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An Energy-Aware Clustering Protocol Based Grid for WSN

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***Abstract*—One of the most critical problems in Wireless Sensor Networks (WSNs) is to how to reduce energy consumption and prolong the network lifetime of WSNs. Clustering is of the solutions, which have been used to reduce energy consumption by partition the network into clusters. However; most of the clustering schemes select the cluster head (CH) either randomly or based on centralized manner. Both approaches lead to deficient utilization of WSN resources. Therefore, the purpose of this paper is to illustrate a new multi-hop clustering protocol called EACPG, which aimed to provide energy efficiency and maintain load balancing. In EACPG the network is divvied into multiple numbers of virtual square grids. Also, different parameters are considered for cluster head election based on distributed manner. In addition, a new mechanism for CH rotation is used in order to maintain load balancing between CHs. Finally, Results show that the proposed scheme has better performance in term of energy consumption and the number of alive sensor nodes and throughput.**

***Keywords*— WSN, Clustering, Load balancing, Multi-hop Communication.**

I. INTRODUCTION

A The design and advance in sensor technology such as low power CMOS technology, microprocessors and low power radio frequency (RF) have made it feasible to develop cheap tiny sensors with a wireless network. These Sensors will be utilized for monitoring different environments, for example, battlefields, tracking objects and construction distortion detection [1]. One of the most critical issues in WSN is power source as powered by limited small batteries that can't be replaced or recharged. Therefore it is very important for having a power efficient plan for delivering packets to the base station [2].

Different clustering schemes have been proposed to provide energy efficient in WSN. Generally, in clustering schemes, there are mainly two major phases. In the first phase, some nodes are appointed as CHs and formulate different cluster while the second phase is usually related to data collection and forwarding. Within each cluster, all member nodes transfer their sensory information towards their respective CH, which perform further processing (i.e. aggregation, compression, and scheduling and resource allocation) and forward their data towards base station or so-called sink node. An example of a cluster based WSNs is shown in Figure 1.

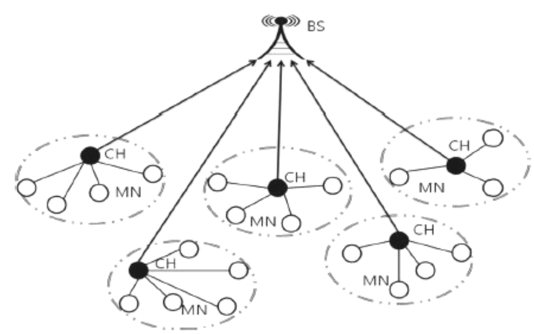

Fig. 1 Clustering architecture

As CHs is responsible for several functions such as data collection and forwarding, hence consume more energy compared to member nodes [3]. Therefore, CH selection plays a vital role and has a great impact on network lifetime [4]. However, Most of the clustering schemes select the CH randomly without considered important parameters, where this can lead to select the deficient node as CH. Subsequently, others clustering schemes are based on centralized manner whereas the CHs selection is done by the base station, which can affect the network scalability as nodes require sending their parameters such as energy and distance from other nodes to the BS frequently, which in turn leads to increases network overhead.

However, Many proposed clustering schemes employed, single-hop communication between cluster head and BS where this results in deplete the energy of far away CHs in the large-scale network more rapidly as energy consumption has a linear relation with distance.

Despite many clustering schemes proposed a multi-hop communication between CHs, but, an increase in the distance between CHs, required higher energy consumption for data forwarding to the next CHs, which can result in reducing network throughput and disturb the connectivity. In addition, deficient selection of next relay node for data forwarding can also raise the energy consumption and imbalanced load distribution between CHs.

Therefore, this paper presents an energy efficient and load balancing clustering scheme based on distributed manner for CH election. In order to optimize the cluster heads selection process, two parameters are considered in this work. Furthermore, multi-hop communication between CHs is employed with maintaining minimum energy consumption

The remainder of this paper is arranged as follows. The related work is described in Section 2. Section 3 presents the proposed scheme. Performance evaluation via simulation is illustrated in Section 4. Concluding remarks of the paper are made in Section 5.

