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A Centralised Group Aware Duty Cycle Control Protocol for Wireless Sensor Networks

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***Abstract-* Wireless sensor networks are collection of autonomous devices comprising of sensors to sense the effects of temperature, pressure or pollutions in our environment at different locations in real time. These devices may be termed as sensor nodes that have the job of computations, sensing and communication. The network lifetime of these devices is limited by the power issues due to the use of batteries. With this paper we bring out the design and implementation with the help of centralised group aware duty cycle protocol for wireless sensor networks. In this arrangement the nodes form a set with already fixed diameter. One node like a sentry out of the group remains active while others go to sleep mode. After some time somebody else takes the responsibility of this sentry and the current sentry goes to sleep mode. This is like the duty cycle of sentry which is followed by all the nodes in the group one by one. Thus energy efficiency and fault tolerance is achieved. The group is transparent to the network except that active node.**

I. INTRODUCTION

Wireless sensor networks (WSNs) are formed by densely [2, 17, 18], usually randomly deployed and large in numbers, may be hundreds or thousands of sensor nodes in the area being monitored. WSNs are becoming an interesting research area and thus gaining a keen attention of researchers, as they inherently support unique network application for the wireless communication in an environment where people rarely reach. The potential applications of WSN are highly varied such as underwater monitoring, battlefield surveillance, glacier activity monitoring etc. Inherent properties of WSNs are power, bandwidth, computation and memory constraints despite of traditional wireless networks [9]. SNs in such a network possess sensing, data processing and wireless communication capabilities which are usually application dependent. Being the autonomous devices, SNs doesn't require much human attention in hostile environments such as battlefield and volcanoes, but it makes them difficult or sometimes impossible to re-charge or replace their batteries.

The resources in WSNs such as energy, transmission media etc should be utilized efficiently in order to extend the lifetime of the network. Although much attention has been paid, in various protocols, to low power designs at hardware level and signal processing techniques, energy efficiency must be provided at various networking layers. The balance of energy consumption among all the SNs must be maintained in order to avoid the "hot spot" problem.

The main emphasis, while designing and developing the routing protocols in WSNs, is on uniform load distribution among the SNs in order to increase the network lifetime. To minimize energy consumption lots of protocols exist [8, 14-16]. They may increase energy efficiency, but they do not always, increase the lifetime in the network. If certain nodes become "popular" or more commonly termed as "hotspots", i.e., present on most of the forwarding paths towards sink in the network efficiency of the node and hence the efficiency of network decreases. It may cause problems such as unbounded delay and routing loops. In most of the protocols almost all of the nodes are in high energy awake mode or even if certain sleep and awake pattern is applied over the network nodes, the scheduling is inefficient in terms of hardware requirement (eg. GPS) or in terms of complexity.

In WSN as the density increases so the inbuilt redundancy increases in the amount of data sensed by the overall network. In such a network, nodes which fall in a close proximity of each other will almost sense the similar data and will route it over the network using certain existing protocol. This unnecessarily brings about redundancy and leads to bandwidth wastage, congestion and an unnecessary lifetime. By avoiding such redundancy we can achieve efficiency.

In this paper a Centralised Group Aware duty cycle protocol (CGDC)[1] for WSNs is designed and implemented which optimally utilizes the closeness of nodes falling within a predefined diameter called grouping diameter (gD). This protocol enables a configurable group formation among the set of nodes which mutually fall within this diameter with respect to each other. The members of this group are made to go to a low energy sleep, allowing one of its members to remain awake to represent its group. The protocol also provides a fault tolerant scheduling algorithm for members of the group, so that, there is always one member awake to listen to surrounding, i.e. to sense and transmit. This group is completely transparent to the rest of the network and is treated as a single node for any routing protocol applied at the abstract level. The group awareness is only at the lower level. By reducing the number of nodes competing for the communication channel, CGDC reduces chances of network congestion and provides better bandwidth utilization. It also reduces various overheads at the abstract level by providing the routing protocol with a lower number of nodes to be handled. Even if some member of the group stops working, goes faulty or destroyed, the rest of the members are reconfigured to form a group again. This provides robustness and fault tolerance to the protocol.

Rest of the paper is organized as follows. Section II Summarizes related work. In Section III the useful network

Model is introduced. In Section IV we present the grouping and scheduling within the group members of CGDC protocol in detail. In Section V we show effectiveness of CGDC protocol via simulations. Finally, we conclude our paper and draw directions for future work in Section VI.

