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Mathematical Modeling of EDCH Clustering Algorithm for WSNs

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Abstract— In WSN, the energy consumed by each sensor node of the network influences the lifetime of the networks, more than the utilization of energy increases more than the lifetime of the networks decreases, this is why the enhance of the lifetime of the networks requires a strategy or protocol which reduces the power utilization of the transmission or reception of data by the nodes. In the recent years to a great extent research has been done to maximize a life time of network node. The hierarchical protocols (Cluster based-approach) have been developed in order to decrease the network traffic toward the BS (Base Station) and therefore extend the network lifetime. The number of clusters and also distribution of CH (Cluster Heads) are necessary for energy efficiency and adaptability of clustering approaches. EDCH (Effective Distance Cluster Head) is a novel energy-efficient clustering algorithm proposed recently for WSN (wireless sensor networks) to extend network lifetime by uniformly distributing of CHs (Cluster Heads) across the network. In this paper, we propose an mathematical method to model the energy utilization of the EDCH (Effective Distance Cluster Head) algorithm. The results of our extensive simulation study prove a reasonable accuracy of the proposed mathematical model to predict the energy utilization under different operational conditions. Here proposed mathematical model reveals a number of implications about the effects of different parameters on the energy utilization pattern of the EDCH (Effective Distance Cluster Head) clustering algorithm.

Keywords— WSN, Clustering, Energy Efficiency, EDCH, Mathematical Model.

I. INTRODUCTION

Wireless Sensor Networks have newly occurred as a leading research zone. They have great extensive period of economic potential, ability to alter our lives, and position many up-to-date system-building challenges. Sensor networks also pose a number of newest abstract and optimization difficulties, certain of these such as tracing, location and exploitation are chief important problems, in that some applications depend on them for essential information. Coverage in common, answers the questions about quality of service that can be delivered by a specific sensor network. The addition of several types of sensors such as acoustic, seismic, optical, etc. in one network platform and the study of the total coverage of the system also presents many exciting challenges.

Wireless sensors have turned into an outstanding tool for military applications involving intrusion detection, perimeter monitoring, and information gathering and elegant logistics provision in an unidentified deployed part. Various added applications: location detection, sensor-based individual health monitor with sensor networks and movement detection [6].

Energy productivity is required for this sensor network's efficiency because sensor nodes batteries recharging or substituting is impossible. A huge number of studies have been conducted in order to suggest energy efficient routing algorithms for WSNs [2], [3]. The main problem of energy in take for WSNs is their communications [4].

Clustering is one of the greatest methods [1], [5] for dropping energy consumption. In a clustered Wireless Sensor Network, sensor nodes are gathered into a certain number of clusters, each of which involving of a cluster head (CH) and certain non-cluster head nodes (non-CHs). CH gathers information from all the cluster nodes and then forwards to other CHs or base station (BS), whereas non-CHs nodes are accountable for sensing atmosphere and transferring information to the corresponding CH [7].

The researches have been showed for reaching high energy effectiveness in clustered algorithm WSNs [8], [9], [10], [11]. Current methods can be mainly divided into two types: centralized clustering methods [12], [13], [14], [15], [16] and distributed clustering methods [17], [18], [19], [20]. Centralized cluttering methods characteristically demand knowledge of the location of each sensor nodes or the location circulation of all the sensor nodes such that decisions can be made to reach a definite kind of universal optimization. Distributed clustering methods, on the additional hand, make all decisions based on local information, typically with restricted information exchanges between neighbourhood sensor nodes. The distributed clustering ways help achieve enhanced scalability of networks, while the central clustering methods are valuable where location of all sensor nodes or location distribution of all the sensor nodes is known to a central controller. Centralized clustering methods also aid as a noble reference for sensor network pre-plan and a supportive benchmark for calculating the performance of circulated clustering methods or methods based on inexact global information.

WSN nodes are liable to physical attacks, therefore several security advanced methods should also be incorporated in cluster based routing rules for the both necessities to go hand in hand. The key requirements of security comprises verification, secrecy, integrity, resilience against node capture, resistance against node duplication, etc. and that for energy effectiveness includes network connectivity, extreme supported network size, least memory storage, small computational and communication overhead. A clustered design establishes the sensing component nodes into clusters. A dedicated node called as cluster head manages each cluster. The nodes in the cluster communicate straight to its cluster head and then to the base station. The sensed data grouped by all the members in each cluster is bounded by the cluster head and then the collected message will be sent to the base station. The benefits of WSN clustering contain more scalability, combination of data, less load, collision avoidance, less energy consumption, etc.

