{tot}^i\right)_{opt} = \left(E_{tot}^1\right)_{\min}$
    find $(p_i)_{opt} = p_i$ that give $\left(E_{tot}^i\right)_{opt}$;
end for

Figure 6. Pseudo-code for finding solution of CHs probability optimization problem

b. *On-line* Stage

Generally, the on–line stage contains two activities: Clustering and Routing. Both tasks are done by each node autonomously after they are deployed and be assumed they know their position and the region where they are located. The clustering consists of the steps of choosing the CHs and determining the members associated to each CH. The CHs are selected based-on probability values that obtained from off-line stage. Any non-CH node will choose a CH to be affiliated based-on the closest distance. The detailed steps of the clustering are explained in algorithm Figure 7.

```
Deploy node with uniform density = σ ;
for j=1 to (Number of  Node);   // choosing the CH's
        find reg(j) ;   //each node autonomously determines  its region based on its position
        choosing (p_j)_th = (p_reg(j))_opt ;   // each node determines its CH-probability (p_j)_th
        p_j = rand(0,1) ;       // each node generate a random value between 0 to 1.
        if  p_j ≤ (p_j)_th
                CHstat(j)=1;       // Node status is as a CH
        else
                CHstat(j)=0;       // Node status is as a member
        end if
end for
for  j=1 to (Number of  Node);  // forming the clusters
        if CHstat(j)==1             // if the node is a CH
                broadcast a CH announcement;       //
                listen the member messages for joint;          //
        else                        // if the node is a member
                listen the 1st CH announcement:
                send message to 1st CH for joint
        end if
end for
```

Figure 7. Pseudo-code of clusters formation

The second activity in online-stage is route establishment. There were many routing algorithms for WSN that had been proposed by researchers. So, in the paper, we do not propose a new routing method, we just simply choose one of them. We only make a rule that must be followed by the routing to be chosen. The rule is any CH must be directed to transmit its data to another CH located in the region below its region.

Both activities on the on-line stage, clustering and routing, did not contain any complex computation such as solving optimization problems. The stage only contains logical operations.

All optimization solving processes are performed in Off-line stage therefore the WSN nodes not be burdened by any high complexity operation. The combination of the activities on both stages, off-line and on-line, gives a complete clustering algorithm that ready to be implemented.

V. PERFORMANCE EVALUATION

In this section, performances of the proposed algorithm are compared with those of the equal clustering with the similar network model. We cannot compare it with previous unequal clustering algorithms because of the differences of assumption and network models. The evaluation is performed using Matlab on a computer with Intel Dual-Core 2.13 GHz processor and memory 3 GByte RAMs. The simulation parameters used in the evaluation are determined in Table 1.

Table 1: Simulation parameters

Parameter	**Symbol**	**Value**
Network radius	L	500m
Partition angle	B	π/8
Node density		0.0125 nodes/m2
Electronic Energy	E_{elec}	50 nJ
Energy multipath	ε_{mp}	0.013 uJ
Energy free-space	ε_{fs}	10 uJ
Data length	L	1
Base station coordinate	(Bx, By)	(0,0)

Although performed by using simulation, the communication parameter is referred to a real and practical device, i.e single-chip 2.4GHz transceiver nRF24L01 for no-ACK [15]. For completing the analysis, the time delay that affected by multi-hop communication also presented by using the following calculation :

$$T_{delay} = T_{UL} + T_{stby2a} + T_{OA} + T_{IRQ} + T_{pr} \tag{31}$$

where T_{UL} is upload time:

$$T_{UL} = \frac{B_{payload}}{R_{SPI}} \tag{32}$$

T_{OA} is on-air time:

$$T_{OA} = \frac{B_{packet}}{R_{ad}} \quad (33)$$

and T_{pr} is propagation time of a packet on over distance d with v_{em} is the speed of electromagnetic wave:

$$T_{pr} = \frac{d}{v_{em}} \quad (34)$$

All other radio parameters also refer to the nRF24L01 parameters as shown in Table 2.