II. RELATED WORKS

There are three classes in which WSN routing protocols can be classified [13]: direct communication and flat protocols are simple to implement, robust in action and easily extensible. There is no structure formation e.g. clusters (LEACH), chains (PEGASIS), etc to be maintained query in these protocols. However these protocols are unable to do data aggregation and compression functions since there is no management node in the network, being homogeneous in nature.

LEACH [4] cluster based, distributed and heterogeneous (in terms of node functions) routing protocol. In this protocol base station randomly chooses a portion of the SNs as cluster heads and the remaining SNs choose their nearest heads to join, thus forming a cluster. The cluster members' data is transmitted to the head (TDMA), where the data is aggregated and is forwarded to the sink(base station). Since the protocol randomly chooses cluster heads in each round, the energy consumption is theoretically evenly distributed among all SNs. This protocol suffers from the probability of forming a cluster head in a close proximity and also is inefficient for time critical applications.

TEEN [10] is quiet similar to LEACH in its clustering mechanism. It sets two threshold values, a soft threshold and a hard threshold, during the data collecting stage, for further reducing the communication traffic. This further reduces network traffic and overall energy consumption thus enhancing the network lifetime.

In the PEGASIS protocol [3], the cluster is a chain based on geographical location unlike leach where the clusters are in form of huddled SNs. This SNs only communicate with their adjacent nodes in the chain so that they can send data at the lowest power level. In each round, the system randomly chooses a SN as the cluster head to communicate with the BS, it reduces the communication traffic. Lindsey provided an improved solution by employing a combination of the binary data aggregation and three-tier data aggregation mechanisms [9].

In [5], a technique called Back casting is described to identify redundant sensors. This work assumes that the field is densely deployed and thus turns off as many sensors as possible to maintain a certain level of fidelity of data sensing. Their method uses measurements from the densely deployed network to estimate the spatial nyquist frequency throughout the field. When this frequency is low, sensors can be shut down to conserve energy by using a human user.

Next approach views the WSN as a database query response system: Model-based Data Acquisition [6]. In this user issues a query to a densely deployed network. Using a gaussian process (GP) model built from past data, the system chooses a selected number of sensors to be queried to get an appropriate response. Thus, the algorithm finds a particular subset of sensors that is useful to answer to the query and can direct a human user to remove the other sensors.

The above approaches are either very complex or need human effort after the network deployment which is not actually possible in many cases. Moreover few of protocols use removal of SNs which may be problematic in cases where SNs are already prone to some physical damage, thus resulting in even fewer of nodes and resulting in an inaccurate and inappropriate data.

SIPF[9] uses the duty cycle technique of removing redundant density of the network by using the alternate awake and sleep patterns of the nodes, but the main drawbacks being the requirement of location awareness of all nodes (which increases hardware cost), requires a high setup energy, doesn't guaranty the scheduling even if one node is out of desired range, and applies complex logic for scheduling.

In this article we present a protocol called CGDC which is fault tolerant, robust and energy efficient. This protocol puts its main emphasis on the utilization of network density by using a simple BS controlled grouping algorithm and a fault tolerant scheduling scheme within the group for alternating the sleep and awake patterns of the group members. Unlike certain previous efforts CGDC doesn't require any human endeavour after the deployment of SNs. Moreover this is more like a system working at the lower level over which other routing protocols can implemented. The group awareness being only at the lower another level does not impose any overhead for the abstract level protocol. At the same time the fault tolerant reconfigurable nature of the group always provides a node to the routing protocol, unless all its members are not depleted or destroyed.

III THE SYSTEM MODEL

Energy efficiency is major aspect that need to be taken care of while developing any protocol for the WSNs. This is because of the fact that the sensor nodes are highly constrained in terms of power and their batteries are generally neither replaceable nor rechargeable. The system model of CGDC takes care of this issue.

In CGDC we have assumed that all sensors are distributed in an evenly randomized manner in a square region, and the network has the following properties:

1. There exists a unique BS, located far away from the network
2. Each SN has a unique identity
3. All sensors cannot move after being deployed
4. Network is homogeneous i.e. all sensor nodes are equivalent, having the same computing and communication capacity
5. The network is location unaware i.e. physical location of nodes is unknown
6. The transmitter can adjust its amplifier power based on the transmission distance

The third assumption about lack of mobility is typical for WSNs employing some clustering or grouping methodology for network organization. Nodes that travel rapidly in the network may degrade the group quality, because they alter the organization of nodes in their group. Assumptions like node homogeneity and location unawareness are rather advantageous as far as hardware cost and resource requirements are concerned. This paper uses the same energy dissipation model as discussed in [13].

