Applied Soft Computing 35 (2015) 386–397

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Energy efficient chain based cooperative routing protocol for WSN

Shalli Rani [a,*], Jyoteesh Malhotra [b], Rajneesh Talwar [c]

[a] SSD Women's Institute of Technology, Comp. Sci. Department, Bathinda, Punjab, India
[b] ECE Department, GNDU Regional Centre, Punjab, India
[c] ECE Department, CGC Technical Campus, Jhenjeri, Punjab, India

ARTICLE INFO

Article history:
Received 16 October 2014
Received in revised form 22 March 2015
Accepted 7 June 2015
Available online 7 July 2015

Keywords:
Wireless sensor networks
Clustering
Energy consumption
Transmission time

ABSTRACT

In this paper, we investigate the reduction in total transmission time and the energy consumption of wireless sensor networks using multi-hop data aggregation by forming coordination in hierarchical clustering. Novel algorithm handles wireless sensor network in numerous circumstances as in large extent and high density deployments. One of the major purposes is to collect information from inaccessible areas by using factorization of the area into subareas (clusters) and appointing cluster head in each of the subarea. Coordination and cooperation among the local nodes via relay nodes in local cluster (By forming sub clusters) helped to serve each and every node. Routing is based on the predefined path, proposed by new transmission algorithm. Transmission distance is minimized by using cluster coordinators for inter cluster communication and relay nodes within the cluster. We show by extended simulations that Chain Based Cluster Cooperative Protocol (CBCCP) performs very well in terms of energy and time. To prove it, we compare it with LEACH, SEP, genetic HCR and ERP and found that new protocol consumes six times less energy than LEACH, five times less energy than SEP, four time less energy than genetic HCR and three times less energy than ERP, which further validate our work.

1. Introduction

A new category of wireless networks i.e. Wireless sensor networks (WSN) is the consequence of recent growth in wireless infrastructure united with the customary improvement in electronics that facilitate the assimilation of composite components into smaller devices. This network is a group of very low-priced tiny sensor nodes randomly distributed in a monitoring area. Due to the low cost of sensors it is possible to have a network of hundreds or thousands of these wireless sensors which depends upon the requirement of applications, thereby enhancing accuracy of data, the reliability and the area coverage as well. These applications include border security surveillance, disaster relief operations, military protection services, environmental monitoring, location supervision, robotics and many more [11]. WSN is a distributed network, which is different from traditional ad hoc networks as only a little bandwidth is enough for transmitting data and the rate of transmission is low; mostly sensor nodes are static and only few nodes are mobile; energy of sensor nodes is very limited so new ideas are generated to conserve the energy. That is why traditional routing protocols developed for mobile ad-hoc network (MANET) cannot be used for WSN. Some fundamental differences between wireless sensors and mobile ad-hoc network (MANET) can be summarized on the basis of following attributes [26]:

1. Data centric: Redundancy is required in WSN but this concept is avoided in MANET until sharing of the some file or data is required.
2. Global Identification: Identification at the global level is not preferred in WSN (Increases overhead at run time) due to the vast number of applications and nodes but it is required in MANET.
3. Soundness and Quality of Service metrics (QoS): MANET is more reliable than WSN and reliability per node is necessary at fair level but in WSN requirements of QoS metrics is different because applications using WSN must be more energy efficient as batteries of sensor nodes cannot be replaced once they are deployed.
4. Scalability: Most of the applications require large number of the nodes to be deployed e.g. USA aims to deploy a huge number of nodes in smart roads project, safety monitoring of the people in country etc., making the network denser which makes it dissimilar from MANET.

* Corresponding author. Tel.: +91 9914080394.
E-mail address: shallir79@gmail.com (S. Rani).

http://dx.doi.org/10.1016/j.asoc.2015.06.034
1568-4946/

5. Fault-tolerant: WSN is expected to work even after the failure of large number of nodes, which is result of restricted battery capacity of sensors. So more attention is needed in case of WSN to make it fault tolerant as compared to traditional network.
6. Traffic patterns: MANETs have more conventional traffic patterns. In contrast to that, WSNs tend to have low data rates for long periods intervened by bursts of data flows and high data rates are frequents in case of some events.
7. Operating Software: WSN's have limited memory and processing capabilities so operating software must be simple but in MANET complexity software (heavy weight routing protocols) can be used.