Effective Distance Cluster Head (EDCH) is a fresh energy efficient clustering algorithm offered newly for wireless sensor networks to prolong network lifespan by uniformly distributing the CHs. In this paper, an mathematical model for expecting the energy consumption of EDCH is proposed. The model details the affecting aspects and analyses the energy consumptions below numerous functioning conditions. The accurateness of the proposed model is calculated using simulation.

II. RELATED WORK

Heinzelman et al. [2], [21] proposed a Low Energy Adaptive Clustering Hierarchy (LEACH). In LEACH CH (cluster Head) nodes are chosen arbitrarily. This is the main aim of LEACH. Selection of CHs arbitrarily, so high energy is disintegrated in the communication to the BS (Base station). There are two phases in LEACH first phase is Set-up phase and second phase is Steady state phase. In set-up phase, all nodes choose to become CH or not for that round. The choice of CHs is decided by percentage of CH (Cluster Heads) in the network and how much the node becomes a CH. A node becomes CH (Cluster Head) if the values of those nodes are lesser than the threshold.

In the past few years, a number of clustering algorithms for WSNs have been introduced such as Low Energy Adaptive Clustering Hierarchy (LEACH) [2], Hybrid Energy-Efficient Distributed (HEED) [22], and EDCH. LEACH is a popular clustering algorithm for WSNs. Popularity of LEACH is not only because of its easiness, but also for the idea of rotating CHs to efficiently balance energy consumption among nodes [2].

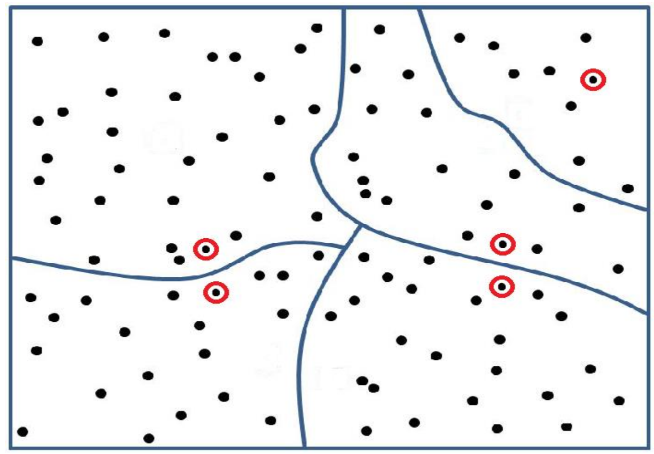
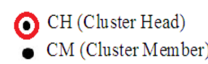


Figure 1: LEACH algorithm, (Cluster Heads and Cluster Members)



Younis et al. [22] introduced a Hybrid Energy-Efficient Distributed clustering (HEED). HEED is a multi-hop clustering algorithm. HEED is an energy-efficient clustering routing with explicit concern of energy. HEED does not choose CH arbitrarily. HEED is different from LEACH. The way of cluster formation is attained on the mixture of two factors. First factor is communication cost of intra-cluster and the second factor is residual energy. In HEED, Cluster Head have higher average residual energy than the MNs.

HEED [22] is a distributed clustering algorithm for WSNs which takes into account a combination of sensors residual energy and communication cost during CH selection. In HEED, the transmission power of every node is set to a constant value and each sensor considers other nodes as its neighbouring nodes if they are within its transmission range. Furthermore, two neighbouring sensors, which are within the transmission range of each other, are not elected as CH concurrently, trying to consistently dispense the CHs across the network.

EDCH likewise, similar to HEED, avails the benefit of consistent distribution of CHs in order to attain optimized, or close to, network energy consumption. However, it has few key advantages over HEED. Initially, the set-up phase overhead of EDCH is much lesser than HEED because HEED executes a procedure to find the nearest sensors. Similarly, in this phase, each sensor in HEED executes a complex iteration including some message passing to choose its CH. Secondly, by the end of each iteration in HEED, a node elects itself as a CH if no other CH notice has been received. Therefore, in many rounds, the number of formed clusters is much more than that of EDCH algorithm where all sensors receive CH notice if there exists at least one CH in the network. Finally, EDCH and LEACH are the two scalable algorithms with both processing time and message exchange complexity of O(1) and O(N). While, HEED has O(N) complexity for both processing time and message exchange complexity [23], [24].