The main emphasis of most of the existing WSN routing protocols is on energy conservation of the network. This concept is used to improve the overall network lifetime. The fact that the nodes lying in a small diameter, termed as grouping diameter (gD) in our approach, will certainly sense almost the same data. This increases the amount of redundant data that travels across the network in given time, moreover, all nodes are active at almost all the times. This consumes a lot of energy and at the same time it leads to the network congestion and thus packet losses.

Grouping provides an effective way for prolonging the lifetime of wireless sensor networks. With grouping, a node is guaranteed to sense and transmit data to the BS during its turn. When the network is partitioned into groups, data transmission can be classified into two stages, i.e. communication within the group and communication to the BS. First awake member of the group send their data to the BS, and then send a message within the group to awake another member in the group before going to sleep mode.

CGDC takes care of redundancy by allowing certain nodes in network to be in a low energy sleep mode by an efficient group formation strategy. In this protocol the nodes that fall in the close proximity of each other combine logically to form a group. Then there is a scheduling technique that allows one of the nodes to be in awake mode, working like a sentry, who takes care of any data that requires to be sensed in its locality and the rest of the nodes go to a doze mode. The sleep and awake patterns are taken care of by a simple fault tolerant scheduling algorithm.

The group formation is mainly guided by the gD that is decided at the grouping phase. If the value of gD is small then the group covers quiet a small area, which can be treated as a single node, who is actually the node remaining awake to represent the group. Then any other existing routing protocol, like LEACH, PEGASIS etc can be implemented over this type of scheduled grouped network. Our group is treated as a node by the protocol at the abstract level. The group id that CGDC assigns to the group can become the id of the node for the abstract level protocol implementation. All group IDs are maintained by BS. Fig. 1 shows the idea.

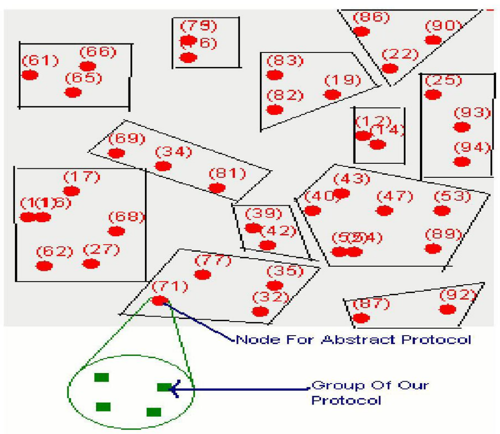

Fig. 1. The Network Deployment

Suppose LEACH is implemented at abstract level, and then while implementing it use the group ids, available with the BS, as the node ids. The abstract level protocol can forget about the grouping at the lower layer. Once the protocol iS implemented the LEACH re-clustering overheads are also reduced because now it's not the single node that is a cluster head (CH), rather it's a group and there are other members in the group too. They will take over the responsibility of the CH in scheduled manner, as defined by our scheduling algorithm. Same is the case with PEGASIS, where the transmitting node will actually be the group and can work for a longer duration. The grouping algorithm is itself so efficient that it forms a group with a complexity of O(l) as compared to O(!V!) in certain clustering algorithms[9]. There is a negligible load over the individual node for the group formation; rather our protocol exploits the resources of the BS for all the grouping operations. Thus, the overall concept is simple to understand, rather than one member working in the family there are a few more, this no doubt is going to improve the overall working capacity of the family.

IV. Implementation

A simple model is used for the communication energy dissipation. Both the free space (d^2 power loss) and the multi-path fading (d^4 power loss) channel models are used, depending upon the distance between the transmitter and receiver. The energy spent for transmission of an *l*- bit packet over distance d is:

$$E(l,d) = \begin{cases} lE_{elec} + l\varepsilon f_s d^2, d < d0; \\ lE_{elec} + l\varepsilon m_p d^4, d \geq d0; \end{cases}$$

And to receive this message , the radio expends:

ERX(l) = lEelec (1)

The electronics energy, Eelec, depends on factors such as the digital coding, modulation, whereas the amplifier energy, efsd2 or d4 depends on the transmission distance and the acceptable bit-error rate. CGDC includes three phases: Grouping, Scheduling and Protocol Implementation.