There are many scientific challenges faced by sensor networks, like energy-efficient routing protocols, data aggregation techniques, self-organizing algorithms, and network lifetime improvements. So the routing algorithms which are responsible for the information transmission influences the performance of the network. Recently, research on routing algorithms is mostly focused on some routing metrics, such as the energy consumption, time consumption, reliability, network lifetime etc. Protocols for WSNs must be designed so that the limited battery power in the sensor nodes is proficiently used. Some parameters which can be changed during operation of WSN depending on the application are: Power availability, Reachability (nodes are in the range of base station or not), Type of task (cause for which sensor nodes are deployed). In this type of dynamic environment routing protocol should be fault tolerant.

Performance of energy aware protocols is affected by propagation environment and the fading due to multipath propagation of the signals as explained in [1]. Larger the distance traveled by the packet, greater is the effect of propagation environment combined with the effect of multipath fading on the performance of an energy aware algorithm. When a node, C sends data to a node, D with power P_T then the power at D node must be $P_R = P_T / dist(C, D)^j$. Where $dist(C, D)^j$ is the function to compute the Euclidian distance for n nodes coordinates i.e.:

$$dist(C, D) = \sqrt{\sum_{1}^{n} (C - D)^2} \quad (1)$$

and j is the path loss component and it holds the value in the real world from 2 to 6 according to the topology [1] of the space. As energy consumption is directly proportional to the distance between the communicating nodes, multi-hop forwarding is preferred over direct transmission when distance between the nodes is increased. In addition, power consumption depends upon the transceiver's architecture as some energy is consumed by active transmitter and receiver when a sensor sends or receives a message. Energy of sensor node as a normal node and as a cluster head (CH) is consumed in the steps mentioned in Figs. 1 and 2.

From these figures it can be concluded that more energy is consumed by node in the role of CH. Therefore number of cluster heads must be optimal. To balance the load on the nodes several techniques can be used as: the rotation of the role of the CH, election of CHs according to some optimized formula, to develop a routing path in which load over single CH is not increased and so on.

A most popular routing protocol, LEACH [2] was developed in 2000, used the adaptive cluster approach to maximize the energy efficiency. Protocols developed thereafter LEACH, which use the similar approach as used in it but with different communication algorithms show the improvement over it, are TEEN [3], APTEEN [4], PEGASIS [5], HEED [6], SEP [8], HCR [9], ERP [10], EECHA [11] etc. But reconsideration is still required to fulfill the most proficient requirements of WSN like energy, delay and reliability. By considering the problems faced by the WSN due to the limited power of the sensor nodes, we exploit the communication of sensor nodes with cluster heads and the base station, and proposed the chain based and cooperative routing among the sensor nodes, CHs and the base station (BS) for wireless sensor networks. Cooperative routing for source seeking can be all to all (Single hop communication) or

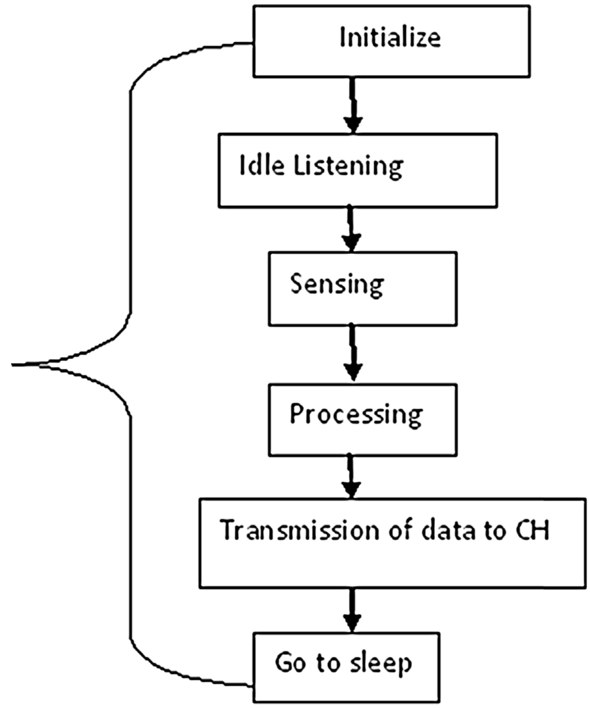

Fig. 1. Energy released by sensor node.