In order to design an energy efficient algorithm for wireless sensor networks, it is important to make a trade-off between different parameters involved in a specific application to certify that the optimal configuration has been applied to maximize the lifetime of network. Specifically, it is quite difficult to balance the energy costs of individual nodes in order to attain the best overall network energy cost. Simulation study of the results of different parameters on the performance of a network under various network conditions is critical because of the time consuming feature of these kinds of tools. Mathematical modeling, in contrast, is advantageous as it offers a cost-effective tool to estimate the network energy consumption accurately within an acceptable amount of time. Thus, in addition to the research on introducing efficient algorithms for wireless sensor networks, a number of studies have also been led to develop an mathematical models [25],[26], [2], [27].

Heinzelman et al. [17] introduced the first mathematical model for LEACH algorithm. In this study, it manifests that the energy consumption in a network is proportional to the square of transmission distance in clusters. This can be attained for each sensor using the following expression:

$$E[d_{toCH}^2] = \rho \int_{\theta=0}^{2\pi} \int_{r=0}^{\frac{N}{\sqrt{\pi q}}} r^3 \, dr d\theta = \frac{N^2}{2q\pi} \quad (1)$$

Where:

$E[d_{toCH}^2]$ is predicted square distance of sensors from their CH,

$\rho = \frac{q}{N^2}$ and is also called sensors density,

q is the number of clusters,

N is one side of network area.

Nevertheless, some non-realistic assumptions have been made when developing the model; the area of all clusters are disc-shaped with radius r, all clusters are assumed to be equally formed, and also the area of the network is covered by these k non-overlapping clusters.

In [28], Bandyopadhyay and Coyle had introduced a mathematical model for hierarchical clustering algorithms for wireless sensor networks. They presumed that the sensors are very simple and all sensors transmit at a static power level. Their model mathematically recommends the number of CHs at each level of clustering. They led a set of experiments to show the optimal number of CHs in different levels of hierarchy in condensed networks, with up to 25,000 nodes. However, their proposed model is not general enough due to a number of impractical assumptions on the fixed power level imparting capability of nodes

III. THE EDCH CLUSTERING ALGORITHM

The appropriate position of CHs is important in energy efficiency of clustering algorithms. This has been ignored in the LEACH algorithm and as a result there might be several CHs which are positioned too close or too far from each other. In either case, some unwanted energy might have occurred for data transmitting from sensors to the base station.

To overcome this, the EDCH algorithm attempts to equivalently distribute CHs through the network as greatly as possible. To ensure that, a parameter d is defined as the closeness dependent on the region size and also network density. If two CHs are set up too close to one another in a particular round, closer than d, one of them must stand as the CH. Thus once the first CH is selected after regular LEACH procedure, the subsequent potential CH checks its distance from the first CH before publicizing itself to other sensors as a CH. If the distance is less than d, it withdraws its call to be a new CH in the present round and remains a CH candidate for the expectations rounds.

Further development in EDCH is also gained by considering the prime number of CHs through the network. This is as a result of variety of potential CHs would possibly cancel their call of being a CH because of their close position to different CHs. Thus, the amount of clusters would be less than the optimum number proposed in the LEACH algorithm. This results in the larger cluster size and a lot of energy consumption over the intra-cluster transmission.

This problem is addressed in the EDCH algorithm by growing the threshold T(n) and accordingly increasing the number of prospective CHs in each round. As an outcome, in every round more than p percent of sensors will be chosen as CHs, on average, to become closer to the optimum value, p, after releasing a number of them because of closeness issue. Later setting the fresh threshold, close to p percent of sensors are eventually selected as the CHs in each round which are more equally distributed compared with LEACH. The new threshold, T' (n), in EDCH is defined as follows:

$$T'(n) = T(n) + (1 - T(n)) \times f \quad (2)$$

T(n) is the threshold value of the LEACH algorithm [2] and a, the additional coefficient, is a constant, whose value rests on network configuration and also on the closeness value, d. This value plays a vital role in the EDCH algorithm efficiency.