Table 2: Radio parameters

Parameter	**Symbol**	**Value**
Air data rate	R_{ad}	2 Mbps
SPI rate	R_{SPI}	2 Mbps
Payload length	$B_{payload}$	8 bit
Packet length (Payload + header)	B_{packet}	57 bit
interrupt time	T_{IRQ}	6.0 uS
Standby time	T_{stby2a}	130 uS
Maximum Transmission Range		100 m

a. Calculation of the region width, *a*

By varying the number of hops of eq. (28), the value that gives the minimum E_{path} can be obtained. The curve of E_{path} that varies with the number of hops for six different values of super-region length *L* is shown in Figure 8. The number of hops that give E_{path} minimum for each L value is presented in Figure 9. For L=500 m that will be used in the next step, the optimum number of hops, i.e. number of hops minimizes E_{path}, is 8 hops.

The value of region width *a* can simply be calculated by dividing the L by the optimum number of hops, therefore: $a = 500m / 8 = 62.5m$. Beside giving minimum path energy, the reliability of the link also could be maintained by the resulted region width because the value did not exceed the maximum transmission range of the radio transmitter, i.e. 100 m.

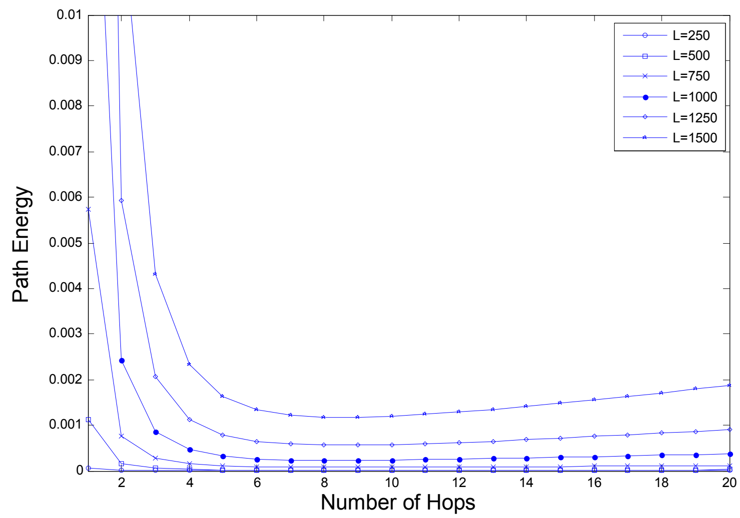

Figure 8. Path energy for various number of hop and area length

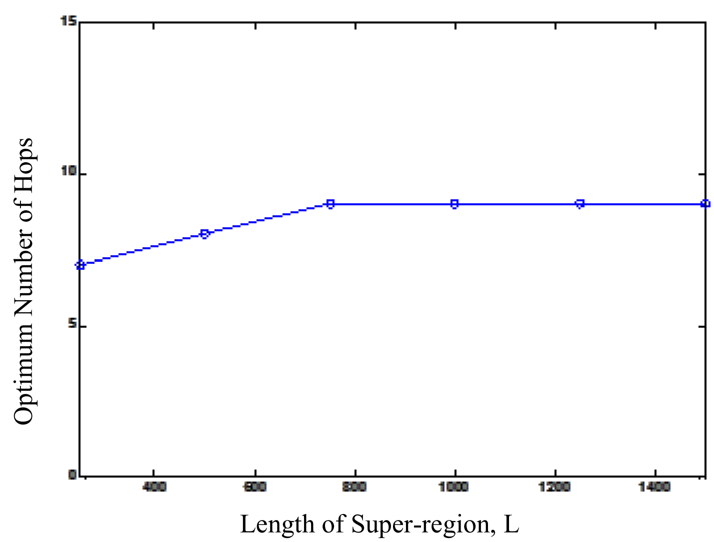

Figure 9. Number of hop that gives minimum path energy for various area lengths

A negative effect associated to delay time is presented by multi-hop communications. Based-on model of eq. (31) with parameter value from Table , the time delay effect of multihop communications is shown in Figure 10. From the figure we can see that increasing the number of hops linearly increases the delay time. This situation can be understood as follows: generally, time delays composed of two components: processing delay and propagation delay. Processing delay is time that needed by a node processor to perform communication protocol. It's meant that the processing delay is increased proportionally to the number of relay nodes. The propagation delay is time that needed by a packet to travel from transmitter to receiver that means depends on the distance. With typical application of WSN is just in distance order about tens to hundred meters, the propagation delay has not significantly given contribution to the total delay. However, the time delay that be raised is still in order of milliseconds. For commonly WSN applications, e.g. periodical environment monitoring, habitat movement monitoring, and building structure monitoring, the time delay about one to ten milliseconds can be negligible.