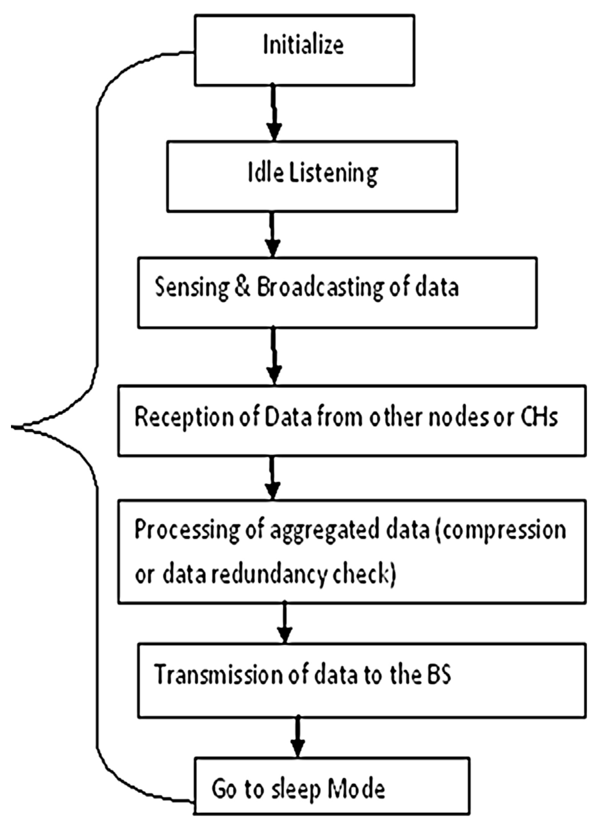

Fig. 2. Energy released by CH.

the limited communication (neighbor to neighbor) [29]. For this routing location awareness is required in nodes and location of the nodes can be accessed by any localization technique which is beneficial than using GPS capable antennas [30].

To improve the overall network properties, cost in terms of distance for the communication of sensor nodes, should be decreased.

Compared with the traditional algorithms, Chain Based Cluster Cooperative Protocol (CBCCP) can efficiently improve the quality of service (QoS) metrics of WSN. In this paper we are considering the network in which nodes monitors the data continuously.

Objectives of this paper are (1) to decrease the communication distance among the nodes to conserve energy (2) to maintain the connectivity of the nodes (3) manage the working of nodes by multi-level hierarchies (4) to recommend the new robust transmission algorithm (5) to balance the load on the cluster heads to avoid the exhaustion of the energy by overloading.

Rest of the paper is organized as follows. In Section 2, related work is contemplated, followed by discussion of problem definition and explanation in Section 3. Process of new protocol (CBCCP) is expressed in Section 4. Performance analysis and discussion is evaluated in Section 5 with conclusion in Section 6.

2. Related work

Routing method can be categorized into three types based on their fundamental network structures as hierarchical, location based and flat as described in [26]. These routing protocols can be query-based, coherent-based, negotiation-based etc. which depends upon the nature of the applications. A large number of prior studies on hierarchical cluster based approach have investigated the problems of minimizing the power utility, meeting the large throughput, increasing the network lifetime etc. It has been well demonstrated that hierarchical cluster based routing protocols are very effective in combating with the multiple fading effects in WSNs hence proved to be best approach by improving the network performance in terms of QoS metrics such as adaptively, energy-efficiency, reliability, outage probability and network throughput. In low energy adaptive clustering hierarchy (LEACH) [2] the approach of local coordination and randomized election of cluster heads has been used and showed eight times improvement in energy efficiency over minimum transmission energy routing protocol (MTE) and direct routing (DR). Data is transmitted directly to the sink by the CHs which consume a lot of energy of CHs. But multi-hop communication is more beneficial in terms of energy as used in HEED [6].

