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Energy efficient protocols for coverage maintenance in WSNs

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Abstract: Recent advances in wireless and sensing technologies enabled variety of applications in sensor networks. Some challenging issues have yet to be solved to achieve potentials of WSNs. Researchers focused much on energy conservation methods and little attention has been paid to coverage maintenance as quality of service (QOS) requirements. In this paper we have focused on improved heterogeneity aware clustering protocols and compare their performance on network life time and coverage maintenance under heterogeneity. Simulation results show the superiority of the proposed protocol for prolonging network life time and coverage maintenance.

Keywords: WSN, QOS, Heterogeneity, Coverage maintenance

I .INTRODUCTION

Latest developments in WSNs paved a way for developing diverse applications and services. The demand is rising for WSN nodes to handle more complex tasks such as video streaming and biometric recognition but sensor nodes battery powered, battery is a limited resource and battery should be used in an effective manner implementing energy conservation schemes. Researchers paid much attention to energy conservation WSNs [3].Robustness in WSN applications closely connected with energy consumption and coverage maintenance. Uneven spatial distributions of active (live) nodes can quickly loss coverage to certain locations for monitoring. This is not desirable in survaivelance applications where persistence coverage is essential to satisfy a specific QOS. Existing clustered based WSNs have mainly investigated in homogeneous networks, in which all the nodes have same energy capacities. But in realistic applications sensor nodes can be failed, damaged and can be replaced. These lead to heterogeneity among network sensor nodes. We must be attentive toward such factors because they can reduce network life time as well as quick failure in maintaining network coverage .Inspired by previous works [7[[8] we have investigated the effect of energy heterogeneity in clustering protocol that supports both energy preservation and coverage maintenance.

At a glance we model the energy imbalance existing in the network with a three tire hierarchy and we analyze the performances of the protocols with respect to coverage maintenance. We further investigated the spatial uniformity of active nodes distribution and define a quantitative metrics for performance evaluation .The rest of the paper is organized as follows; section II presents review of related work. In section III new sensor network models are presented .simulation settings and results presented in section IV. Section V presents conclusion and future scope

II .RELATED WORK

Clustering is an effective approach to handle energy management in WSNs .Low Energy Adaptive Clustering Hierarchy (LEACH)[6] is pioneering work in this respect. HEED [9] proposed a hybrid approach for cluster head (CH) selection based on Residual Energy (RE) and a nodes proximity to its neighbors. Both LEACH and HEED solutions assumed a homogeneous environment, Which does not conform to real world operation of a typical WSN. Nodes will have different energy levels as a result of terrain recharging or new nodes deployment for replacing dead nodes. .In stable election Protocol (SEP)[7] it is proved that how energy heterogeneity can be better used by adapting the CH election probability according to sensor nodes to characterize the heterogeneity problem. This is extended in SEP-E approach [2], which proposes three tire hierarchical setup and further adapted CH election probabilities to enhance the network life time. All the above works focused much on a stochastic model to prolong the life time in WSNs. Of late a Deterministic model was proposed [1], which achieves better network life time than in previous methods in both homogeneous and heterogeneous environments. This paper is an extension to [1] by considering coverage maintenance and spatial distribution of energy as a performance criteria. The significance of network coverage is discussed along with network life time and energy efficiency in [4].In [8] Soro and Heinzelman proposed coverage aware cost metrics and presented a cluster based network organization.

They further proposed an unequal clustering to force a balanced energy consumption .Functional network life time (FNL) in WSNs is defined as the time until the first node dies out [6][7].In [4] the network life time is defined as the time in which the network is able to perform sensing function and transmit data to the Base Station (BS).Network life time is not defined related to coverage maintenance . In [6] the performance of LEACH protocol is compared with other protocols showing snap shots of live node distribution. In this work we present new performance metrics that measure the coverage maintenance and coverage uniformity in WSNs. We present an empirical study which includes a number of recent clustering protocols and analyzed their coverage maintenance in energy heterogeneity environment.

III .WSN MODELS

A. the energy dissipation Model

we consider an energy dissipation model as presented in [6][7]. Based on communication range two propagation models such as free space and two way are used.