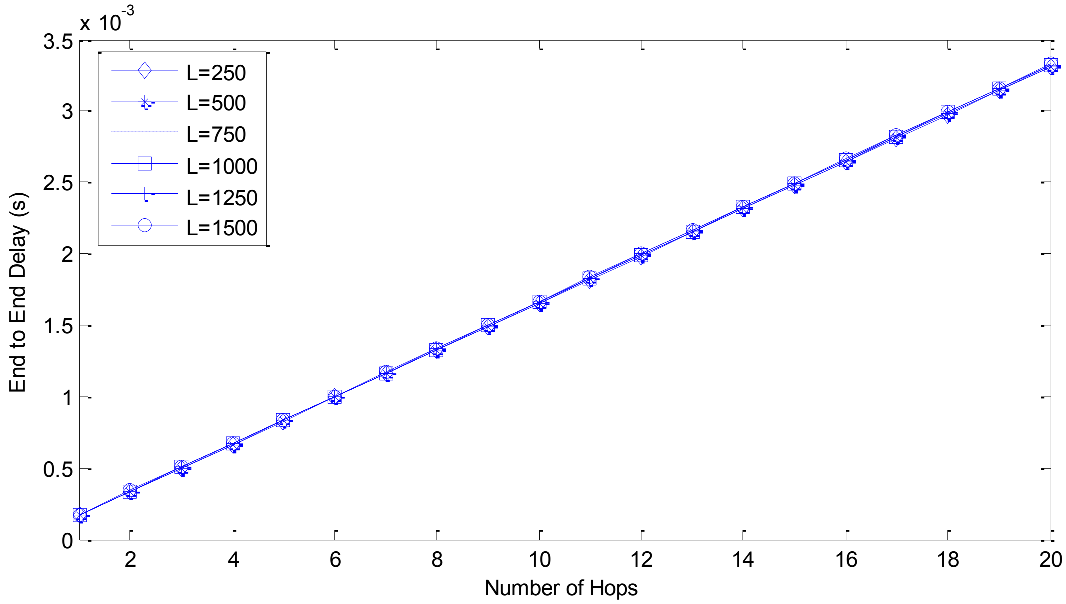

Figure 10. End to End Delay for Different Number of Hops

b. Determining CH Probabilities ($p_1, p_2, ..., p_K$)

CH Probabilities can be obtained by implementing the simulation parameters in Table 1 to the algorithm in Figure 6. For L = 500 m, the CH probabilities be result from by the simulation with three different numbers of region value is presented in 3. From the table, the value of CH probability is proportionally decreased when the region-BS distance is increasing. Until this point, the main objective the proposed algorithm to design unequal clustering is still on the track.

Table 3: Probability of CH for each region

Number of Region	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
10	1.0000	0.3500	0.2400	0.2100	0.2000	0.2100	0.2100	0.2100	0.1800	0.1200
8	1.0000	0.3500	0.2400	0.2000	0.1900	0.1700	0.1500	0.1000		
6	1.0000	0.3500	0.2300	0.1800	0.1400	0.0900				

