Multi-Event Adaptive Clustering (MEAC) Protocol for Heterogeneous Wireless Sensor Networks

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***Abstract*— Clustering of nodes is one of the most effective approach for conserving energy in wireless sensor networks (WSNs). Cluster formation protocols generally consider the heterogeneity of sensor nodes in terms of energy difference of nodes but ignore the different sensing mechanisms (multiple events detection) of them. Observing different type of phenomenas and reporting them at different rates is an important factor effecting the homogeneity. It is, therefore, imperative to consider the multi-event sources in the design of clustering protocols. In this paper, a multi-event adaptive cluster ($MEAC$) formation protocol is proposed that aims to conserve the energy of sensor nodes in the presence of heterogeneity. It is achieved by considering three design factors; (1) electing an appropriate node to function as cluster-head, (2) limiting the number of clusters in the network and (3) reducing the frequency of clusters reformation. Performance evaluation results show that MEAC improves the stability and energy conservation of the heterogeneous wireless sensor networks.**

***Index Terms*— Clustering, Heterogeneous WSN, Multi-Events Adaptive**

I. Introduction

RECENT advances in the field of wireless sensor networks (WSN) have lead to the revolution of Ambient systems. Ambient systems are networked embedded systems intimately integrated with the everyday environment and are supporting people in their activities. Smart environment is a key example of such a system. Smart environment relies purely on the sensory data observed from the real world. The information needed by such an application is provided by hundreds or thousands of low-power nodes of same or different types which are densely deployed in the environment. These nodes are responsible for sensing as well as relaying the data to a central node called sink. It is, therefore, desirable to make these nodes as energy-efficient as possible to increase the lifetime of the individual sensor nodes as well as the network.

Sensor networks are characterized by a highly dynamic topology, due to a significant level of node failures (e.g. because of energy depletion) or re-energizing caused by deploying new nodes. Therefore, the network must be able to periodically reconfigure itself so that it can continue to function. The implementation of self-configuration then become a requirement in order to guarantee efficient network operation.

The importance of self-configuring clustering protocols for heterogeneous wireless sensor networks has been highlighted in [1]. It emphasizes that any clustering protocol should consider the node energy and traffic rate as key elements. A number of protocols [3], [5], [7], [8], [10], [11], [12], [13] have been proposed for WSN. In most of these studies, sensor nodes are assumed to be homogeneous. However, depending on the application, sensor nodes can have different role or capability making the network heterogeneous. These special sensors can be either deployed independently or the different functionalities can be included in the same sensor nodes. For example, some applications might require a diverse mixture of sensors for monitoring temperature, pressure and humidity of the surrounding environment and capturing the image or video tracking of objects. Even data reading and reporting can be generated from these sensors at different rates and can also follow multiple data reporting models.

In this paper, we present Multi-Event Adaptive Clustering (MEAC) protocol for heterogeneous wireless sensor networks. MEAC constructs clusters to cope with uniform as well as non-uniform deployment of nodes in heterogeneous wireless sensor network. It uses an application-oriented weight-based clustering algorithm to select optimal number of cluster-heads.

Generally, the clustering protocols [5], [7] focus on the currently available energy of the nodes and periodically reorganize clusters to do energy balancing. But this strategy is not practical when the nodes are sending traffic at different rates due to different events characteristics. If all the nodes have the same probability to become cluster heads then the nodes reporting events at higher rate will eventually loose their energy earlier than the others. Therefore, the load on a node, that is, its data rate is used as a key factor for cluster-head selection. Hence, MEAC protocol distributes the energy usage of nodes by adapting to the multiple events in the field, in order to increase the stable period of the network. Simulation results have shown that, MEAC is more energy efficient than existing clustering protocols and is capable of handling the network dynamics.

The remainder of the paper is organized as follows. In Section II, we highlight the basic assumptions and a model of WSN. We derive the parameters for optimal configuration of nodes in Section III. The protocol operations are described in Section IV. Finally, performance evaluation and results obtained by a simulation model are considered in Section V.

II. System Model

This section describes the model of heterogeneous wireless sensor network where the heterogeneity of nodes is considered regarding their different initial energy levels and observation of multiple events. Multiple events can be detected either by a single node or nodes have different sensing mechanisms to detect different events. Multi-events observation generate different reporting rates due to the different characteristics and requirement. Hence, it greatly effects the energy consumption of nodes.