In LEACH–C [13] base station decides the number of clusters to evenly distribute the load over the clusters. It improved the lifetime of the network more than LEACH and MTE. Load balancing can help the nodes the uniform energy consumption which prolongs the network lifetime which is also considered in CBCCP.

A protocol for reactive networks i.e. a network where nodes inform immediately about any changes, was introduced in 2002 [3]. Data is transmitted only when change is noticeable in sensed attribute and gain over LEACH and MTE, was proved. In these protocols, processing of CHs increases as their residual energy is checked after every round and number of comparisons increase the use of energy and time.

Another protocol PEGASIS [5], in which idea of optimal chain between the CHs is proposed; revealed the better performance than LEACH by 100% to 300% in network lifetime. In 2004 HEED [6], CODA [7] and SEP [8] protocols were proposed. In HEED cluster formation is done on the basis of node's residual energy and intra-cluster communication cost. CODA differentiates the number of clusters based on distance from sink. More clusters are formed at the higher distance from the sink. HEED enhanced the network lifetime by approx. two times and CODA improved it by 30% than LEACH. SEP worked on the stability of the network and proved that it capitulates longer stability region than LEACH, with higher values of extra energy brought by more powerful nodes i.e. heterogeneity. In HEED two levels of clusters are formed to transmit the data but still distance cover by the CHs is large. By forming the multilevel structure and an optimized parent children topology, distributed weight-based energy efficient Hierarchical clustering protocol [14] improved the performance of WSN than HEED. Multilevel hierarchy is optimized in terms of time and energy and is adopted in novel protocol, presented here.

EECS [15] and EEUC [16] outperforms over LEACH. Later one also demonstrated better performance than HEED. By using more than one CH in cluster, HCR maximized the network lifetime than LEACH. But communication of the CH and sink is direct which does not give optimal results.

In contrast to the greedy algorithm adopted in PEGASIS, a protocol EB-PEGASIS [17] aimed at avoiding the long chain of CHs through average distance of the network and prolongs the life of the network than PEGASIS but at the cost of more delay. In 2007, PANEL [18], CCS [19] and LEA2C [24] etc. were proposed to further mark the optimization in QoS metrics of WSN. But they take more time to execute and not suitable for non delay tolerant applications.

Muruganathan et al, proposed a protocol in 2010, Base Station Controlled Dynamic Clustering Protocol (BCDCP) [21] which is a centralized clustering-based routing protocol. The main purpose of BCDCP is to form balanced clusters where each cluster comprised approximately equal number of neighboring nodes or cluster members. It shows the improved results than PEAGSIS. Centralized technique is difficult to implement in the large areas. It is suitable for the small areas only.

Liu et al., in 2011 proposed a GA-based adaptive clustering algorithm LEACH-GA [22]. Norouzi et al. in 2011 proposed a genetic algorithm based algorithm to develop the optimum clusters [23]. It used Direct Distance to Base Station (DDBS), Cluster-based Distance (CD), Cluster-based Distance-Standard Deviation (CDSD), Transfer Energy (E) and Number of Transmission (T) as the fitness parameters. This algorithm outperforms over the LEACH and M-LEACH clustering protocols in terms of network lifetime and consistency in performance. The discipline of meta-heuristics Evolutionary Algorithms (EAs) has been utilized by several researchers to tackle cluster-based routing problem in WSN. These biologically inspired routing mechanisms, e.g., genetic HCR [20], have proved beneficial in prolonging the WSN lifetime, but unluckily at the outflow of falling the stability period of WSN. It is possibly due to the conceptual modeling of the EA's clustering fitness function; a new fitness function that incorporates two clustering aspects, viz. cohesion and separation error. ERP outperforms LEACH and HCR in prolonging the stability period. But these algorithms are not suitable for the applications where long delay is not tolerable.

