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# Energy efficient cluster head scheduling for tiered wireless sensor network

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***Abstract*— Wireless Sensor Network (WSN) has a significant contribution in the field of emerging. Load balancing and optimization of network resources are crucial areas for network longevity. Since clustering is the significant method to enhance system scalability and energy efficiency. In this paper, a multi-tiered clustering (MTC) technique is introduced. In this technique, the network is subdivided into a number of tiers based on the area of the sensing field. The proposed MTC supports for tiered WSN architecture and selects cluster heads and gateway nodes using Received Signal Strength Indication (RSSI) and residual energy level of the sensor nodes for each tier. The experimental results show that the proposed MTC yields better performance than the existing LEACH, LEACH-C, HEED and DCHS Protocols in terms of energy consumption.**

***Index Terms*— Energy efficiency; wireless sensor network; cluster head selection; RSSI**

## I. Introduction

A Wireless sensor network is a complex system consists a number of small wireless sensor nodes and a base station (BS). Sensor node consists of sensor, processor, memory, RF transceiver (radio), peripherals, and power supply unit (battery) [1]. These sensor nodes are spread over an area of interest and connected in an ad-hoc manner for event detection and collect data for various ambient conditions. The WSN has many applications like disaster management such as earthquake monitoring, tsunami warning, pipeline monitoring systems and flood forecasting. The self-organization, rapid deployment and fault tolerance characteristics of wireless sensor networks make them a very promising sensing technique for military applications [2]. Since WSN has limited resources due to the limited size of the node, either changing or recharging batteries are not feasible. The failure of a single node can prostrate the entire system hence system become unreliable. This problem imposes many challenges to the researchers for developing energy-efficient protocols. The routing protocols in sensor networks are classified into three categories: data centric protocols, location based protocols, and hierarchical protocols. This paper considers the hierarchical protocols which deal with organizing network into a set of tiers. In each tier, sensor nodes are categorized as a cluster head (CH), gateway nodes (GN) and cluster nodes (CN). The role of each CH is to gather sensed data from the cluster nodes periodically and aggregates the received data by removing redundancy among correlated data. The cluster head also generates a Time Division Multiple Access (TDMA) schedules for cluster nodes through which sensor nodes transmit sense data in fixed slot. The aggregated data is transmitted by cluster head via gateway nodes. Hence, the lifetime of CH and GN would be a very short span of time if the fixed node performs all the tasks and it becomes essential to rotate the cluster head operation periodically in a well-structured manner. In this paper a new CH and GN selection process is proposed for the multi-tiered WSN architecture based on residual energy and RSSI. The proposed work taken real-time experimental data of RSSI versus estimation of distance among the sensor nodes from [3].

This paper is organized as follows: section II presents the related work. Section III consists the network and radio energy model. Section IV presents the proposed MTC technique in detail. Section V contains simulation setup and results. Section VI concludes with future enhancement of this work.

## II. Related Work

Lot of research have been carried out in the area of energy-efficient clustering technique in sensor networks, which are mainly focused on enhancing the network lifetime.

Low Energy Adaptive Clustering Hierarchy (LEACH) proposed in [4] is the first and most popular hierarchical routing protocols designed to aggregate and disseminate data to the base station for network lifetime enhancement. LEACH obtains energy efficiency by partitioning the nodes into clusters. The LEACH operation time is subdivided into rounds where each round comprised of setup phase and steady state phase. In setup phase sensor nodes selects a random number between 0 and 1. If this selected random number is lower the threshold value $T(i)$, then the corresponding sensor node act as a cluster head during the given period, called round. LEACH distributes the role of cluster head among the member nodes in the cluster based on random number and threshold value which is calculated by the following formula:

$$T(i) = \begin{cases} \frac{p}{1-p\times mod(r,round(\frac{1}{p}))} & if \quad i \in G \\ 0 & otherwise \end{cases} \qquad (1)$$

where $P$ is the desired percentage of cluster heads, $r$ is current round, and $G$ is the set of nodes that have not been CH in the last $1/P$ rounds. During steady state phase, each CH creates a TDMA schedule and assigns a time slot for each member a node for data transmission. After a particular period of time clustering operation return to the setup phase to select new CH. This approach selects the cluster head based on a predetermined probability for cluster heads and does not follow any energy efficient mechanism while choosing $T(n)$.

LEACH-Centralized (LEACH-C) follow centralized mechanism for the selection of CH and the same steady state phase as LEACH [5]. In this base station collects the position and energy level of the sensor nodes and the node having greater energy than the average energy of all sensor nodes selected as CH. Since this approach only considers the energy level of sensor nodes while selecting the CH, there may be a greater probability of elected CH is far away from BS which consumes more energy when the communication between BS and CH.