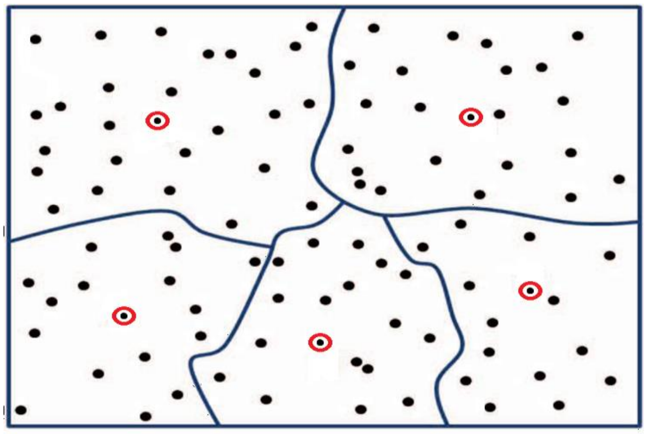


Figure 2: EDCH (Cluster Head and Cluster Member)

CH (Cluster Head)
CM (Cluster Member)

The EDCH algorithm suggestively improves network energy intake and therefore, extends the network lifetime compared with the LEACH algorithm. An instance of the positions of CHs and CMs in EDCH is showed in Fig 2. Comparing this plan with the one showed in Fig 1 discloses more uniformly distribution of CHs in the EDCH algorithm.

IV. EDCH MATHEMATICAL MODELING

In this division, our suggested mathematical model for the energy consumption in the EDCH clustering algorithm is presented. Using the model, a complete understanding of the aspects affecting the performance of a network emerges. Since a clustering methodology is employed in the EDCH algorithm, the entire network energy consumption can be derived after the energy consumed by one cluster is calculated.

Let us assume that M sensor nodes are randomly circulated in a N x N region and the number of clusters, on average, is q through the lifetime of the network. As an outcome, there are $\frac{M}{q}$ sensors, on The energy required for a CM to guide its data to a CH can be calculated with the following expression [2]:

$$E_{CM} = lE_{ele} + l\,\epsilon_{amp}\, d^2_{toCH} \qquad (3)$$

Average, per cluster with ($\frac{M}{q}$) -1 sensors as CMs and moreover one node as the CH

Also, for all sensor nodes in a cluster or group, this energy can be calculated as follows:

$$E_{Cltr} = lE_{ele}(q-1) + l\epsilon_{amp} E\left[\sum_{nds \epsilon Cltr} d^2_{toCH}\right] \qquad (4)$$

Where:
l is the length of messages,
E_{ele} is the transmit electronics,
ϵ_{amp} is transmit amplifier,

d_{toCH} is the distance between a CM (Cluster Member) and its CH (Cluster Head), and $E[\sum d^2_{toCH}]$ is the expected summation for square distance of CMs (Cluster Members) from their CH (Cluster Head).

Except for $E[\sum d^2_{toCH}]$, all other parameters in (4) are known with constant values. Therefore, by calculating $E[\sum d^2_{toCH}]$ we are able to calculate all the energy utilization in the network.

$E[\sum d^2_{toCH}]$ can be calculated using the following expression for LEACH [29]:

$$E\left[\sum_{nds \epsilon Cltr(j)} d^2_{toCH}\right] = 2\pi\lambda_{CM} \times \int_0^{\infty} r^3 \, . \, P\{(r,i) \in cltr(i)\} dr \qquad (5)$$

In (5) and (6), λ_{CM} and λ_{CM} represent density of the CHs and CMs in the network and are given by $\frac{q}{N^2}$ and $\frac{M-q}{N^2}$ respectively. $P\{(r,i) \in cltr(i)\}$ is the probability of a sensor node to become member of cluster i. The distance between the node and the head of cluster i is also represented by r. According to [30], $P\{(r,i) \in cltr(i)\}$ can be derived from the palm distribution as follows:

$$P(r,i) \in cltr(i)\} = exp\{-\lambda_{CM}\pi r^2\} \qquad (6)$$

In EDCH, the space between any two CHs is not less than d. Each cluster region is divided into two different parts, which are treated distinctly in our model. The first half is that the circular space with the radius of d/2 from the CH (Cluster Head). Every sensor in this area firmly belong to that cluster. The second space covers those sensors whose distance from this CH (Cluster Head) is more than d/2. For the first part, (5) with the probability $P\{(r,i) \in cltr(i)\} = 1$ can be used. Thus, the expected summation for square distance of CMs (Cluster Members), located in the first part of the cluster area, from their CH can be obtained using the following expression:

$$E\left[\sum_{nds \epsilon Cltr(i)} d^2_{toCH}\right] = 2\pi\lambda_{CM}\int_0^{d/2} r^3\, dr \qquad (7)$$

On the other hand, all sensors whose distance from other CHs is less than d/2 are secure members of other CHs (Cluster Head) and are not members of the current CH (Cluster Head). Thus, $P\{(r,i) \in cltr(i)\} = 0$ for those nodes. Accordingly, the value of (5) for those nodes is 0. To calculate the second part of the cluster area, we must subtract the cluster areas whose nodes' distance from a CH is less than d/2.