B. Cluster formation in SEP-E and DEC

In LEACH protocol all the nodes have same probability to become CH. In SEP and SEP-E both nodes have weighted probability to become CH.SEPE introduced an intermediate node whose energy lies between normal node and advanced node. Thresholding and random election process are discussed in detail in [6[[7][2].The cluster formation process in DEC[1] is different from the process used in LEACH, SEP and SEPE. In DEC deterministic model is used to elect CH in each cluster based on residual energy of the node and average energy of the network. At the beginning of the network (round1) the BS sets up cluster by choosing high residual energy node as a CH. In subsequent rounds the cluster self elect the next CH depends on the residual energy information. Which is piggy based during the exchange of JOIN REQUEST sent by non CHs to their corresponding CH at round 1. This process repeats until the nodes die out. After forming cluster the CH node sets up a TDMA schedule that governs the data transmission in the cluster. The TDMA schedule ensures that there are no collisions among the data packets .i.e. cluster members can communicate CH in their allocated time only to reduce interference among CHs .The communication with BS is don using CDMA codes .

C. Network coverage

In [4][8] there are two basic coverage problem associated with WSN: point coverage and area coverage. The farmer is used in the application where the node deployment is deterministic, while the latter is used in random deployments. In our approach, we deal with area coverage and define the network coverage as a summation of coverage of each individual node modeled as a circular area of radius R with the sensor node selecting at the middle. We assume that each sensor node does not move once deployed and equipped with an omni directional antenna that monitors its own range. Uniform distribution of nodes allow the coverage to be above 95% .Our cover definition has two implications first it deviates from the assumption in LEACH that sensor nodes of the same cluster detect the same event in LEACH it was assumed that the distance between nodes within a cluster is small compared with distance from which events are sensed. The robustness of coverage is inherent under this condition .i.e. one or two nodes death does not cause coverage loss because the remaining nodes in the cluster can sense the same event .In the new definition, the death of even a single node will substantially cause coverage loss. Though there may be overlapped regions between sensor nodes .Hence it is stringent definition. Secondly, the sensor nodes will detect different events, which strengthen the new definition more suitable for modeling monitoring applications that demand localized information .This motivated us to introduce a new metric called Full Coverage Time (FCT),which combines the coverage maintenance with network life time .FCT is defined as the time from the beginning of the network operation till the network suffers from coverage loss.FCT is different from the definition of network lifetime (NLT), which is indirectly related to coverage maintenance ,as initial node may or may not cause coverage since $NLT \leq FCT$.

D .Spatial Uniformity

Some application areas do not require strict coverage maintenance, which can tolerate one or two sensor node deaths. Active nodes distributed throughout monitoring area can maintain sensing coverage. Energy consumption overtime, node deaths and how a network maintain its sensors energy across the monitoring area, is related to coverage maintenance. Therefore this translates to measuring spatial uniformity of coverage as network evolves .An effective protocol design is essential to maintain spatial uniformity of coverage which implies that energy consumption is more even and less chance for the network to suffer from coverage loss due to early node deaths .To evaluate how energy consumption occurs spatially over time, we choose a limit point during the simulation where the amount of dead nodes reaches 50%.The complete sensing area is split by $s \times s$ grid and active nodes in each of $\left(\frac{M}{s}\right)^2$ cells can be counted. We use the variance of the number of live nodes across all cells as a measurement of the spatial uniformity of coverage .Smaller the variance is ,energy is consumed more uniformly throughout the network. This is shown in the figure 1.Further we carry F test to verify whether the difference on the variance measurement is significant or not across different protocols.

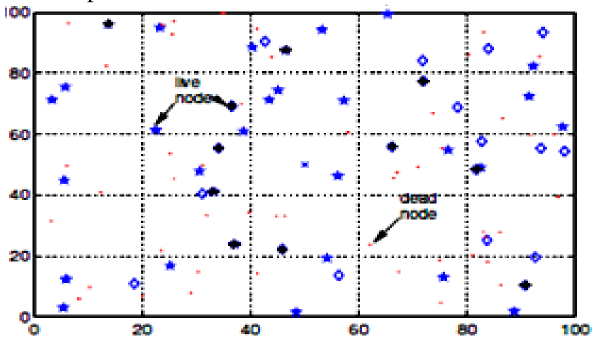

Figure 1: Live node distribution using 5×5 grid

IV. EXPERIMENTAL SETUP

Following parameters are used in [6][7].We consider a $100m \times 100m$ area with 100 nodes distributed randomly throughout. MATLAB is used for simulation of protocols. Parameters used in simulation are shown in table 1.

Table 1:Simulation parameters

Parameter	Values
E_{elec}	50nJ/bit
E_{DA}	5nJ/bit/msg
E_0	0.5J
P_{opt}	0.1
K	4000

ε_{fs}	$100\mathrm{PJ/bit/m^2}$
ε_{mp}	$0.0013\ \mathrm{PJ/bit/m^4}$
R	10/15m
η	100

The heterogeneity configurations that is tested for the protocols is $m = 0.2, b = 0.3, \alpha = 3\ and\ \mu = 1.5$. Different settings will affect the operation of the network such as 20% and 30% of nodes be advanced and intermediate nodes with an extra energy(3 and 1.5 time more than normal node).