Younis [6] presents a protocol, HEED (Hybrid Energy-Efficient Distributed clustering), that periodically selects cluster heads according to their residual energy. The authors do not make any assumptions about the presence of infrastructure or about node capabilities, other than the availability of multiple power levels in sensor nodes. However, the proposed algorithms support only for building a two-level hierarchy and lack for multilevel hierarchies.

Yu et al. [7] present a new energy-efficient dynamic clustering technique which deals with each node estimates the number of active nodes in real-time and computes its optimal probability of becoming a cluster head by monitoring the received signal power from its neighboring nodes. The authors also developed energy-efficient and power-aware (EEPA) routing algorithm and lifetime is compared with AODV, MTE, and MRE routing protocols. A cluster-based energy-efficient forwarding scheme is also proposed which ensures that while multiple nodes in a cluster receive a packet, only one node among them is elected to send the acknowledgement back. The binary exponential back-off algorithm was used to select the node.

Akhtar et al. [8] present RSSI based energy aware intra-cluster routing techniques and are not focused on inter-cluster routing. The algorithm has got increased energy efficiency up to 17%.

Xiang et al. proposed an energy-efficient clustering algorithm to maximize the lifetime [9] . The clustering algorithm with optimum parameters was used to reduce the energy conservation among the nodes. An analytical clustering with one hop distance and clustering angle were used. Moreover, the optimal one hop distance and clustering angle were conveyed by reducing the energy consumption between inter and intracluster. For each cluster, the continuous procedure gets repeated until the optimum number of clusters were obtained. It reduces the frequency of updating the cluster head and significantly reduces energy to establish a cluster head.

Karaboga et al. formulated an energy-balanced routing protocol for data gathering. Enhanced mechanisms were used to identify and eliminate the loops [10]. Dervis et al. utilized an artificial bee colony algorithm for energy-efficient clustering. The artificial bee colony algorithm was used to prolong the lifetime of the sensor nodes and the network [11]. Yuea et al. discussed the balanced cluster-based data aggregation algorithm. The sensor network was divided into rectangular grids. For each grid, the cluster head was elected to manage the nodes and balance the load among the sensors [12].

Rout et al. introduced an adaptive data aggregation mechanism based on network coding. Here, the group of nodes acts as network coder nodes and the remaining nodes were used for relaying purpose. The network coder nodes were sometimes used as aggregation points based on the measure of the data correlation [13].

Hui et al. formulated an exact and heuristic algorithm for data gathering. The data-gathering algorithm was based on the cluster-based approach. A mixed-integer linear programming model was used to calculate the BS and CH position and also the data flow in the network area. This method utilizes both the energy and position of the sensor for selecting the CH. Hence, it avoids the highest energy consumption. The benders decomposition was incorporated into the upper bound heuristics algorithm [14].

Mathapati et al. designed an energy efficient reliable data aggregation approach. A clustering approach was used to group the node into clusters. A coordinate node was elected to monitor the cluster nodes. The CH was elected based on the energy level and the distance from the node to the coordinate node. The messages were gathered by CH and forwarded to the BS [15].

G kannan et al. proposed DCHS protocol for two-tier WSN architecture and gives suggestion to select the cluster head nodes and gateway nodes for both primary and secondary tiers [3]. The DCHS mechanism satisfies a distribution of the cluster head among the sensor nodes and avoids frequent selection of cluster head, based on Received Signal Strength Indication (RSSI) and residual energy level of the sensor nodes.

The probabilistic clustering algorithms described above are considering the two important parameters such as distance among the nodes and residual energy of the nodes. They also consider only two-tiered architectures and does not consider gateway node scheduling. In this work a multi-tiered architecture is considered. The real-time experimental data was also taken to estimate the distance between the sensor nodes and incorporated with the simulation parameters to validate the proposed MTC scheme.

## III. Network and Radio Energy Model

In this section assumption about the networks and parameter used in energy consumption model is described.

### A. Network Model

The following assumptions with respect to the MTC are made.

- Sensor nodes and base station are static.
- The base station does not limit by energy.
- Sensor nodes do not aware about their geographic location.
- Sensor nodes know the relative position of the base station in the field.
- The distributions of sensor nodes are random over the sensing field.

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- The Sensor nodes are densely deployed in the sensing field. This dense deployment of sensor network achieving Quality of Service.
- Sensor nodes are heterogeneous in energy level.
- Sensor nodes are able to measure the current energy level.
- The communication among sensor nodes is multihop symmetric communication.