II. Related Works

Low energy adaptive clustering hierarchy (LEACH), and it is well-known as LEACH protocol [5]. LEACH was aimed to provide a solution to resolve the energy consumption in WSN and prolong the network lifetime. LEACH is a probabilistic clustering protocol and it is based on single-hop communication. It structures the network into clusters based on the strength of receiving signals. In LEACH, nodes are either ordinary SNs or CHs. Every SN sends their sensing data to its CH. In addition, CHs node work as gateways to the BS, Initially a node in LEACH protocol, generates a random number between 0-1 to decide which node to be a CH and this is done by computing a threshold value T (n). Generally, LEACH provides a good model for energy consumption. Despite of LEACH has the ability to reduce the energy consumption of WSN. However, the random selection of CHs can produce a deficient selection of CHs. Also, communication between CHs and BS are based on single-hop that leads to increasing the energy consumption of those CHs located in far from BS. In addition, periodic rotation of CHs in LEACH raises the network overheads.

In order to reduce energy consumption in [6], researchers present power efficient gathering in sensor information systems (PEGASIS). In PEGASIS sensor nodes are arranged to form a chain topology. The chain is established from the farthest node to closest node to the sink or base station. In order to form a chain, each node sends its sensed data to its closest neighbor. Finally, the closest node to the base station takes the responsibility for transmitting the collected data, towards the base station. However, such an algorithm can produce high transmission delay with an increase in the chain size or network size. Moreover, failure of an intermediate node can cut off the link between other nodes.

In [7] proposed LEACH-C each node sends its residual energy level and location information to the sink node at the beginning of each cluster formation, In turns sink node elects CHs and builds clusters based on simulated annealing algorithm. Once the CHs and associated nodes are determined, the sink broadcasts CH IDs and Time Division Multiple Access (TDMA) schedules for each node. All nodes look for their IDs to be matched as the CH ID, if not matched then the nodes follow the Time Division Multiple Access (TDMA) schedule to broadcast their data. The data transmission phase of LEACH-C is identical to that of LEACH. Using this scheme in clustering the network can form more uniform sized clusters, but it can suffer from scalability problem and high overheads.

To improve LEACH protocol [8] proposed DBCH scheme where the distance from the base station and the energy of the node is considered while selecting the CHs. Based on the specified parameters for selecting CHs, the node which is nearer to the base station and has more residual energy will be elected as the cluster head. The proposed work shows better performance than LEACH in term of energy consumption. However, single hop communication is used by CHs to forward their data to the BS which results in increased energy consumption of CHs in a large-scale network. In addition, periodic rotation of CHs in LEACH raises the network overheads In [9] researchers proposed WECRR which aims to reduce energy consumption and provide load balancing between sensor nodes WECRR optimizes the CH election whereas CH head election is done in distributed manner and different parameters are incorporated in the CHs selection process, However, election mechanism produces a lot of network overheads as nodes require exchanging its parameters such as energy and location over the whole network which results in additional network overheads.

In [10] [11] present unequal clustering schemes which are proposed to solve the problem of unbalanced energy consumption between sensor nodes specifically those clusters located near the base station as they suffer from heavy traffic load coming from faraway clusters. Unequal clusters are formed with a different size based on the distance from the BS. However, these schemes are based on centralized manner where all the operations are done by utilizing the BS, therefore, they suffer from scalability problem and significant network overheads.

In [12] proposed LEACH- DT which aimed to improve the well known LEACH by incorporating the distance parameter in the election of CH. Also, LEACH-DT reduces the energy consumption of CHs by employing multi-hop data routing towards the BS. In the Multi-hop data routing, the distance between the CHs is incorporated in the selection of next relay CH which in turn guarantee shortest multi-hop route and minimum energy consumption. However, such algorithm suffers from high overheads and also uncontrolled cluster size which results in imbalanced the energy consumption.