V. SIMULATION RESULTS

Following performance metrics are used to evaluate the performance

Stability period: The time period from the start of the network operation to first node death

Instability period: The period between the first node death and last node death

Full coverage time (FCT): The period from the start of he network operation till full coverage is no longer maintained.

Number active nodes and dead nodes per round

Half time: The period from the start of the network time when any node uses up half of its energy

Spatial uniformity of energy spread in the network

Table 2: Summary of average life time of the sensors for 10 rounds with $E_{total} = 102.5J$ when BS is placed at the center.

Protocol	FCT	Stability	Half Time	Instability
LEACH	1241	995	478	4585
SEP	1398	1385	631	5050
SEP − E	1624	1450	704	3751
DEC	2075	1839	945	640

Multiple simulation runs are carried out for LEACH,SEP,SEP-E and DEC. We fist evaluate network coverage performance using FCT under energy heterogeneity conditions, then we examine the network life time with different load of extra energy and finally investigated the spatial uniformity by using visual comparison of node heat maps and the examination of spatial uniformity statistics.

A. Network life time and heterogeneity

Figure 2 shows coverage evaluation over time measured in rounds during one set of simulations. Obviously DEC has full coverage for the longest time. Similarly SEP-E performed better than both SEP and LEACH till about 75%.Further LEACH seems to take over SEP-E after 2000 rounds.SEP has only 60% coverage .i.e. at about 3000 rounds. Remember LEACH and SEP is able to keep around 20% coverage after 4500 rounds.

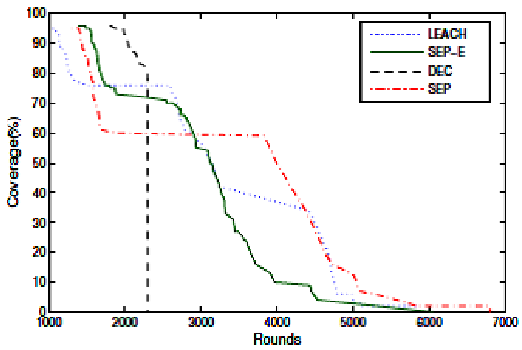

Figure 2 : Comparing coverage performance of DEC,SEP,SEP-E and LEACH

Previous works proved that LEACH performs well in homogeneous set up[7] because of optimized CH election. The comparison of the performance of four protocols is summarized in table 2.The stability period and half life time of DEC and SEP-E are longer than LEACH and SEP.SEP has better stability period than LEACH. In figure3 the network lifetime (stability period) is plotted against the percentage of total extra energy added to the network. It is obvious that DEC optimizes the other protocols .Though SEP and SEP-E are close in performance, SEP-E constantly performs better than SEP.As energy heterogeneity increases in the network DEC, SEP-E and SEP performs better. The main advantage of DEC is that it chooses CHs based on their residual energies .Hence it performs well with energy heterogeneity.

B. Spatial Uniformity

To show the energy distribution in the network over time we plot heat map of the sensor node energy at different (3 point) points in the time. Round 1500 and round 2200 roughly located at the stable and instable periods respectively..

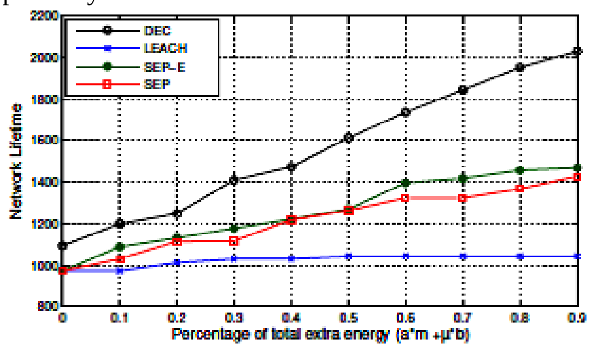

Figure 3: performance of DEC,SEP,SEP-E and LEACH as the percentage load increases

The heat maps are shown in the figure 4 and in figure5. A red pixel on the map indicates that the location is close to active node. The faded red indicates that the location is away from active node but still covered by an active node. From figure 3 we notice that both DEC and SEP-E have better coverage than LEACH and SEP at round 1500 when we investigate the coverage in early instability period at round 2200.DEC still shows better performance than other protocols. Furthermore DEC is able to evenly balance the energy consumption among the nodes resulting to a prolonged FCT and hence the nodes die out almost at the same time. For mission critical applications with full coverage requirements DEC is better to SEP,SEP-E and LEACH .To summarize, heat maps are used to assess the spatial uniformity of the coverage.DEC and SEP-E shows better spatial uniformity than LEACH and SEP.DEC has proved its efficiency in heterogeneous environment .