Here calculated the second part of each cluster area by this eqn.

$$E\left[\sum_{nde\epsilon Cltr(i)} d_{toCH}^2\right] = 2\pi\lambda_{CM}\int_{R_1}^{\infty} r^3.P\{(r,i)\ \epsilon\ cltr(i)\}dr \qquad (8)$$

In the above expression, R1 can be calculated as follows

$$\pi R_1^2 = q\pi(\tfrac{d}{2})^2 \Rightarrow R_1 = (\tfrac{d}{2})\sqrt{q} \qquad (9)$$

Using equation (7) and equation (8), the first and second parts of each cluster area can be merged. Thus, the expected summation of square of each CM (Cluster Member) from its CH (Cluster Head) can be obtained from following expression:

$$E\left[\sum_{nde\epsilon Cltr(j)} d_{toCH}^2\right] = 2\pi\lambda_{CM}\left[\int_0^{d/2} r^3\,dr + \int_{\frac{d}{2}*\sqrt{q}}^{\infty} r^3.\exp\{-\lambda_{CM}\pi r^2\}\,dr\right] \qquad (10)$$

In Fig 3, the inner circle shows the first part of each Cluster in which $P\{(r,i)\ \epsilon\ cltr(i)\} = 1$. The region between inner and outer circles, demonstrates the primary part of other clusters in which $P\{(r,i)\ \epsilon\ cltr(i)\} = 0$. The region beyond the outer circle, shows the secondary part of present cluster in which $P\{(r,i)\ \epsilon\ cltr(i)\} = exp\{-\lambda_{CM}\pi r^2\}$.

The accuracy of the proposed mathematical model for EDCH is evaluated in the next section.

V. MODEL VALIDATION

The precision of the defined mathematical model has been verified by comparing it with simulation effects. Extensive validating experiments have been performed for numerous combinations of cluster size, network dimension, different values of nearness, density of sensors in the network, and the number of messages which are sent from CMs to their CHs during the steady phase, called MN. In order to choose the parameter, different values including f = 0.02, 0.05, 0.15, 0.25, …, 0.75 have been considered and the most effective value is chosen. Each duplication scenario is run for 100 different arbitrarily generated topologies and the average results are presented. In our experiments, the sensors' inner computational events do not consume energy: all of their energy used for message passing only. The energy model in all of our experiments is quite same as the one employed in [2].

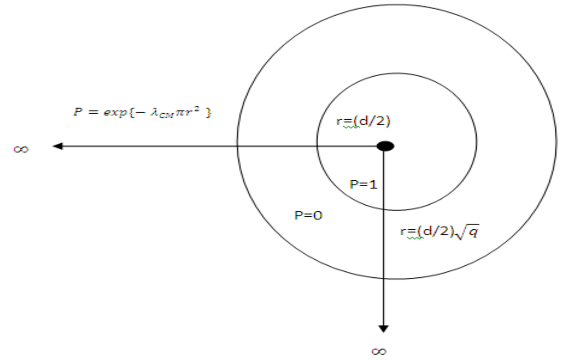


Figure 3: An example of the first and second parts of cluster regions defined in the mathematical model for EDCH.

As the first experiment, the results of changing the number of clusters on the precision of our proposed model is compared against the results obtained from simulation. The network area is considered to be 50 x 50 square meters when base station is 100 meters away from the network's edge. Furthermore, d = 15 meters and the preliminary energy of each node is 10 J. Finally, in this experiment the number of clusters varies from 4 to 15. The result is presented in Fig 4. In this figure, the horizontal axis manifests the number of clusters where the vertical axis represents the total consumed energy. Figure 4 shows the precision of our model for three different networks with different number of nodes, N = 50, 100, and 200, when MN is considered to be 25. 96.3% precision in Fig 4 represents that the simulation results closely match those predicted by the mathematical model.