c. Deployment of The Network

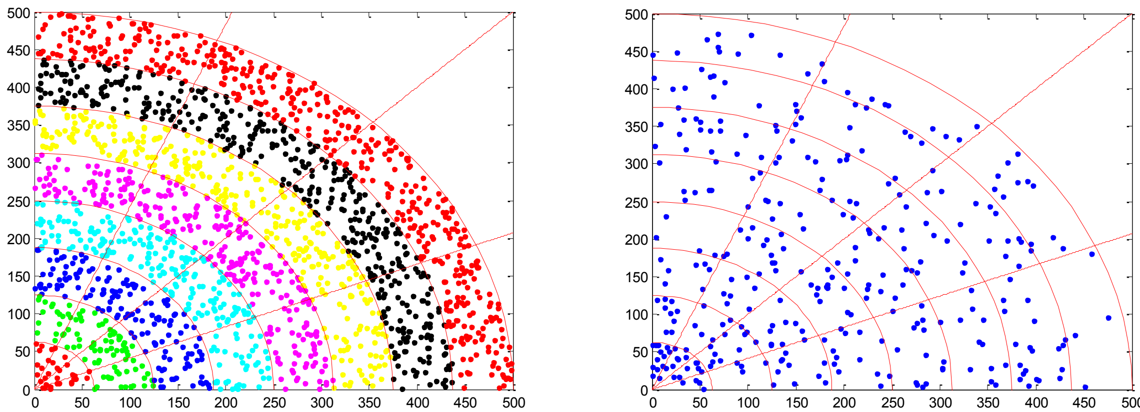

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Figure 11. Network deployment (a) all nodes deployment (b) CHs deployment

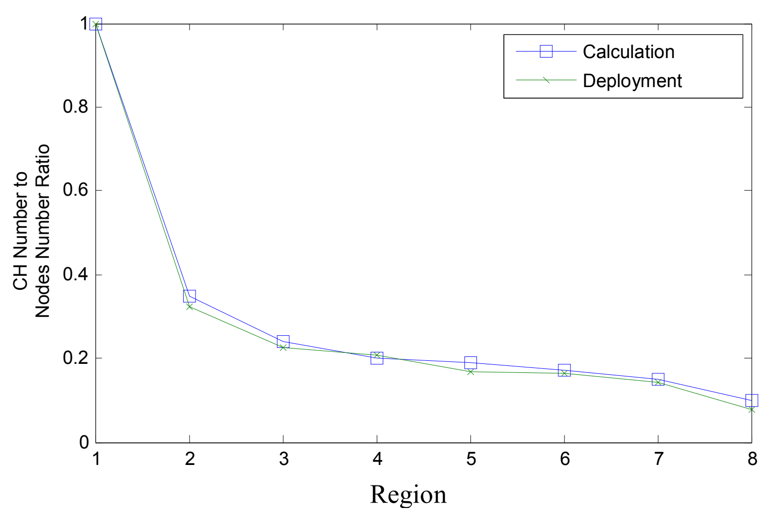

Figure 12. CHs-number to nodes-number ratio of each region

The next step is deploying the network and implementing the on-line stage. Deployment method that be used in the paper is similar to the method for evaluating the previous clustering algorithm [4], [8], [11]. Figure 11 shows the network after deployed. The Figure 11.a demonstrates the deployment of all nodes and their regions, and whereas Figure 11.b shows the CHs that has been selected based on the probability value from Table 3. The number of CH for each region resulting from in the deployment is very similar to the expected number as shown in Figure 12.

d. Energy Consumption Calculations

The final step is calculating energy consumptions of the CHs for measuring the performance of the proposed algorithm. The performance is indicated by the balancing of CH energy consumption among the regions. The average of CHs energy consumption for each region is presented in Figure 13. In the figure, the difference between the highest average energy with the lowest on the proposed algorithm is less than 10 uJ. On the other side, the difference on the equal clustering is more than 30 uJ. It suggests that the proposed algorithm results in a more balance load among nodes compared to the equal clustering.