III. Design EACPG

This section presents the proposed Clustering scheme whereas the configuration of the scheme discussed in details in the subsection. The configuration of the scheme constitutes of cluster formation, cluster head election phase, and data transmission phases. In clusters formation, network filed is divided into multiple square grids based on the threshold d0 mentioned in the equation, in order to maintain minimum energy consumption for inter-cluster communication between CHs. The second phase is cluster head selection phase whereas the process of CHs head election is carried in this phase. To optimize the CHs selection two parameters are considered for CH election named residual energy and distance between the nodes since the node with maximum residual energy is preferred to be CHs in order to save those sensor nodes with minimum residual energy from being died as CHs consume more energy compared to other sensor nodes. Moreover, the with high residual energy can minimize the number of CHs rotation which in turn leads to reduce the network overheads.

In the end, Multi-hop between CHs is utilized in data transmission phase where multiple parameters are incorporated to assist in routing decision for example; selecting the route with minimum energy May results in low network throughput.

Moreover, EACPG employs a new mechanism for CH rotation based on demand rather than a periodic interval, which is aimed to reduce network overheads and provide load balancing between CHs. The figure below illustrates the operation of the proposed scheme

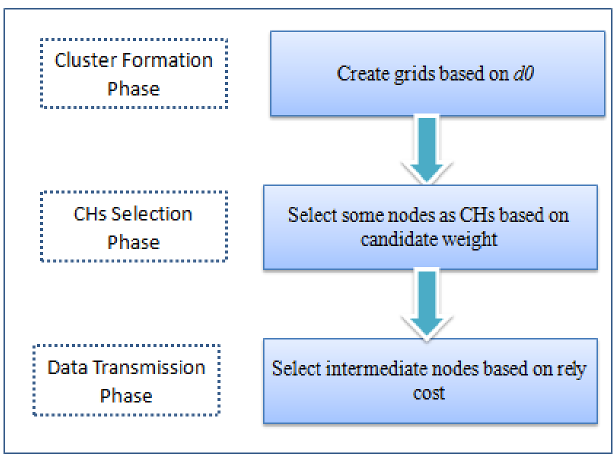

Fig. 2 Operation flow of EACPG

A. NETWORK MODEL

The network model used in this scheme is based on some assumptions which are listed below.

- N of nodes are distributed randomly in a square area of M x M.
- The base station or sink is located at one certain location out of the network filed.
- The base station and all the nodes are stationary.
- Same initial energy is equipped to all the sensor nodes.
- A unique ID is assigned for each node.
- The sensor node is location-aware either by GPS or position algorithm.
- The same energy model as given in [4] is used The schematic of the model is presented in Figure 3, where the energy required for transmitting and receiving 'l' bits over a distance is calculated using the subsequent equations.

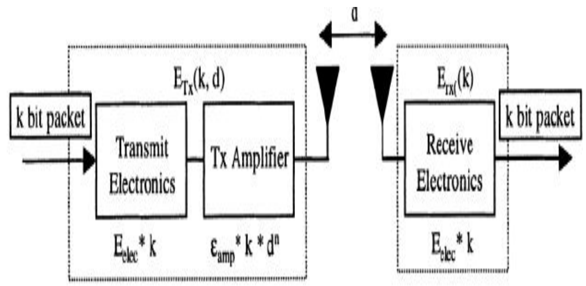

Fig. 3: Radio energy dissipation model

$$E_{TX}(k,d) = \begin{cases} k * E_{elec} + k * E_{fs} * d^2, & d < d0 \\ k * E_{elec} + k * E_{mp} * d^4, & d \geq d0 \end{cases} \quad (1)$$

Where E_{elec} is energy consumed to transmit or receive a bit, E_{fs} is transmitter amplifier energy for free-space, E_{mp} is transmitter amplifier energy for multi-path. Respectively, d0 is the threshold distance that is computed with the following equation

$$d0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \quad (2)$$

While receiving 'I' bits, radio consumes energy is calculated as follow

$$E_{rx}(K) = k * E_{elec} \quad (3)$$

B. CLUSTER FORMATION

In order to reduce energy consumption and prolong the network lifetime of WSNs, as most of the existing schemes show EACPG divides network filed into multiple virtual square grids and each square grid in the network represents a cluster. The square grids are constructed based on do which shown in Equ (3) to guarantee that adjacent CHs can communicate with each other based on free space model which means that CHs communicate with each other with minimum energy consumption. The second reason behind such division is to initiates the CH election process within the square grid based on composite metrics instead of the whole network.