### B. Radio Energy Model

According to the radio energy dissipation model [5] , to attain an acceptable Signal-to-Noise Ratio (SNR) for transmitting an $l$ -bit message over distance $d$, the energy consumption by the radio is given by:

$$E_{TX}(l,d) = \begin{cases} lE_{ele} + l\epsilon_{fs}d^2 & if \quad d \leq d_0 \\ lE_{ele} + l\epsilon_{mp}d^4 & if \quad d > d_0 \end{cases} \tag{2}$$

Where $E_{ele}$ is the energy dissipated per bit to run the transmitter or the receiver circuit. $\epsilon_{fs}$ and $\epsilon_{mp}$ depend on the transmitter amplifier model. $d$ is the distance between the transmitter and the receiver. By equating the two expressions at $d = d_0$, we have $d_0 = \sqrt{\epsilon_{fs}/\epsilon_{mp}}$. To receive an $l$ -bit message the radio expends $E_{RX} = l * E_e le$.

## IV. Proposed method - MTC: Multi Tiered Clustering

An efficient-energy-aware clustering protocol is necessary for sensor network. All the sensor nodes categorized into two categories, normal and heterogeneous. Heterogeneous nodes have more energy than normal sensor nodes. This motivates the need for improving the lifetime of the sensor network. The objective of the proposed MTC methodology is to reduce the energy consumption and increase the network longevity. Here, random distribution model is used for deployment of nodes in the sensing area. The proposed MTC approach subdivides the network into tiers based on network area. The MTC protocol consists four phases: Tier formation, cluster-head and gateway selection, cluster formation Phase, Reelection of cluster-head and gateway nodes.

### A. Tier formation

In this phase base station broadcast an initialization message within sensing field and compute a number of tiers needed in the field using the formula given in eq 3.

$$Tier = \lfloor Area/Cr \rfloor \tag{3}$$

Where $Cr$ is the communication range of the sensor node. On reception this message, each sensor node sends back a control packet to the base station. The BS form tiers and selection cluster head and gateway nodes. The base station also creates the lookup table with node id and its RSSI level for each sensor node. The BS calculates the average RSSI values from the lookup table by summing up the RSSI values of all the nodes and dividing by the total number of nodes, then BS determines a range of RSSI for each tier. Now the BS segregates the network into tiers. The node that has the RSSI value in a specific range are grouped by a set of nodes, denoted by $N_i$.

### B. Cluster head and gateway node selection

The base station selects cluster head nodes which communicate with cluster nodes, gateway nodes which forward the data between tiers and BS. Initially, cluster heads are determined in such a way that the CH should be in a center of the tier. For that, the sensor node which is close to the average RSSI value within the tier can be selected as CHs. The threshold ($T_{CH}$ for initial CHs determination is given in eq 4.

$$T_{CH}(i) = \sum_{j=1}^{|N_i|} RSSI_j/|N_i| \tag{4}$$

where $i$ is the number of tiers. The sensor node having higher RSSI value selected as the gateway nodes for a respected tier. Heterogeneous nodes have higher priority than the normal nodes for gateway selection.

### C. Cluster formation

In this phase base station broadcasts a message within the sensing field to inform about the newly selected cluster head and gateway nodes. The nearby sensor nodes send a Join Request packet to CH. On reception of join packet CH acknowledges the request and forms a cluster. After a constant time, CH creates a TDMA schedule for each node in the cluster for data transmission. During the allocated time slot cluster node sends the sensed data. The cluster head aggregates the received data and sends it to the respected gateway node, then gateway node sends this aggregated data to the base station.

### D. Reelection of cluster-head and gateway nodes

In this phase, cluster head and gateways are reelected when its residual energy reach below predefined energy threshold $(PE_T)$ value. If the residual energy of the current CH reaches below than $PE_T$, then CH broadcasts cluster head scheduling message within the cluster using the multi-casting method. This message represents, the current CH does not have adequate residual energy to act as CH and immediate cluster head shifting is required for increasing the network lifetime. In response to the scheduling message, the cluster nodes send the $T_{new}$ , to the respective CH. Now the cluster head calculates the threshold value $T_{RCH}(i)$ for identifying the next cluster head. The threshold value for new CH selection can be expressed by

$$T_{new} = (RSSI_j \times RE_j)/d_{jtoBS} \tag{5}$$

where $RE_j$ is the residual energy of the $j^{th}$ sensor node and $d_{jtoBS}$ is the distance between node $j$ to base station.

$$T_{RCH}(i) = \sum_{j=1}^{|N_i|} T_{new}(j)/|N_i| \tag{6}$$

Now the current CH compares the $T_{RCH}(i)$ with $T_{new}$ value for each node. The node which has $T_{new}$ value nearer or greater to $T_{RCH}(i)$ will be elected as the CH for next round. The senor node is selected as gateway node which has highest $T_{new}$. The clustering process summarized in algorithm 1.