The network is stable as long as all the nodes are alive and they have enough energy to detect and relay packets. This period is known as *stable period* of the network and the throughput is maximum during this time. In heterogeneous wireless sensor networks, sensor nodes may have different energy levels and might report events at different data rate. The nodes having initial energy E_o are termed as energy-constrained (EC) devices and all other nodes having energy higher than E_o i.e. $E_o + \delta$ are energy-rich (ER) devices. The degree of heterogeneity is also affected by multiple data rates in the network. Other factors like computational or memory capabilities also contribute to network's heterogeneity, but they are not considered in this work.

The degree of the heterogeneity (λ) is due to change in energy level and data rate that can be measured as:

$$\lambda = \lambda_{energy} + \lambda_{rate} \tag{1}$$

where λ_{energy} is the contribution of energy to λ and λ_{rate} is contribution in λ due to different data rates.

In next subsections, we show how individually λ_{energy} and λ_{rate} contribute to the overall degree of heterogeneity.

1) Contribution of λ_{energy} to λ: Let us assume that there exist *m* number of ER nodes among total of *n* nodes in the network. Let $\delta_1, \delta_2, ..., \delta_i, \delta_j, ..., \delta_m$, be the extra energies of *m* nodes. When δ is constant for all *m* nodes, then $\delta_i = \delta_j$; where $i \neq j$. In other words, there are only two different kind of nodes having energy levels E_o or $E_o + \delta$. In this case, λ is large when $m \approx \frac{n}{2}$, but λ is small when $m < \frac{n}{2}$ or $m > \frac{n}{2}$ for $m \leq n$. Then the fraction of nodes (m_λ) making the network heterogeneous due to energy is:

$$m_\lambda = 1 - \left|\frac{n - 2m}{n}\right| \tag{2}$$

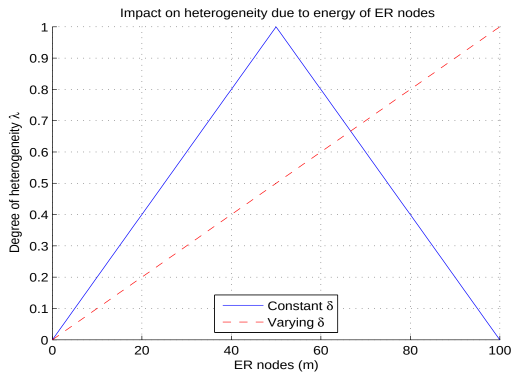


Fig. 1. Heterogeneity due to number of *m* nodes.

On the other hand, when $\delta_i \neq \delta_j$, where $i \neq j$; ER nodes have different energy levels above E_o. Hence, energy levels of ER nodes will be $E_o + \delta_1, E_o + \delta_2, ..., E_o + \delta_i, E_o + \delta_j, ..., E_o + \delta_m$. This behavior of δ is depicted in Fig 1, λ increases continuously by increasing *m*. Therefore, when δ is variable, the fraction m_λ is simply m/n. Let α be the energy factor that ER nodes have higher than EC nodes. We can calculate α as:

$$\alpha = \frac{1}{mE_o} \sum_{i=1}^{m} (E_i - E_o) \tag{3}$$

The above equation can be simplified for constant δ as:

$$\alpha = \frac{m(E_i - E_o)}{mE_o} = \frac{E_i}{E_o} - 1 \tag{4}$$

Therefore, heterogeneity due to energy λ_{energy} or the energy gain in the network due to ER nodes is α times m_λ i.e. $\lambda_{energy} = \alpha \times m_\lambda$

2) Contribution of λ_{rate} to λ: Let ρ_o be the lowest initial data rate of a node(s) in the network and *q* be the number of nodes among the total of *n* nodes which have data rate higher than ρ_o in the network. Similar to Eq. 2 for constant δ, the fraction of nodes (q_λ) making the network heterogeneous due to data rate difference can be calculated as:

$$q_\lambda = 1 - |\frac{n-2q}{n}| \quad (5)$$

Let $\rho_i = \rho_o + \delta$ be the data rate of node i, then the data rate fraction φ that *k* nodes produce more than ρ_o can be defined similar to α as:

$$\varphi = \frac{1}{q\rho_o}\sum_{i=1}^{q}\rho_i - \rho_o \quad (6)$$

The simplified equation of φ for constant δ is:

$$\varphi = \frac{q(\rho_i - \rho_o)}{q\rho_o} = \frac{\rho_i}{\rho_o} - 1 \quad (7)$$

Hence, the fraction of heterogeneity due to different data rates (λ_{rate}) can be given as $q_\lambda \times \varphi$.