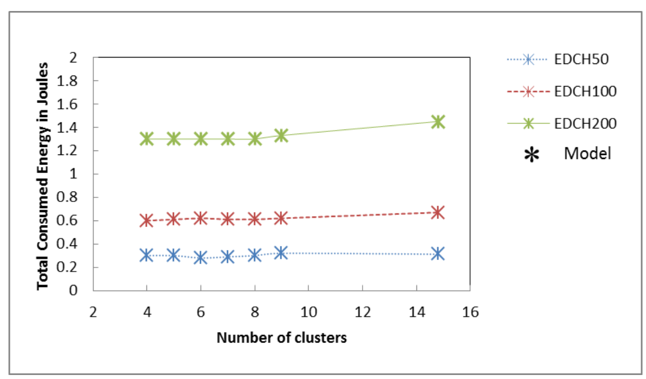


Figure 4: Accuracy of the model evaluating against simulation outcome varying number of clusters for three networks with dissimilar number of nodes, N=50; 100; and 200.

In the second experiment, we aim at perceiving the effect of network size on our mathematical model. various network extents from 10 to 100 meters are examined while the value of d is 30% of one extent. Moreover, the preliminary energy of each node is 10 J and the number of clusters, q, is 5. These are depicted in Fig 5, emphasizing that the proposed model on average presents an accuracy of 95.4%. Fig 5 shows the correctness of our model for three different networks with different number of nodes, M = 50, 100, and 200, when MN is considered to be 25.

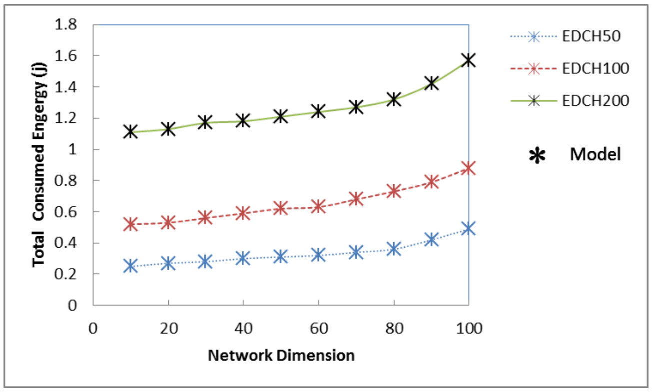


Figure5: Accuracy of the mathematical model comparing against simulation outcome varying network dimension for three networks with dissimilar number of nodes, N=50: 100: and 200.

In the third experiment, we target at observing the effect of intimacy parameter, d, on our mathematical model. Different intimacy values from 5 to 25 meters are observed where the network region is considered to be 50 X 50 square meters and BS (Base Station) is 100 meters away from the network's edge. Moreover, the preliminary energy of every sensor node is 10 J and the number of clusters is 5. This is depicted in Fig 6, emphasizing very close agreement between the model and replication in this figure, 95.8 resemblances on average. Figure 6 proves the accurateness of the proposed model for three different networks with different number of nodes, M = 50, 100, and 200, when MN is measured to be 25.

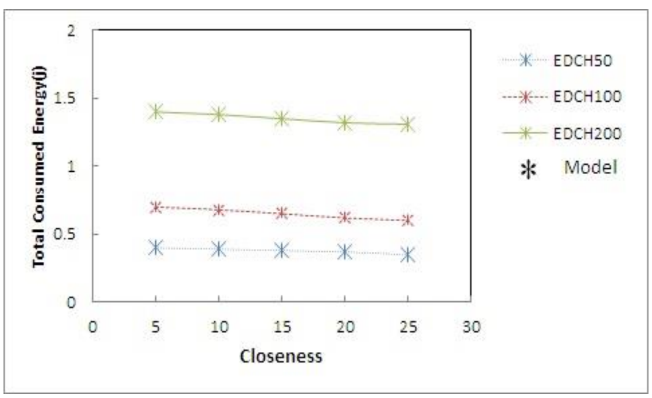


Figure 6: Accuracy of the mathematical model comparing against simulation outcomes varying parameter d for three networks with dissimilar number of nodes, N=50, 100, and 200.

In the fourth experiment, we target at observing the effect of network density on our mathematical model. In this experiment, different number of sensors, from 40 to 500, is inspected. Moreover, the network area is 50 X 50 square meters when BS (Base Station) is 100 meters away from the network's edge, d=15 meters, the preliminary energy of each node is 10 J, and the number of clusters is 5. The outcomes are presented in Fig 7 for three different arrangements, MN, M = 25, 50, and 100.