Moreover, cluster formation occurs only once in whole network lifespan so this can reduce the network overheads, in turn, reduce the energy consumption of WSNs.

At the cluster formation, each node calculates its grid CID, whereas each square grid has its unique grid identification (GID). All sensor nodes located in same grid share the same cluster CID. In addition, the only node shares the same GID can participate the in the CH election process of that square grid. Figure 1 shows an example of virtual square grids.

GID (0,3)	**GID (1,3)**	**GID (2,3)**	**GID (3,3)**
GID (0,2)	**GID (1,2)**	**GID (2,2)**	**GID (3,2)**

GID (0,1)	**GID (1,1)**	**GID (2,1)**	**GID (3,1)**
GID (0,0)	**GID (1,0)**	**GID (2,0)**	**GID (3,0)**

Fig. 4 Grid construction

Additionally, the grid size (GZ), which is determined by the predefined threshold d0, which is further defined as $GZ = d0 /2\ \sqrt{2}$, the calculation of the grid size is illustrated in Figure 5. This will allow the node to communicate directly with its adjacent grid cells with low energy. After deployment, each node calculates the GID of the grid cell to which it belongs with its geographic coordinates (X, Y).

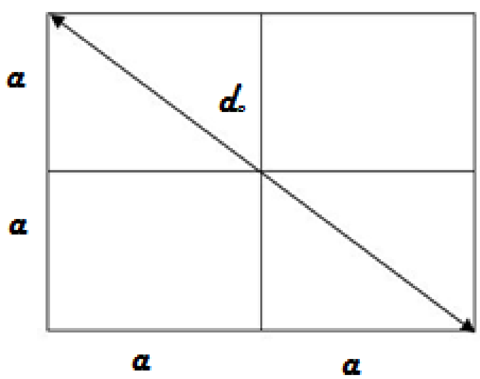

Fig. 5 Calculation of grid size

C. CHs election phase

In this phase, CHs election process will be initiated in each cluster region. The election of CHs is executed in a distributed manner where nodes only require exchanging local messages with those sharing the same GID and located in the same grid which results in low network overheads.

The local messages contain the residual energy and its location in the network which is represented by (X, Y). In this clustering scheme, nodes keep track of their residual energy levels as sensor nodes with high residual energy will be considered for CH election. Secondly, by using Euclidean distance formula, a sensor node can estimate its distance from other sensor nodes, which is shown in the following question

$$dist\ ij = \sqrt{(xi - xj)^2 + (yi - yj)^2} \qquad (4)$$

Therefore, the node with minimum distance from other nodes represents the optimal position inside the cluster as the CH with minimum distance from other nodes will reduce the energy consumption of member nodes during intra cluster communication. Once, the residual energy and location of sensor nodes are determined, These values are summarized in a weighted way to estimate the candidate weight for CH selection. Question 5 shows the node that optimizes the weighted metrics is a suitable candidate to be elected as CH.

$$Candidaite\ weight = \frac{residul\ E.}{dist\ ij} \qquad (5)$$

After the CHs are selected, each CH floods some information in the form of ADV message to its member nodes including CH identity (ID), geographical location and grid ID (GID) in which it belongs. Then member nodes will forward the ADV message with their neighbors located in the same cluster till all the nodes are informed about the selected CH. Other nodes with different GID will ignore the ADV message. Once the CHs are selected, the CHs will allocate a TDMA (Time Division Multiple Access) time slots for the cluster members. After receiving the time slot, each member node sends its sensory data towards its CH.

Algorithm 1 cluster head selection

```
for each node i ∈ Cluster M
do
CW_i = E resd + dist_ij
formulate a list of qualified nodes LQN(n)
end for
for each CH j ∈ Cluster M
do
Flood ADEV msg.
    for each node i ∈ CH j
    do
    Send response
    end for
CH j parts the cluster cycle
end for
```

D. Data transmission phase

In order to reduce energy consumption in a large-scale network, multi-hop data collection is employed between CHs nodes in data transmission phase. As CHs which located far away from BS drain out their energy quickly, therefore, multi-hop is used for between CHs node which can reduce the energy consumption for data transmission. However, in this clustering protocol, CH selects one of the CHs as relay node according to several parameters that should be considered in the selection of next relay node. To optimize data forwarding, each CH sends a route message to its upper CHs. This message contains the residual, energy, number of member nodes of its cluster and its location. By compromising these parameters the relay cost is calculated. The purpose of the relay cost is to reduce energy consumption in data transmission and maintain load balancing between CHs.