For example, assume that the network contains 30% ER nodes having $E_o = 1.5j$ and EC nodes with $E_o = 0.5j$. 10% nodes report readings at 40 packets/sec while the other nodes at 10 packets/sec. We find out the value of λ. We get $\alpha = 0.2$ by using Eq 3 and $m_\lambda = 0.6$ due to constant change δ in all the *m* nodes. Similarly, for $\rho_o = 10$, $q = 10$, the higher data rate factor $\varphi = 3.0$ making $q_\lambda = 0.2$. Hence, λ is 1.8 by using Eq 1.

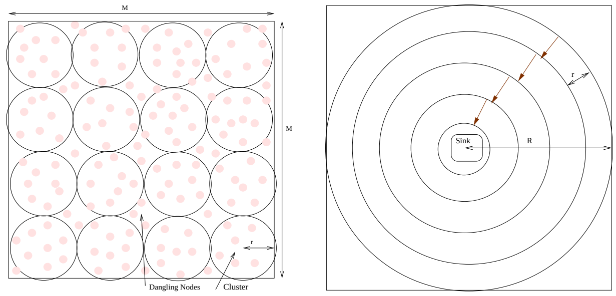
III. Design Parameters of MEAC Protocol

In this section, the design parameters for clustering protocol are derived. We call the node responsible for collecting the data locally as *cluster-head* and the other nodes in a group as *members* of the cluster. Under some circumstances, there may exist some nodes which have not joined any group or cluster are referred as *dangling nodes* (DN). All the member nodes transmit their data packets to their cluster-heads. The basic design of MEAC consists of calculating the optimal number of clusters (k_{opt}) and the optimal members of a cluster (N_{opt}).

A. Optimal Number of Clusters (k_{opt})

MEAC computes optimal number of clusters (k_{opt}) such that it decreases the energy consumption, while providing high degree of connectivity. We devise a formula to find k_{opt} that is directly proportional to total number of nodes and the area of the network, while it is inversely proportional to the transmission range.

Let r be the transmission radius of each node regardless of its functioning. In the clustering process, there is some probability that a number of DN nodes may exist due to the deployment of nodes or coverage of the elected cluster-head. To find out the probability of such nodes, we map the sensor field ($M \times M$) to non-overlapping circles of radius r as shown in Fig 2(a) and assume that the nodes lying outside the boundary of the circle are DN nodes and the others are member nodes. These DN nodes affiliate to cluster-heads through the nodes insides the circle (member nodes) and become the multi-hop members of cluster-heads. The square field M^2 can be packed by $M^2/(2r)^2$ non-overlapping circles of radius r. Thus, the probability p_{DN} of a multi-hop member is



(a) (b)

Fig. 2. Network model to formulate the optimal clusters. Fig 2(a) represents the model to find the probability of DN nodes. Fig 2(b) illustrates the model of routing packets from cluster-heads to the sink node.

$$p_{DN} = \frac{M^2}{(2r)^2} \times \frac{(2r)^2 - \pi r^2}{M^2} \approx 0.214$$

Let E_{elec} be the energy consumed by the electronic circuitry in coding, modulation, filtration and spreading of the signal. Whereas, $\epsilon_{amp} r^2$ is the energy consumed for signal amplification over a short distance r. Thus, the energy consumed by each member node is

$$E_{Member} = l(E_{elec} + \epsilon_{amp} r^2 (1 + p_{DN}))$$

where l is the size of data packet. The above equation can be simplified by taking the area as circle given in Eq. 16 of [6].

$$E_{Member} = l(E_{elec} + \epsilon_{amp}\frac{M^2(1+p_{DN})}{2\pi k})$$

Let us assume that the sensory field is covered by a circle of radius R, where the sink node lies at the center of this circle as shown in Fig 2(b). This assumption is made for sending packets from cluster-heads to the sink. Cluster-heads do not extend their transmission range and, therefore, has the same radius r as member nodes. This adapts the multi-hop model proposed by [4] to route packets from cluster-head to the sink.