Study of hierarchical protocols inspired us to develop a novel routing protocol for WSN. We studied the LEACH based protocols as some of them are mentioned above and found that they use the optimization formula to decide the number of clusters and CHs. And it is repeated after completion of every round; this makes it different from the proposed methodology and provides us gain in terms of energy consumption in initial phase. Above protocols either follows the chain communication or the cooperative routing but novel protocol presented here exploit more benefits by using both types of communication at inter and intra cluster level. This strategy again proved to be optimal by achieving gain in total energy and time consumption over the traditional protocols. We have compared our work with LEACH the basic cluster protocol, SEP a LEACH based protocol, genetic HCR which is the optimization of HCR protocol based on LEACH and genetic ERP which is based on LEACH and genetic HCR. No protocol (Protocols which are LEACH based) till now has used the architecture as is proposed in this paper. From review given in [25], it is clearer that idea proposed in this paper is innovative.

3. Problem definition and explanation

3.1. Network model

It is considered that sensors are dispersed randomly in the field and we assume the following features about the sensor network:

1. The sensor nodes are stationary which is requirement of many sensor network applications.
2. Two nodes $b1$ and $b2$ can communicate using the same transmission power level that means links are symmetric.
3. The network serves stationary observers located at the border of the area, which implies that energy consumption will not be uniform for all nodes. Routing techniques are required to balance the energy consumption.
4. Each node has a fixed number of transmission power levels which is straightforward to set as in Berkeley Motes with *ioctl*() system call.
5. Nodes are location aware.
6. After deployment, nodes are left unattended. So, re-charge of battery is not possible. Thus for energy conservation, energy efficient sensor network protocols are required.
7. All nodes have equivalent importance and similar potential (communication/processing). The need for extending the lifetime of every sensor is inspired by this property.

3.2. The clustering dilemma

According to the above mentioned assumptions, suppose that n nodes are dispersed in a field. Our main objective is to recognize a set of cluster heads (CHs) which cover the entire field. Each node Ni where i must be $1 < i < n$ mapped to exactly one cluster Cj, where $1 < j < k$, and k is the number of clusters. A node must be able to communicate with cluster head by minimum energy utilization.

Cluster heads can use a routing technique multi-hop communication for energy efficiency. Some main requirements of clustering which should be met are:

1. Each node should make independent decisions based on the local information and sub clustering in clusters is completely distributed.
2. Each node is elected as a CH, a cluster coordinator (CCO) or normal node during clustering time (Tc) and each of them belongs to one cluster only.
3. Clustering should be optimized in terms of data switching and complexity.
4. Cluster heads and cluster coordinators use efficient path in data transmitting.

Let us assume that time taken in making the clusters is Tc and this time must not be increased by the operational time (To). The operational time is the time in which data transmission process starts and accomplished when the data is available at the BS. To make the things less complex for clustering protocols, clustering time must be less than the operational time ($Tc < To$). Clustering can be better performed in the initial period of To by using some idea of area dimensions and by self announcements nodes to be elected as the CH in the sub areas. One advantage of taking the nodes as non-mobile is that clustering is not affected by their position else nodes can deplete their energy more rapidly if they are mobile and can affect the clustering.

4. CBCCP protocol

4.1. Clustering attributes

The main objective of our approach is to conserve the energy in communication to prolong the network lifetime. To achieve it cluster head election, is made in each cluster and to make the protocol more reliable, re-election of cluster heads is accomplished when earlier cluster heads reached to the threshold level of energy level. Residual energy of nodes can be easily estimated by computing the energy used in sensing, processing and communication.