Grouping: For enabling the grouping of sensors we propose a novel method which finds all the cliques in the given graph of adjacency matrix of the deployed nodes. The adjacency will be considered as follows. If G(V,E) is graph with V as set of all nodes in network and E is the edge set then two nodes are adjacent if:

$d(nl, n2) < gD$ where $nl, n2 \in V$ (2)

After the deployment of nodes in the area, all nodes broadcast a HELLO packet to each other such that the signal strength of the broadcasted packet be sufficient to transmit the packet to a distance b_D called broadcast distance, such that

$$b_D = g_D + \delta \qquad (3)$$

Where δ is the very small distance beyond gD this is included such that the packet can safely reach the destination.

Since initially every node knows that it has to transmit with this signal strength, thus every node knows every other nodes initial transmit signal strength (Ptx) Now using free energy dissipation model[12]:

$$P_r(d) = P_{tx} \times \frac{\varepsilon}{d^2} \quad (4)$$

Where Pr is the strength of received signal, P(tx) strength of transmitted signal, d is distance and $\mathcal{E}$ is attenuation coefficient.

Then each node calculates distances using :

$$d=\frac{r}{\sqrt{p_r}} \quad (5)$$

where, r is constant

If the $d \le g_D$, (not $g_D + \delta$) then receiving node will accept the packet else will discard it. The format of HELLO packet will be as:

ID source

HELLO Packet

This will include the ID of the source only. The receiving nodes, if accepting the packet, i.e. based on (1) will make its entry in its neighbourhood list (NL). After this first transmission, each node will have its NL as shown in **Fig. 2.** This is something like having a local link state information rather than the complete network information with each node as implemented in certain protocols. SNs then transmit the neighbourhood list packet, NLP, to BS the format of NLP is as follows,

ID source	NL

NLP

NLP of node D will be like

D	B, E, F

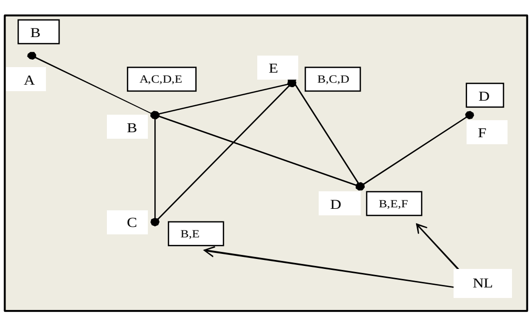

Fig. 2 Network node with their neighbourhood Information.

The BS adds the NL of a node against its ID in its Neighbourhood Table (NT). Now BS has got with itself the neighbourhood of every node in the network. This is like the link state table. Then it uses the grouping algorithm to form all the groups in overall network. BS assign a unique id to each group which is equivalent to a nodes ID in any other routing protocol. The group ID could be the ID of first member in the list.

The BS then broadcast this group information to the network in the form of group allocation Packet, GAP, who's format is as follows.

Group ID	Group List

Every node on listening to this packet will look for its own ID in group list GL. If its own ID is there in this list it keeps it with itself and does not read any other NLP after this. Thus every member of group has list of every other member in its group. Receiving nodes will look for their own IDs in GAP and accordingly save it if ID is present, thus knowing its own group ID and other group members too. Fig. 3 shows uneven grouping topology.

Scheduling: Every group member on receiving the GAP will receive the node IDs in certain Sequence. This sequence will determine the awakening & sleeping pattern of nodes in the group. The scheduling will take place as following:

1. The first ID (or node with first ID), node in GAP will be the first one to be in an active mode, rest will go to sleep mode.

2. The switching will be done if:

a) Time $t > T_{max}$,

where T_{max} is maximum time given for switching. (The '>' factor is included since node might be receiving and sending packet when $t = T_{max}$), or

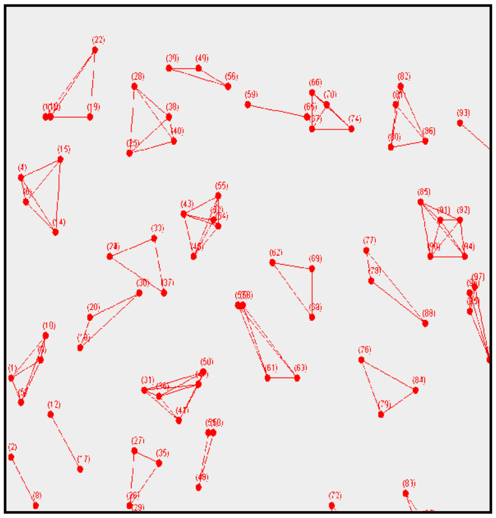

Fig.3. Non Uniform grouping of sensors in WSN

b) $$t < T_{\max} \&\& n_p = c_p \quad (6)$$

Where n_p is no of packet yet sent and c_p is the count of maximum packets allowed to sense when awake. Before going to a low energy state this active node will send a signal to node next in the sequence. The receiving node will become active only if:

a) $$E_{remaining} > E_{cp} \quad (7)$$

E_{cp} is the threshold energy required to send c_p packets, else,

b) It must transmit remaining packets (< c_p) till it has energy to wake up rest of nodes in list one by one(in case the next doesn't reply in a given time) and broadcast a NACK (-ve acknowledgement) to declare itself dead.

All members receiving this packet will remove if from their list and the node next after this will send an ACK to previous awake node if it satisfies the energy condition. If the awake node doesn't get a ACK packet from it in a predefined time, it assumes it as dead and informs rest to remove it from list. Then it tries the next in list. Another fault tolerant approach is that if the awake node itself is dead then next node in list will wait for a T_{max} time after which it will signal the previously awake node as dead to rest of the members and take over the task.

Algorithm

The array A[n,n] contains the adjacency matrix of every node in network based on NLP received by BS the list 'nbr' contains the neighbourhood list of the current node under consideration. The list 'group' contains all node IDs which can form a group with current node [A group is a complete sub graph of the network graph, i.e., a clique]. The list best contains the biggest 'group' yet that could be formed by the node under consideration. All list are initially set to null.

1. for i=l to N step 1
   a. if node visited (i) then continue
   [if node already visited or member of some group]
   b. for j in I to N step I
      if Not (node-visited ()) AND A[i.j] 1
      add_ neighbour (nbr,j)
      [add j to neighbourhood list]
      [end of step b for Loop]
   c. add-group (group, i)
   d. clique (nbr, i)
   [call this function with neighbourhood list & root node]
   e. broadcast (best)
   f. set nbr->null , group-> null , best-> nulls
      [mark all lists empty]
      [enn off step 1for loop]
2. Exit

Function: Clique (nbr,node)

1. IF(size (nbr) = 1)
   a. add group (group, node)
   b. checkbest(group) pJ/bit/m4
      [check whether this is the best yet, if yes add it to 'best' list]
   c. remover group (group, last_two_nodes) energy is less than 0. 002 J
   d. return.
2. Else if size (nbr)=O
   a. checkbest (group)
   b. remove_group(group, last-node)
   c. return
3. For i in 1 to size(nbr) step 1
   a. add_group(group ,i)
   b. checkbest(group)
   c. For L in i+1 to N stepI
   (i) if a[i,L] = 1 AND contains (nbr, L) and L>node
      add_neighbour(xnbr, 1) i=1
      [adding neighbour's neighbour to xnbr]
      [End of step C for loop)
   d. if size(xnbr)>0
      clique(xnbr,i)

e. Else
remove_group (last_node)
[End of step 3 loop]
4 remove_group (last_node)
5. Return

V. PERFORMANCE EVALUATIONS

The no of awake nodes formed plays an important role in energy efficient implementation of application in hand. We need to define a few parameters that need to set properly by initially performing the simulation so that optimal no of application dependent groups are formed. We will provide a method to get an optimal grouping factor so as to get an energy efficient communication. The following are the simulation parameters considered for the implementation of CGDC Protocol:

- The distance between the BS and the network is taken as lOOm.
- the size of data packet is 500 bytes
- the electronic power is 50 nJ/bit
- free space attenuation coefficient is 12 pJ/bit/m2
- multipath attenuation coefficient is 0.0012 pJ/bit/m4
- nodes' initial energy is 6.0 J
- A node is treated as dead when its remaining energy is less than 0. 002 J

Error free communication links are assumed for simplicity. We assume a square network field. A WSN of varying network sizes with varying node density and gD were simulated. The variations are done with keeping the deployment area constant and then gradually varying the number of nodes and also the grouping diameter. Finally the deployment area is also varied.

avGpDeg = $\sum_{i=1}^{nc} GpDeg_i) / N_c \quad GpDeg_i$ (8)

is the number of members in the i^{th}group and g is the total number of groups formed after applying the grouping algorithm. This gives the Grouping Factor (GF), on the basis of which we will compare the network lifetime. The simulation parameters and results are listed in Table 1. The result is calculated for many simulations and then the average taken over it.