In the model, a circle is divided into concentric rings with the distance of r. The energy spent to relay the packet from outside ring towards inside ring is $l(2E_{elec} + \epsilon_{amp} r^2)$. The number of hops H_{CH-S} require to route packet from cluster-head to sink node can be calculated by $\frac{R}{r}(1-p_{hops})$, where p_{hops} is the probability indicating the distance in terms of hops to the sink. This probability can be calculated by using the nodes distribution in the rings given in [4].

$$p_{hops} = \frac{r}{R}\sum_{i=1}^{R/r}\frac{R^2-(ir)^2}{M^2}$$

Packets from cluster-heads that are far from the sink are relayed through intermediate nodes. Therefore, if N_s is the number of neighbors of the source node s then $N_s \times E_{elec}$ is the energy consumed by the electronic circuitry of the neighbors during the transmission of a data packet by s. The number of neighbors N_s of a node can be computed by $n\frac{\pi r^2}{M^2}$. Hence, the energy consumed in forwarding data from cluster-head to sink is measured as:

$$\begin{aligned} E_{CH-S} &= l(N_s E_{elec} + E_{elec} \\ &+ (2E_{elec} + \epsilon_{amp} r^2 + N_s E_{elec}) H_{CH-S}) \end{aligned}$$

The total energy dissipated by the network is

$$\begin{aligned} E_{total} &= l((n + nN_s)E_{elec} \\ &+ k(2E_{elec} + \epsilon_{amp} r^2 + N_s E_{elec}) H_{CH-S} \\ &+ n\epsilon_{amp}\frac{M^2(1+p_{DN})}{2\pi k}) \end{aligned}$$

For $r < R$, the optimal value of k can be found by taking the derivative of above equation with respect to k and equating to zero

$$k_{opt} \approx \sqrt{\frac{n(1+p_{DN})}{(2\pi(1+\frac{2E_{elec}}{\epsilon_{amp}r^2}+\frac{N_sE_{elec}}{\epsilon_{amp}r^2}))H_{CH-S}}} \times \frac{M}{r} \quad (8)$$

The optimal value depends on the transmission range r. For long range transmission, the value of optimal clusters k_{opt} is small. For example, Let $n = 100$, $M = 100$ and the sink is at the center of the field $(x = 50, y = 50)$. Then the value of radius R is obtained by drawing a circle at $x = 50, y = 50$ to cover the field. The estimated value is $R = 60$ and let set the range r of individual nodes to 25. In this scenario, we obtain the value of $k_{opt} \approx 10$. By increasing the range of nodes to 40 meters, we obtain $k_{opt} \approx 7$. Whereas, the value of k_{opt} in SEP [7] is 10 regardless of the transmission coverage of individual nodes.

B. Optimal Cluster Size (N_{opt})

When the deployment is uniform, the optimal value of member nodes N_{opt} can be easily found by n/k_{opt}. However, for non-uniform deployment, the number of member nodes depends on the density in a particular zone of the sensor field. Therefore, we put the maximum and minimum limits N_{Min} and N_{Max} respectively on the size of cluster, such that, we still achieve k_{opt} clusters in non-uniform deployment. Let N_i be the number of neighboring nodes of any ith node. $Max(N_i)$ is the maximum number of neighboring nodes that any of the ith neighbor node have. We measure density of nodes in a particular zone by comparing the neighbor nodes N_i with N_{opt}. It can be concluded that the deployment is:

$$\begin{aligned} N_i/N_{opt} &> 1, \quad dense \\ N_i/N_{opt} &\approx 1, \quad uniform \\ N_i/N_{opt} &< 1, \quad sparse \end{aligned}$$

Therefore, the number of nodes in a cluster can be constrained by setting the lower bound N_{Min} and upper bound N_{Max} according to the deployment as:

$$N_{Max} = Max(N_{opt}, Max(N_i))$$

That is, the maximum of N_{opt} and maximum number of neighbors of any cluster-head at the time of cluster formation.

$$N_{Min} = N_{opt} \times Min(N_{opt}, Max(N_i))/N_{Max}$$

These limits allow the configuration to manage the dense as well as sparse deployment of nodes.