To meet the objectives, CBCCP starts its processing by dividing the area into ten subareas (clusters) with dimensions of 200 m by 20 m. From each dimension one node is assigned the role of CH randomly. The subarea in the region of 0–200 m × 0–20 m is the first level cluster which has one CH to transmit the data to next level cluster (0–200 m × 21–40 m) and received by the node which act as the cluster coordinator (CCO) for the first level cluster. It is forwarded to the next level CCO in the next cluster (0–200 m × 40–60 m). This process continues until the data is forwarded to the BS. Each cluster has one CH and varied number of CCOs. Number of CCOs depend the number of clusters beneath the cluster in which CCOs are located. It is the responsibility of cluster to have one CCO for each cluster for the data of cluster lying below to it. For example if there are seven clusters below to the one cluster then there will be seven CCOs in that cluster to handle the data of each cluster.

Transmission (Eqs. (2) and (3)) and reception (Eq. (4)) equations to calculate the energy consumption are same as used in the first order radio model [2] and can be observed from Eqs. (2)–(4). To transmit l bit message for a distance d, Eq. (2) is used to compute the energy consumed in long distance communication and Eq. (3) is used to compute the energy expenditure for short range communication (E_T). Eq. (4) is used to compute the energy in reception of data (E_R). E_e is the energy used per bit to run the transmitter or the receiver circuit whereas E_l and E_s depends upon the transmitter amplifier. Values of these parameters are given in Table 1.

$$E_T = l * E_e + l * \varepsilon_{\text{mp}} * d^4 \quad (2)$$

$$E_T = l * E_e + l * \varepsilon_{\text{fs}} * d^2 \quad (3)$$

$$E_R = l * E_e + l * E_{\text{bf}} \quad (4)$$

With inter-cluster communication distance of the cluster heads to the BS is decreased to optimize the energy usage. To conserve more energy, we also consider a secondary clustering attribute that is intra-cluster communication cost. Cost can be observed in terms of cluster density or neighbor proximity. Usually in routing protocols it is checked whether a node falls in the range of more than one cluster [6,13] with extra processing. Hence extra measurements are needed to make sure that a node belongs to one cluster only. But in proposed protocol, static clustering is done on the basis of dimensions of the sensor field. Therefore this problem does not occur here as it avoids extra processing of checking the membership of

Table 1
Values of the parameters used in simulation.

Area of simulation	200 × 200 m^2
Number of nodes	1055
ε_{fs} (energy used in short distant communication)	10 pJ/bit/m^2
ε_{mp} (energy used in long distant communication)	0.0013 pJ/bit/m^4
l (length of data)	4000 bit
E_e (Initial energy of the nodes)	0.5 J
E_T (Transmitting energy)	50 nJ/bit
E_R (Reception Energy)	50 nJ/bit
E_{bf} (Energy consumption in Beam Forming)	5 nJ/bit

the nodes for different clusters. With the help of factorization with fixed dimensions, clustering process turns out to be simple. For better understanding, first and second cluster dimensions with cluster heads are shown in Fig. 4. In second upper cluster CCO (i) is situated for first cluster to implement the chain based communication, where value of i determines the number of cluster coordinators which must be $0 < i \leq j - 1$ where j determines the cluster level in the hierarchy. For example, if Cj denotes the level of cluster where value of j is 2 then total number of CCO in the second cluster is 1. If it is the third cluster then there will be two CCOs and so on.

Two questions arise at this step are

1. Why CCOs are taken in varied numbers in each cluster?
2. Why there is no CCO in first cluster?

Let us assume, there are 100 nodes in each of the cluster and CH is responsible for the data aggregation and each cluster CH aggregates the data and sends it to upper CH of the next level cluster. In the second level cluster, load will consist of data from local nodes and data from lower level cluster which will make it more burdened that is load of 200 nodes will be there on second level cluster. In the last highest level cluster (Assume there are 10 levels of cluster) i.e. 10th cluster load of 1000 nodes will be there (including data from its own nodes and data from all low level clusters). Then the CHs in the last cluster will deplete their energy earlier than the other clusters and will create the hot spot problem which arises due to depletion of energy at large extant by the nodes acting as the relay nodes nearest to the base station and can make the network obsolete. To avoid this problem, and to balance the consumption of energy by the nodes, we have taken the varied number of CCOs. Strategy (defined above) is made so that each CH and CCO have only burden of nodes of one cluster only i.e. if there are 100 nodes in each cluster then each CH and CCO has load of 100 nodes only not more than that.