Area	No_nodes	g_D	avGpDeg
100	100	5	1.5196
100	100	10	2.452
100	200	5	2.0132
100	200	10	3.636
200	200	10	1.8604
200	200	20	3.5772
200	300	10	2.2164
200	300	20	4.6176
300	300	15	2.2518
300	300	30	4.7064
300	400	15	2.5428
300	400	30	5.4706

Table 1 Simulation Parameters

The metric evaluated is the average grouping degree (avGpDeg)

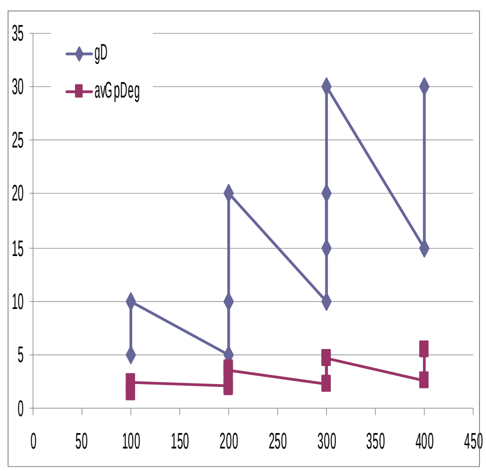

Fig.4. Relation Between Node Density, g_D and avGpDeg

It is clear that as the network density increases, the GF also increases, this further increases with the increase in g_D .The graph in the figure shows the same results pictorially. It is also clear that the network gives almost same avGpDeg for certain different network configuration. This gives the choice at the time of deployment about having same efficiency improvements while having different densities and g_D .
We determine the effect of GF on network lifetime. This is pictorially depicted in figure 5. This clearly shows almost a linear relationship between average grouping degree and network lifetime. Finally the effect of grouping factor is visible on network lifetime. The reading with avGpDegree as 1 is the case for deployment without CGDC Protocol implementation and with avGpDegree >1 are with CGDC Protocol implementation.

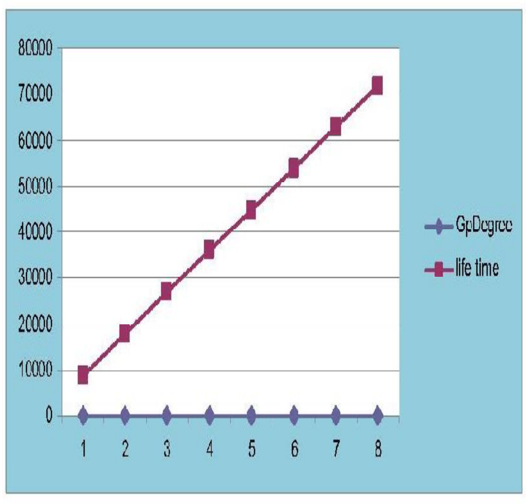

Fig. 5. Effect of avGpDegree On Network Lifetime

Thus to conclude we can say that:

$$Lifetime = k * avGpDeg - AWK_{factor}$$

Where k is a constant and AWK_{factor} depends upon number of times sleep awake pattern take place in lifetime, avGpDeg and gd. More is gd farther will be the awake packet required to be sent.

VI. CONCLUSION AND FUTURE WORK

In this paper we have presented design and implementation of a Centralised Group Aware duty cycle(CGDC) protocol for WSNs. CGDC optimally utilizes the closeness of nodes falling within a predefined gD. The set of nodes which mutually fall within this diameter with respect to each other can be allowed to form a group. The members of this group can be made to go to a low energy sleep mode, while one of the members remaining awake to represent its group. The protocol also enables a fault tolerant scheduling scheme among the group members such that there is always one member awake to listen to the surrounding, i.e., to sense and transmit. This group is transparent for rest of the network and can be treated as a single node for any routing protocol applied at the abstract level. The Group Awareness is at the lower level. If the gD is taken as big enough to be treated as a cluster rather than a group, then this same approach can be used as an efficient clustering algorithm with very low complexity and overheads for the nodes in the network. Like LEACH, the grouping here will not suffer from problem of CHs falling in the close area and thus leading to undesirable cluster formations.
Finally, one simple variation here can be that the scheduling be in a manner that the first node be awake till it's able to transmit data and finally awakes rest of the nodes in cyclic manner (in case the immediate next dies) then the next node in sequence takes over and the process continues. The awaked node may periodically broadcast a signal of certain strength, which other nodes may receive lifetime. The reading with avGp Degree as 1 is the case for and be assured that the work is going on smoothly. In case the signal is not received in that period the next node in the sequence takes over.

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