IV. MEAC Operation

When nodes are initially deployed in the field, every node broadcasts hi beacons. A receiving node updates its neighborhood table {*ID, Weight, Energy, Neighbors, Hops, Expiry*}. If a node does not hear any hi beacon from a neighbor during the duration of $Expiry$ value, it is considered unreachable and is deleted. These beacons are exchanged periodically to deal with the network dynamics. After the exchange of hi beacons initially, every node calculates K_{opt} and N_{opt} values. The clustering process starts by electing a cluster-head and then linking the clusters together to form a hierarchical clustered network.

A. Cluster-head Election Procedure

Cluster-heads are elected by effectively combining the required system parameters with certain weighting factors. Every node calculates its weight based on its available power, data rate and the density of nodes. Values of these factors can be chosen according to the application needs. For example, power control is very

Algorithm 1 Elect Cluster-head

Pseudo-code executed by each node N in each round
$W_{max} = 0$
for all neighbor N_i **do**
    if $W_{max} < W_n$ **then**
        $W_{max} = W_n$
    end if
end for
W_i = my-weight()
if $status = NONE$ **then**
    if $W_i > W_{max}$ **then**
        announce-head()
        $W_{th} = W_i \times threshold_{factor}$
    else if $status$ = $HEAD$ **then**
        if $W_i < W_{th}$ **then**
            if $W_i < W_{max}$ **then**
                withdraw-head()
            else
                $W_{th} = W_i \times threshold_{factor}$
            end if
        end if
    end if
end if

important in CDMA-based networks. Thus, weight of the power factor can be made larger. In order to achieve the goal of energy saving, it minimizes the frequency of cluster reformations. It is achieved by encouraging the current cluster-heads to remain cluster-heads as long as possible. On the other hand, the distance weighting factor can be made larger if the density of nodes is high or the deployment is made in hostile environment. This ensures that a node is elected as a cluster-head that can receive the transmission from farther nodes and the number of clusters formed remain close to the optimal value.

Let D_i be the average distance of node i to its neighbors, N_i be the total number of its neighbors, E_i be its available energy and ρ_i be its reporting rate. Node i computes its weight W_i as:

$$W_i = c_1 \frac{\rho_o}{\rho_i} \times \frac{E_i}{E_o} + c_2 \frac{D_i}{r} \times \frac{N_i}{N_{opt}} \qquad (9)$$

where the coefficients c_1, c_2 are the weighting factors for the energy and data rate parameters. Node i announces itself a cluster-head if its weight is high among all its neighbors and sets its threshold W_{Th} = cW_i, where c is the threshold adjusting factor that can be set relative to λ. The pseudo-code of the operations executed by a sensor node in each round of cluster formation is reported in Algorithm 1.

1) Adaptivity to Multi-Events: It can be seen from Eq. 9 that a node having higher energy level than its neighbors is the potential candidate of becoming cluster-head. However, a node reporting events at higher rate is less likely to be elected as cluster-head. The weighting equation includes the ratio of data rate (ρ_o/ρ_i) to consider the multiple data rates due to different events. If a node i has $\rho_i > \rho_o$ then its weight is reduced. Therefore, it has lesser chances to become cluster-head than the other nodes. It is due to the fact that nodes sending packets at higher rates exhaust their energy soon and, thereby, the probability of becoming cluster-heads is reduced.

2) Reducing Clustering Reformation: MEAC reduces the frequency of clusters reformation by setting weight threshold at the time of cluster formation. In each round, each cluster-head recomputes its weight and compares with its threshold value. If W_i of cluster-head i is higher than its W_{Th} value then it keeps functioning as head. if $W_i < W_{Th}$ then it checks whether its W_i is also lower than any of its member node weight. If so, it withdraws itself from being cluster-head and cluster election procedure is initiated.