In the relay cost, CH si would choose CH sj as a relay node, if its remaining energy is the largest value and have least cluster member nodes and nearest to it. The operations of Multi-hop communication are specified in the following steps.

Step 1: after the CHs aggregate data packet collected from the member nodes, If the BS is at the next-hop of source node which means that the distance between the CH and the base station is less or equal to do then the CH will send data packets directly to the base station.

Step 2: if the CHs at a lower level and the distance between CHs and the base satiation is greater than d0, then CHs are not allowed to forward aggregated data towards base station directly and should use upper-level CHs for data forwarding in order to reduce the energy consumption. Furthermore, In case there are multiple CHs located the upper level; CHs in the lower level will select the next relay CH based on relay cost value. The relay cost (RC) value is calculated as shown in equation (6) below.

$$RC = \frac{dist\ CH^{ij} + No.of\ member\ \ nodes}{E\ resd.} \tag{6}$$

Algorithm 2 multi-hop forwarding

1. *for each CH i* $\in$ *Cluster M*
2. ***If*** *next hop=base station*
3. *CH i Send directly*
4. ***Else*** *if Next hop* $\neq$ *Bs.*
5. *Select the next CH i according to relay cost*
6. ***End for***
7. ***End if***

E. CLUSTER HEAD ROTATION MECHANISM

Its well knows that the CH consume more energy compared with ordinary nodes in the network since they perform a different role, thus, its role should be shifted in with other nodes in the same cluster, which is required to perform a re-election of CH. Shifting the role of CHs can impact the lifetime of sensor nodes if it is not well planning, for instance, frequently re-selection of CHs results in additional network overheads. Also, the workload of CHs differs from each other and this can lead to imbalanced the energy consumption of CHs especially those nodes near the base station required to handle heavy traffic coming from faraway CHs, therefore thus, consume more energy.

Another issue can impact the load balancing; it is the number of member nodes within the cluster since the CH with the high number of member nodes consumes more energy in receiving the data packets. Therefore, to maintain load balancing between CHs and reduce the network overheads in the network, a new mechanism is introduced called dynamic rotation for re-selection of CH whereas the rotation of CH is done based on different metrics.

The first one is the distance between the CH and the base station as nodes near the base consume more energy compared to faraway CHs as they need to handle more traffic thus it requires to rotate the role of the CH with other nodes more frequently. The second metric is the number of member nodes within the cluster since the cluster high member nodes, also requires rotating the role of the CH with other nodes more frequently. Thus the dynamic cluster rotation (DCR) is determined using the following equitation

$$DCR = Round\ time * \frac{Dist(i, Bs)}{No.of\ memeber\ nodes} \tag{7}$$

Also, the energy of CHs should be considered in the re-selection process, therefore upon the residual energy of CH reaches a predefined threshold; re-election procedure inside the particular cluster will be initiated. Otherwise, upon reaching the end of the dynamic rotation, the appointed CH sends a false message within the cluster and quit from the data forwarding

Algorithm 3 cluster head rotation mechanism

```
For each CH i
If ( DCR = 1)
call re-election (CHi)
else ( return )
call re-election (CHi)
end if
```

IV. SIMULATION RESULTS AND DISCUSSION

A simulation of the proposed scheme was performed, and three metrics used to evaluate the performance of the proposed work, including the number of alive sensor nodes, energy consumed and network throughput. Whereas the number of the alive senor nodes is measured in seconds and with vs. the number of nodes and it shows the number of alive sensor nodes during the time elapsed.