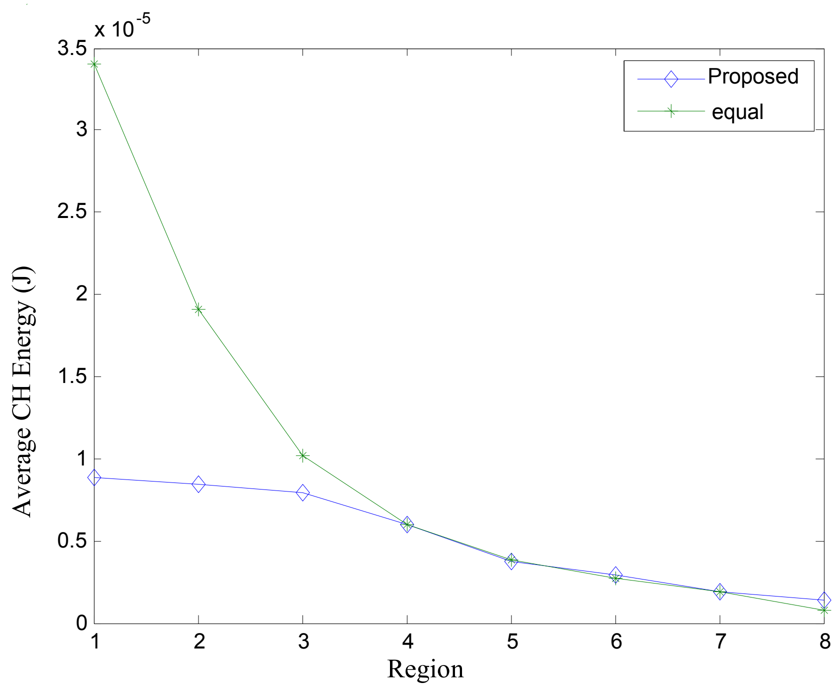

Figure 13. Average of CH energy for each region

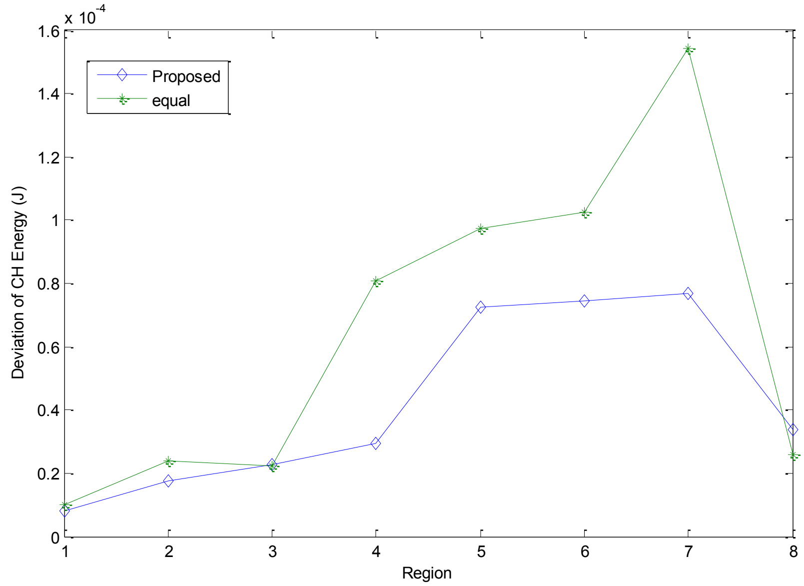

Figure 14. Maximum deviation of CH energy on each region

Balancing of energy consumption among nodes in the same region is presented in Figure 14. From the graph we can see that the proposed algorithm gives more balance energy consumptions than the equal clustering. This phenomenon arises because the CH probabilities are localized in each region so that the range of cluster dimensions is reduced.

VI. CONCLUSIONS

In this paper, a new unequal clustering algorithm using circular partitioning strategy and based on energy-balanced analysis are proposed. The algorithm is composed by a complete set of clustering activity, i.e. cluster parameter determinations, cluster formation, and routing. The WSN nodes are designed to perform the light processing because all hard processing e.g. optimization is moved to off-line stage. The width of the partition-region is obtained using minimum energy consumption path calculation. The multi-hop give delay time effect but on real WSN applications, it’s not significantly affected the system performances. The probability becoming a CH in each region is calculated using heuristic-optimization based on the balancing energy analysis, so that gives a more accurate estimation. The experimental results demonstrate the superiority of the proposed algorithm on balancing energy compared to equal clustering.