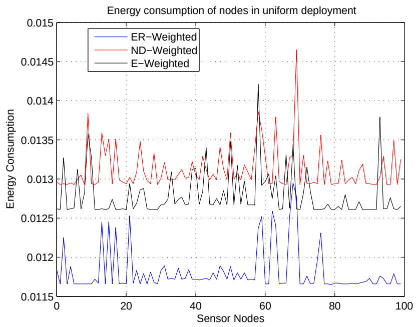
B. Inter-Clusters Connectivity

Energy of nodes is conserved by using minimum transmission energy (MTE) scheme. Obviously, MTE scheme requires multi-hop routing when the sink is not in the transmission range of cluster-head. Thus cluster-heads are linked allowing the packets forwarded through the clusters on the path toward the sink node. Once the clusters are formed after the first round of cluster formation, member nodes keep updating their heads about any adjacent cluster found. The member nodes also forward the membership request of any DN node to heads. It works as follows:

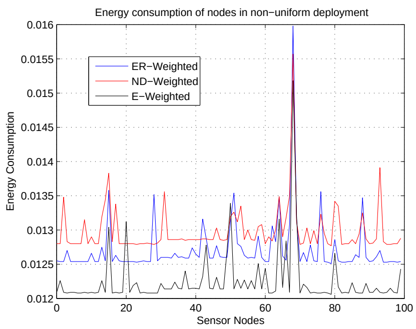
Each node keeps broadcasting hi beacon that contains its cluster-head ID or empty for DN nodes. If a receiving node N_i has different cluster-had ID, a neighbor cluster is found. N_i sends the NEIGHBOR-CLUSTER message to its cluster-head that updates its neighboring cluster table. When the cluster-head ID field is empty in the periodic beacon, member node considers it as membership request for DN and forwards it to its cluster-head. Cluster-head checks whether its member nodes does not exceed the limit N_{Max}. If the limit is not reached yet then it replies with the ACCEPTED message otherwise REFUSED message. N_i ignores the REFUSED message from its head but forwards the ACCEPTED message to the DN node.

C. Adaptivity to Nodes Deployment

One of the key issues in WSN is the deployment of mobile sensor nodes in the region of interest (ROI) [15]. Before a sensor can report observation to the monitoring system, it must be deployed in a location that is contextually appropriate. Optimum placement of sensors results in the maximum utilization of the energy of nodes. However, The deployment can not be determined *a priori* when the environment is unknown or hostile in which case the sensors may be air-dropped from an aircraft [16] or deployed by other means. The proper choice for sensor locations based on application requirements is difficult.



(a)



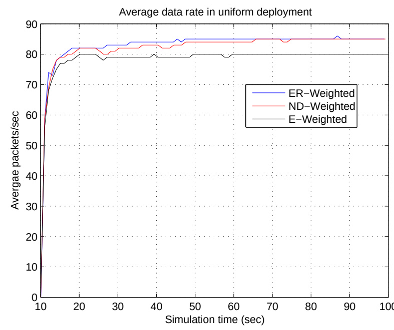
(b)

Fig. 3. Energy consumption in heterogeneous WSN ($k = 30\%, \varphi = 1, m = 20\%, \alpha = 1$) for uniform 3(a), and non-uniform 3(b) deployment of nodes.

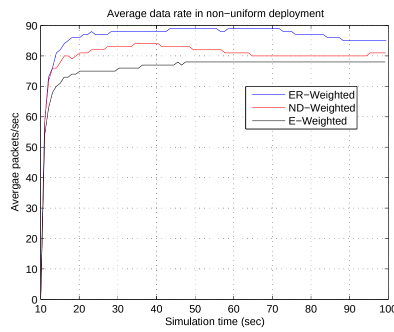
The deployment pattern of sensor nodes greatly affect the performance of the self-configuring clustering protocols. Due to the unpredictable distribution of nodes, MEAC takes into consideration the different system parameters as described in Section IV-A to adapt to the deployment. The performance is evaluated by weighting the parameters according to uniform deployment of nodes as well as non-uniform deployment. We create two different scenarios of deployment; first, 100 nodes are uniformly deployed in 100×100 meters area and second, 50 nodes are deployed in 100×100 meters area at first and then 50 more are dropped in 50×50 meters area of the same region to make it non-uniform.

The performance is measured in both scenarios by adjusting the weighting factors. The experiments are run by; (1) keeping the weighting factors of energy and reporting rate (ER-Weighted) high, (2) considering only the energy parameter (E-Weighted) and (3) setting the factor of neighbor nodes and distance (ND-Weighted). Fig 3 illustrates the energy consumption for both scenarios.