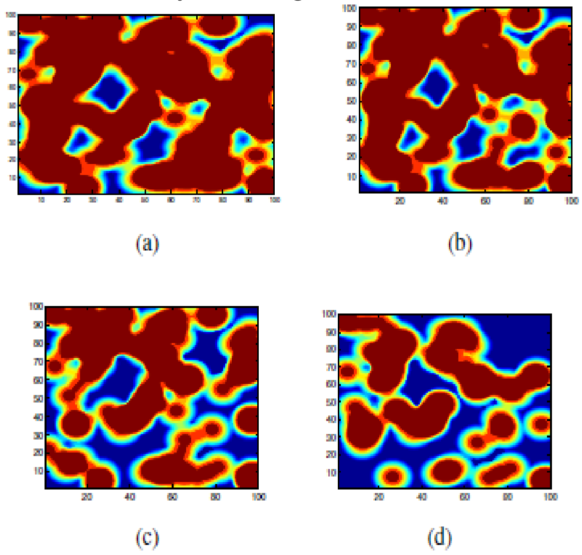

Figure 4: The heat map at round 1500 for (a) DEC (b) SEP-E (c) SEP-E and (D) LEACH coverage

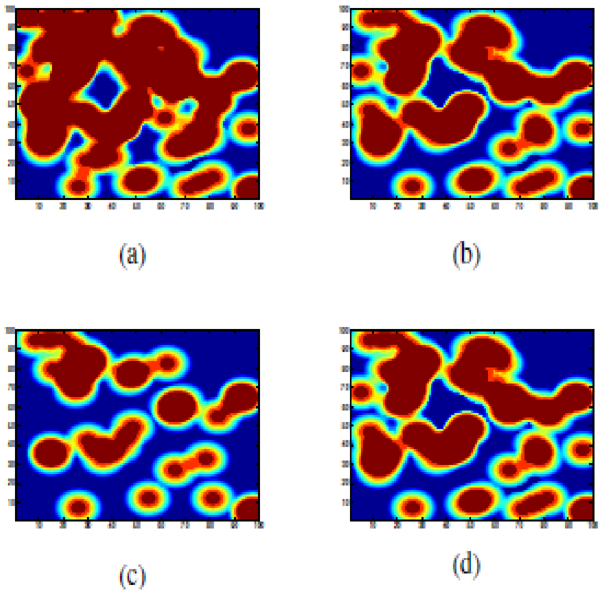

Figure 5: The heat map at round 2200 for (a) DEC (b) SEP-E (c) SEP and (d) LEACH coverage

VI. CONCLUSION

The WSN clustering scheme, initially proposed by [6] also, upgraded by [7], was proposed to adapt to energy utilization in WSN. Taking after this approach, this paper presented an experimental study on energy utilization what's more, scope safeguarding of two new protocols SEP-E what's more, DEC in heterogeneous settings. Heads in SEP-E choose themselves as cluster heads stochastically, in light of their energy levels, holding all the more consistently dispersed energy among sensor nodes. Nodes in DEC utilize a more deterministic way to deal with choose themselves as cluster head, along these lines appearing a superior execution than alternate protocols. Our outcomes demonstrate that DEC and SEP-E is more energy efficient, enhances lifetime and the full coverage time. In the greater part of the cases, DEC and SEP-E keep up an adjusted and the sky is the limit from there uniform spread of energy among nodes. Both the DEC and SEP-E display plan can be exceptionally vital for applications that require persistent re-energization of nodes all through the information recovery handle, by sending new nodes to supplant dead ones, or it could be helpful when testing the impact of presenting redesigned sensor nodes into a current system. This gives a defense for the distinctive energy levels we have utilized as a part of our reenactments. It ought to be noticed that we have not particularly endeavored any scientific structure for coverage enhancement. We have however exhibited experimentally that it is conceivable to take focal points of the energy heterogeneity in WSNs for both energy and coverage conservation. We have not either gone for various heterogeneity settings thoroughly and the reproductions are led in a constrained application situation. Besides, we have concentrated on a design with single node steering (by means of the Cluster head), however for bigger systems a more sensible arrangement is to utilize transferred, multi-bounce steering among the CHs. This would have affect on the energy utilization designs and the coverage consistency, and these will premium headings for further examination in light of energy heterogeneity.

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