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**Algorithm 1** MTC algorithm

*Initialization:* BS broadcast a Init packet within sensing field.
Sensor nodes send back control packet to BS.
BS construct lookup table $(LT_{RSSI})$ using RSSI.
Compute $Tier = \lfloor Area/Cr \rfloor$
Compute $Avg = \sum_{k=1}^{n} RSSI_k/n$
**procedure** TIER–FORMATION($LT_{RSSI}$,$Avg$,Tier)
  **if** $|Avg| < Tier$ **then** TIER–FORMATION($LT_{RSSI} > Avg$,$Avg$,Tier)
   TIER–FORMATION($LT_{RSSI} < Avg$,$Avg$,Tier)
  **else** return $Mean(LT_{RSSI})$
  **end if**
  Assign node belong to tier using $Avg$.
**end procedure**
**procedure** CH AND GW–ELECTION
  **for** each node $j \in N_i$ **do**
   Compute $Diff = Avg_i - RSSI_j$
  **end for**
  $CH(i) = Min(Diff)$
  $GW(i) = Max(RSSI_j)|j \in N_i$
**end procedure**
**procedure** CH AND GW–REELECTION
  **for** each $Energy_{CH}(c) < PE_T$ **do**
   Cluster head send scheduling message within cluster
   Each node $j$ in cluster send back $T_{new} = (RSSI_j \times RE_j)/d_{jtoBS}$
   Each CH compute $T_{RCH}(i) = \sum_{j=1}^{|N_i|} T_{new}(j)/|N_i|$
   Compute $DiffR = T_{RCH}(i) - T_{new}(j)$
   $CH(c) = Min(DiffR)$
   $GW(c) = Max(DiffR)$
  **end for**
**end procedure**

TABLE I
SIMULATION PARAMETERS

| Parameters | Values |
|---|---|
| Area | $50 \times 50$ $meter^2$ |
| Base station position | $(25m, 50m)$ |
| Total sensor nodes $(n)$ | 100 |
| Heterogeneous nodes | 10 % |
| Communication range $(\gamma)$ | 15 meters |
| Initial energy | 1.8 J |
| Predefined energy threshold $(PE_T)$ | 0.9 J |
| Transmitter/Receiver electronics $(E_{elec})$ | 50 nj/bit |
| Data aggregation $(E_{DA})$ | 5 nj/bit/report |
| Reference distance $(d_0)$ | 87 meters |
| Transmit amplifier $(\epsilon_{fs})$ | 10 pJ/bit/$m^2$ |
| Transmit amplifier $(\epsilon_{mp})$ | 0.0013 pJ/bit/$m^4$ |
| Message size $(l)$ | 4000 bits |
| Control packet $(C_l)$ | 800 bits |

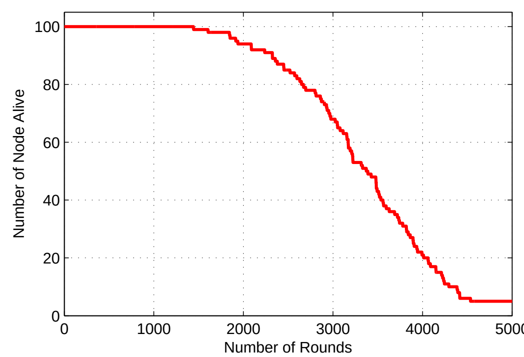


Fig. 1. Number of alive nodes over rounds

## V. RESULTS AND PERFORMANCE ANALYSIS

In this section the performance of the proposed MTC technique is evaluated and compared with the existing distributed cluster head scheduling (DCHS)[3] , HEED [6] and LEACH [4] Protocol. There are 100 sensor nodes deployed in the 50 50 $m^2$ area. The efficiency of the proposed system is evaluated based on the following criteria: the first node dies, half of the node die and remaining residual energy. Table I presents the simulation parameters used in the simulation.

The sensor nodes are randomly distributed having initial node energy 1.8 Joule $(J)$. The total network energy is about 200 $J$. The BS is positioned at the boundary of the sensing field.

Fig. 1 shows that the number of nodes alive over the rounds. It is observed that the MTC approach is able to maintain the load balancing over the period of network operation. The total transmission distance has been reduced in the MTC approach which increases the network lifetime. It is also observed from Fig 1 that the network lifetime of MTC is more than 5000 rounds.