Clearly, the energy consumption is small when the weighting factor of ER parameters is set large in uniform case as shown in Fig 3(a). The energy gain in considering R parameter along with E is about 12% as compared to just E-Weighted clustering that the heterogeneity-aware clustering protocol exploit [5], [7]. Fig 4(a) shows that the reporting rate (packets/sec) is also 7% higher in ER-Weighted approach than the E-Weighted clustering approach. Hence, by including the data rate due to multiple events detection in the clustering of sensor nodes, it not only achieves the gain in energy but also high data rate.



(a)



(b)

Fig. 4. Average reporting rate in heterogeneous WSN ($q = 30\%, \varphi = 1, m = 20\%, \alpha = 1$) for uniform 4(a), and non-uniform 4(b) deployment of nodes.

For non-uniform case, Fig 3(b) illustrates that although the energy consumption is 4% lower in E-Weighted than ER-Weighted, the data rate is also lower by 15%. Therefore, the 4% gain is not actually due to the effeciency of

E-Weighted approach but due to the fact of low data rate. Even if all the sensor nodes have same data rate, ND-Weighted approach delivers events at higher rate than E-Weighted as shown in Fig 4(b), with some extra cost of energy. Hence, there is a tradeoff between high data rate and energy consumption.

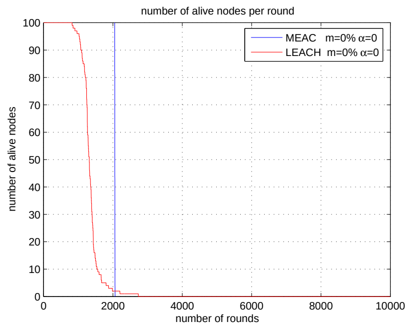
V. Performance Evaluation

We evaluate the performance of protocol in terms of energy consumption, network stability with multiple events and throughput metrics. The heterogeneous WSN is composed of nodes of different energy levels and sensing modules for multiple events detection. The example scenario of wireless sensor networks consists of 100 sensors deployed randomly in a field of 100×100. The sink node is placed at the center of field i.e. $x = 50, y = 50$. The initial energy E_o of EC nodes is set to 0.5 joules. The transmission and reception power is set to 50 nJ/bit and sources produce traffic at 4 kbps.

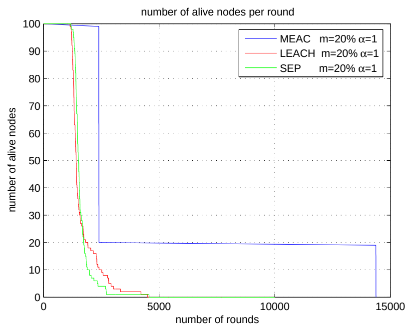
1) Energy: The energy efficiency of MEAC is compared with SEP and LEACH. Both SEP and LEACH periodically elect cluster-heads to balance the energy of nodes. Fig 5 illustrates a detailed view of the behavior of MEAC, LEACH and SEP for different values of the parameters. The number of alive nodes are plotted for the scenarios ($m = 0\%$, $\alpha = 0$), ($m = 20\%$, $\alpha = 1$) and ($m = 20\%$, $\alpha = 3$) in Fig 5(a), 5(b) and 5(c) respectively. Unlike SEP and LEACH, MEAC considers the available energy to elect cluster-heads and a node keep working as head as long as its available energy is higher than its theshold value. This approach reduces the frequency of cluster-head election.

It is obvious in Fig 5(a) that MEAC extends the stable region compared to LEACH by 55% for homogeneous network. The behavior of SEP is the same for $m = 0$ and, therefore, the gain in stability is similar to LEACH. Fig 5(b) shows the results for $m = 20\%$ and $\alpha = 1$ parameters. The stable period is 41% and 33% more than LEACH and SEP respectively. Besides the stable period, the unstable period is also quite large which keep the network alive for 250% more than LEACH and SEP. Fig 5(c) illustrates the stability gain of MEAC and SEP. Fig 5(c) illustrates the stability gain of MEAC for $m = 20\%$ and $\alpha = 3$. MEAC achieves the gain of 58% in comparison with LEACH and 35% from SEP. The unstable region is remarkably larger than both these candidate protocols.