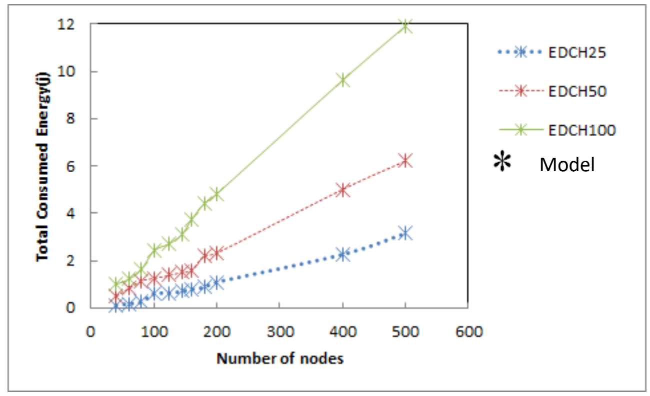


Figure 7. Accuracy of the mathematical model comparing against simulation outcomes for three values of MN, MN = 25: 50: and 100 messages per round.

These outcomes show a close agreement, an correctness of 95.4% on average, between the proposed model and replication results. Finally, in the last experiment, we target at observing the effect of steady phase duration on our mathematical model by changing the number of MN from 5 to 1000 messages per round. The network area is 50 X 50 square meters when base station is 100 meters away from the network's edge, d=15 meters, the preliminary energy of every sensor node is 10 J, and the clusters number is 5. In Fig 8, the contrast of the model and replication results for three different networks with M = 50, 100, and 200 nodes are presented, approving 95.6% correctness on average.

Overall, our widespread validation study shows the reliable accuracy of our proposed mathematical model to expect the total energy spent by the EDCH algorithm.

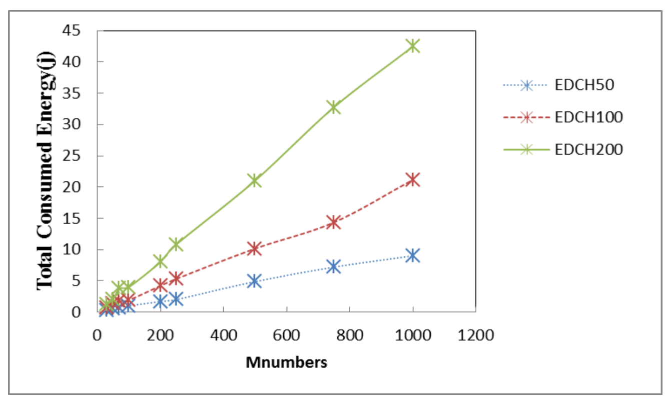


Figure 8: Accuracy of the mathematical model comparing against simulation outcomes for three networks with dissimilar number of nodes, N=50: 100: and 200.

Using the proposed model, a number of consequences have been revealed. First, the energy consumed by the EDCH algorithm is almost unaffected to the optimum number of clusters, k, proposed by the LEACH algorithm. This is due to the vital role of coefficient, f, to balance the energy consumption of each cluster. By increasing the value of k, the optimum value of f is also increased to safeguard the network from forming a large number of clusters with smaller number of nodes in each cluster and hence to avoid progressive energy. Respectively, the optimum value of a is also decreased to block the negative effects of smaller number of clusters.

In the same way, the energy expended by the EDCH Algorithm is almost impervious to closeness parameter. This is again due to the corresponding role of coefficient, f. By increasing the value of intimacy parameter, the optimum value of f is also increased to increase the number of potential CHs (Cluster Heads) to avoid smaller number of clusters. It also avoids forming large number of clusters when the nearness value is decreased.

VI. CONCLUSION AND FUTURE WORK

EDCH (Effective Distance Cluster Head) is a novel distributed energy-efficient clustering algorithm proposed for WSNs (wireless sensor networks). EDCH extends the network lifetime by uniformly distributing of CHs (Cluster Heads) across the network. In this paper, we have presented a Mathematical model for EDCH to prove the effects of different parameters and to expect overall energy utilization under various network conditions. Our new extensive validation study has demonstrated a reasonable scale of accuracy achieved by our Mathematical model compared with the results of simulation software. The proposed Mathematical model has also exposed that energy utilization of the EDCH algorithm is almost insensible to the number of clusters and closeness parameter due to the balancing role of coefficient (f) to optimize the total energy utilization of clusters.

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