The proposed algorithm in this paper does not yet present the strategy of rotating the role as CHs that called dynamical aspect of clustering. Nevertheless, we believe that introducing the dynamical aspect will not affect significantly to the performance of the proposed algorithm, as long as it is done in the same region. The works associated with the dynamical aspect is becoming our future works, beside the adaptation method from circular to another form model.

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REFERENCES

[1] A.A. Abbasi, and M. Younis, “A Survey on Clustering Algorithms for Wireless Sensor Networks”, Journal of Computer Communications, Vol 30, No. 13, 2007, pp. 2826-2841.

[2] W.B. Heinzelman, A.P. Chandrakasan, H. Balakrishnan, “Application Specific Protocol Architecture for Wireless Microsensor Networks”, IEEE Transactions on Wireless Communciations, 2002, Vol. 1 (4), pp. 660 – 670

[3] O. Younis, S. Fahmy, “HEED: A Hybrid, Energy-Efficient, Distributed Clustering Aprroach for Ad Hoc Sensor Networks”, IEEE Transaction on Mobile Computing, Vol.3 No. 4, 2004, pp. 366-379

[4] P. Guo, T. Jiang, K. Zhang, and H.H. Chen, “Clustering Algorithm in Initialization of Multi-Hop Wireless Sensor Networks”, IEEE Transactions on Wireless Communications, Vol. 8, No. 12, December 2009, pp. 5713 – 5717

[5] H. Li, Y. Liu, W. Chen, W. Jia, B. Li, and J. Xiong, “COCA: Constructing Optimal Clustering Architecture to Maximize Sensor Network Lifetime”, Computer Communications Volume 36, Issue 3, 2013, pp. 256–268

[6] Chengfa Li; Mao Ye; Guihai Chen; Jie Wu, "An energy-efficient unequal clustering mechanism for wireless sensor networks," Mobile Adhoc and Sensor Systems Conference, 2005. IEEE International Conference on , vol., no., pp.8 pp.,604, 7-7 Nov. 2005

[7] Soro, S.; Heinzelman, W.B., "Prolonging the lifetime of wireless sensor networks via unequal clustering," Parallel and Distributed Processing Symposium, 2005. Proceedings. 19th IEEE International, pp.8 , 4-8 April 2005

[8] G. Chen, C. Li, M. Ye, and J. Wu, “An Unequal Cluster-Based Routing Protocol In Wireless Sensor Networks”, Wireless Networks, Volume 15, Issue 2, February 2009, pp. 193 – 207

[9] Dali Wei, Yichao Jin, SerdarVural, Klaus Moessner, dan Rahim Tafazolli, “An Energy-efficient Clustering Solution for Wireless Sensor Networks”, Wireless Communications, IEEE Transactions on , vol.10, no.11, pp.3973-3983, November 2011.

[10] A. Suharjono, Wirawan, and G. Hendrantoro, “A New Area Partitioning Strategy for Unequal Clustering of Wireless Sensor Networks”, Proceeding of ICACSIS 2012, pp. 71-74

[11] W. K. Lai, C. S. Fan, L. Y. Lin, “Arranging cluster sizes and transmission ranges for wireless sensor networks”, Information Sciences 183 (2012) 117–131

[12] M. Zorzi, and R. R. Rao, “Geographic Random Forwarding (GeRaF) for Ad Hoc and Sensor Networks: Energy and Latency Performance”, IEEE Transactions on Mobile Computing, Vol. 2, No. 4, 2003, pp.349-365.

[13] H.B. CHENG, G. YANG, and S.J.HU, “NHRPA: A Novel Hierarchical Routing Protocol Algorithm For Wireless Sensor Networks”, The Journal of China Universities of Posts and Telecommunications, Vol. 15, No. 3, 2008, pp. 75–81

[14] X. Yin, Z. Ling and L. Guan, “Low Energy Adaptive Routing Hierarchy Based on Differential Evolution”, International Journal on Smart Sensing And Intelligent Systems Vol. 6, No. 2, April 2013, pp. 523-547

[15] ---, “nRF24L01single-chip 2.4GHz transceiver preliminary Product Specification v1.0” Nordic Semiconductor, March 2008