2) Stability with Multiple Events: Fig 6 shows the impact of multiple data rates with and without deployment of ER nodes. The stability of network increases by deploying more and more number of ER nodes. Whereas, it decreases when sensor nodes are reporting events at different rates to sink. It is obvious from Fig



(a)



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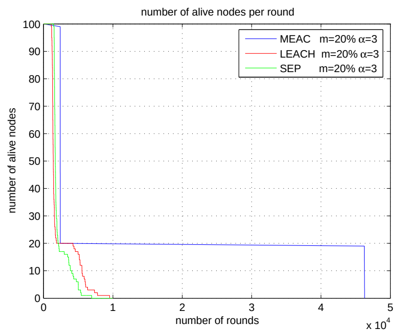

(c)

Fig. 5. Energy consumption comparison among MEAC, LEACH and SEP in the presence of heterogeneity due to energy for $\alpha = 0$ in 5(a), $m = 20\%, \alpha = 1$ in 5(b) and $m = 20\%, \alpha = 3$ in 5(c).

6 that the stability is high in the presence of ER nodes ($\lambda_{energy} > 0$). The extra energy of ER nodes is utilized to accommodate the high data rate. If we keep increasing λ_{rate} (by increasing φ) then the loss in stability is very small as compared to increase in φ.

3) Throughput: MEAC does not imply any aggregation technique at cluster-heads because it does not suit for the reliability measure in terms of packet delay for delay-sensitive applications. Fig 7 shows the throughput comparison of MEAC with LEACH and SEP. MEAC aims to provide in-time packet delivery and sacrifices some throughput at cost of packet delay that increases due to aggregating data [17]. Although the throughput in MEAC is less than SEP but it continues for the

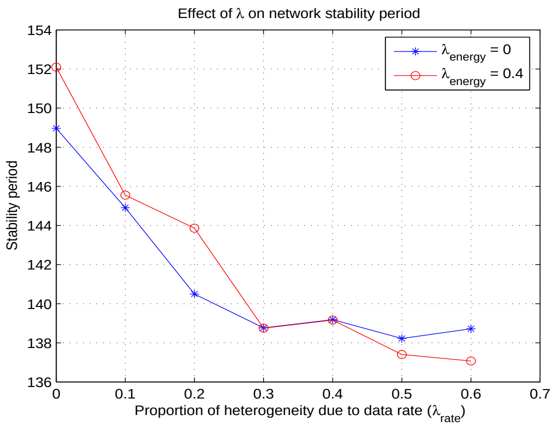

Fig. 6. MEAC stable period in heterogeneous WSNs for different values of λ_{rate}

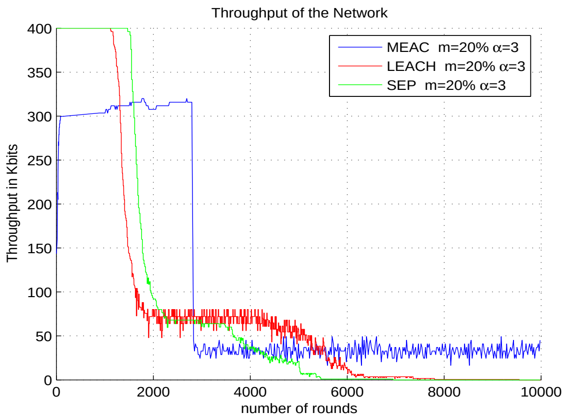

Fig. 7. Throughput comparison among MEAC, LEACH and SEP.

longer time than in LEACH and SEP. Therefore, the low throughput is compensated by longer period. It is observed that when the ER nodes are close to sink then the throughput is high in unstable period but the period is short. When ER nodes are placed far from the sink node then some ER nodes might not reach sink directly or indirectly and, therefore, reduces the throughput but keeps the network alive for longer period. Thus the deployment of ER nodes greatly effect the network performance during unstable period.

VI. Conclusion

A number of clustering protocols have been proposed for heterogeneous wireless sensor networks. However, they do not consider the presence of multiple phenomenon in the sensor field. When a sensor node detects either multiple events or an event whose required reporting rate is higher than the other nodes, it consumes relatively higher energy. $MEAC$ is a cluster-based routing protocol that considers the heterogeneity of nodes due to energy as well as multiple events. MEAC makes use of heterogeneity factors in such a way that energy consumption is reduced and stability period is extended compensating for reduced throughput of non-aggregated data. This conclusion was verified by the simulation experiments compared with SEP and LEACH.

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