While energy consumption it shows how energy is being depleted and it is measured in joules. At the end network throughput which is measured in bit/s. Also, the performance of proposed work is compared with LEACH. The parameters used for the simulation are given in Table 1.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Sensor field	100 x100
BS location	(150, 50)
Number of nodes	100
Initial energy of nodes	2 J
E_{elec}	50 nJ/bit
E_{fs}	10 pJ/(bit m2)
E_{amp}	0.0013 pJ/(bit m4)

Fig 1 shows that the proposed scheme outperforms LEACH in term of energy consumption. The reason behind this is better selection and positioning of the cluster heads where the node with highest residual energy and best position inside the cluster is selected as CH while in LEACH the CHs are selected randomly. Proposed work is simple and it considers different parameter for cluster head selection. Also, multi-hop between CHs is employed and the next hop is optimized where different parameters are considered for next relay node selection such as remaining energy and distance between CHs and number of member nodes in the cluster, which in turn reduce the energy consumption.

Figure 2 shows the number of alive sensor nodes and it is observed that EACPG give a better performance in term of number of alive sensor nodes compared to LEACH because of the re-clustering process to rotate the role of CHs among sensor nodes is done based on dynamic cluster rotation which offers more network stability period and increases lifespan of network. While in LEACH the rotation is done more frequently.

In Figure 3 the throughput for both EACPG and LEACH are calculated. Whereas it measures how many aggregated data packets have been transmitted by CHs to the base station. However, It clearly shows that EACPG gives a better performance compared to LEACH since in the Proposed scheme multi-hop communication has employed and the aggregated data is sent to the base station by closest CH. While in LEACH the aggregated data is sent to the base station directly by using single-hop communication which results in deplete the energy of those CHs located far away from the base station, therefore, the data packets are dropped. Also in the proposed scheme, CHs located in the lower level use the most efficient path to based on the relay cost value thus improved the network throughput.

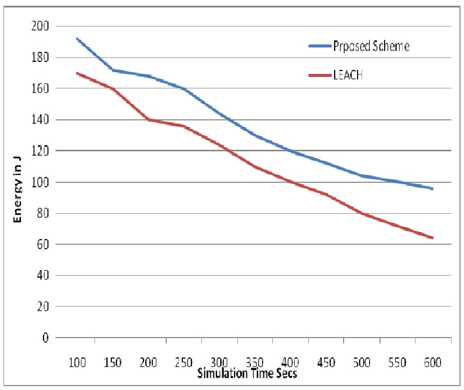

Fig. 6 Number of alive sensor nodes

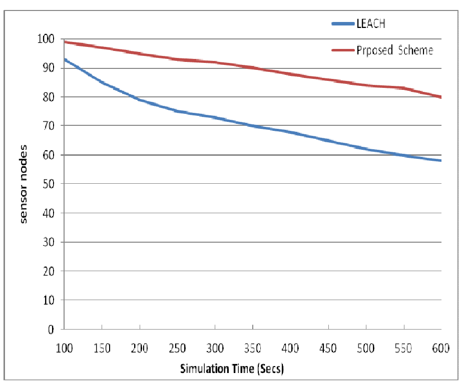

Fig. 7 Energy consumption

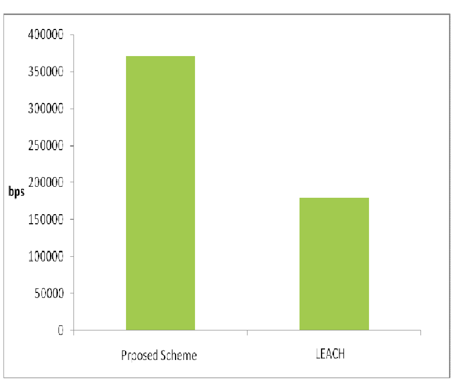

Fig. 8 Network throughputs

V. CONCLUSION

In this paper, an energy-aware clustering protocol based grid for WSN (EACPG) is presented. In EACPG, the residual energy of nodes and location of sensor nodes from other nodes are considered in order to optimize the process of CHs election. This makes the node with more residual energy and has a high degree of neighbor nodes in the network has greater potential to be selected as CHs. In addition, the selection process of CHs is done with minimum network overheads. A new mechanism is also employed for CHs rotation that can provide a load balancing between CHs. .. In the data transmission phase, multi-hop data transmission is used between CHs to avoid the direct communication between CHs and the base station. The results of simulation indicate that the proposed scheme reduces the energy consumption, prolongs the network lifetime, and has a better performance than the original LEACH protocol.

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