Fig. 2 shows that the total network energy degraded over the number of the round. It is a summation of residual energy of all sensor nodes. It is shown in Fig. 2 that the residual energy of MTC approach is higher than existing techniques LEACH, LEACH-C, HEED, and DCHS. The proposed method MTC ensures that the cluster head is located near to the center of the tier by considering the average of RSSI. The updated threshold for CH rescheduling refines center location of new cluster head which improves network longevity. Heterogeneous nodes are considered for the gateway is also prolong the network lifetime. Further, the gateway nodes are also elected closer to the BS to reduce the load of CH.

Fig. 3 shows the comparative results of MTC and other existing techniques LEACH, LEACH-C, HEED and DCHS for stability period. It is observed that the stability period of MTC is much higher than other existing techniques. The proposed approach is able to sustain higher stability because of better rescheduling of cluster head and gateways. Heterogeneous nodes also help to increase the stability period of the network. Similarly, Fig. 3(b) shows that the MTC approach also performs better for half of sensor nodes die.

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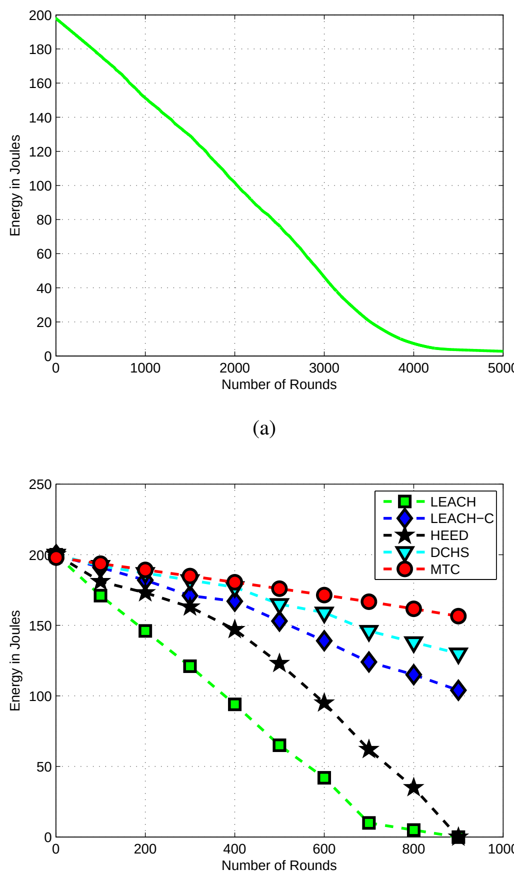


Fig. 2. Total network energy over the rounds

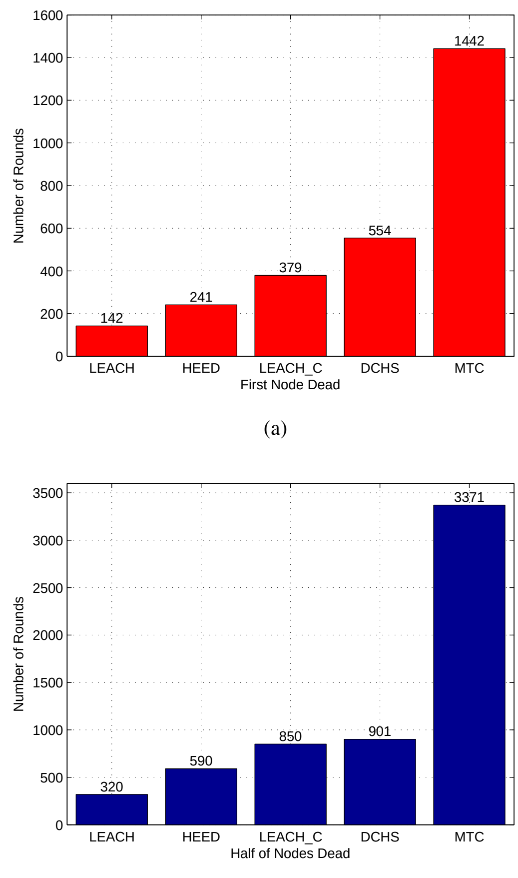


Fig. 3. Stability period of the network

## VI. Conclusion

In this paper a new clustering protocol MTC has been proposed to improve the network lifetime of sensor network. A threshold has been formulated for cluster head selection which is based on the remaining energy of the sensor node and received signal strength indicator. A new method is also proposed for gateway nodes selection. Simulation results show that MTC approach has longer stability period and network lifetime than existing techniques LEACH, LEACH-C, HEED and DCHS.

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