In this way load is balanced to maximize the energy efficiency. As first cluster is situated at the lowest level, so it does not have any clusters below to it for coordination of data. So no CCO is required in it. As the power level is same and fixed for all the nodes, then the communication cost is proportional to either (1) 1/*node degree*, if the need is to create dense clusters or (2) *node degree*, if the prerequisite is to distribute the load among the CHs.

In proposed method, load is distributed among the sub clusters (clusters assumed within cluster to minimize the distance of local nodes from their CH) and relay nodes (nodes which will pass the data of nodes to the CH of respective cluster for intra cluster communication i.e. cooperative communication). It means a node joins the sub cluster head (relay node) with minimum degree and distance to distribute the load. Each node plays the role of sub cluster head for the cooperative routing at internal level i.e. within cluster.

4.2. Process of protocol

Clustering is affected only when any CH or CCO depletes energy up to the threshold level. It is triggered with the re-election algorithm of cluster heads. New cluster heads are elected in each cluster. Clusters are assumed in specific dimensions and static. So clustering process completes in one iteration only, which is different from leach based protocols [2–24]. Let us assume the time taken in sending the message to the cluster head is Tc then total time taken for the nodes ($N1_i$) in the cluster Ci will be $\sum_{j=1}^{j=N1i} Tcj$. Number of cluster heads depends upon the number of clusters and is fixed. For Each cluster Ci there is one cluster head, CHi and cluster coordinators are in the range of $0 < Ncco \leq i - 1$. Probability of becoming a CH and CCO is same for each node as they are elected randomly.

During every iteration it is ensured that energy of cluster head (Ech) and cluster coordinator ($Ecco$) falls in the range of $0.1(j) < Ech \leq 0.5(j)$ or $0.1(j) < Ecco \leq 0.5(j)$ and if it is not then every node has the chance to become CH in the next iteration by calling re-election cluster head algorithm (Fig. 3). This is, how communication with the help of chain, is accomplished which is required in multi hop communication and for the implementation of homogenous load on nodes.

Chain method for inter-cluster communication improved the energy level of protocol. But to enhance it further the cooperative communication at local level was required. Protocol working starts by deploying nodes randomly and electing cluster heads and cluster coordinators by the method mentioned above in Section 5.1. All the nodes have same energy level so probability of election as the cluster head and CCO is same. After the completion of first phase, next phase starts with cooperative communication which is followed by chain methodology (Fig. 3, Transmission Algo and Min_Dist Algo).

All the nodes $n1$ in each cluster Ci find the minimum distance and joins the CH with minimum cost. Minimum cost here does mean that nodes will select the relay nodes to transmit their data to the CH by forming sub-clusters. Relay nodes are the neighbor nodes which help the other nodes in transmitting data to the CH. In the stationery network, where neighbor nodes do not have knowledge about their locations, the neighbor discovery will be done only when re-election CH (Fig. 3, re-election algo) algorithm is called. The pseudo-code for this process is given in Fig. 3.

With the help of uniform distribution of energy consumption, CBCCP has increased the lifetime of each node and hence it has provided the stability to the network. Nodes update their neighbor sets not only at inter-cluster level but also at the intra-cluster level. By controlling the communication at the cluster and sub-cluster level nodes can continuously send data to the BS.

Relay nodes in the sub-clusters (clusters with in clusters at local level) announce to the other nodes in respective clusters about their location. Nodes join those sub-clusters with min_dist algorithm (Fig. 3) and hence transmit data to their CH with the help of relay nodes.

4.3. Complexity and accuracy

Deployment of nodes is completely distributed in cooperative (intra cluster) and chain (inter-cluster) communication. A node can either become a cluster head or cluster coordinator in chain and can become relay node (RN) in cooperative communication or can act as the normal node by joining the cluster or sub-cluster and can transmit data with the help of CH, CCO and RN (Requirement 1).

To prove the correctness of the CBCCP protocol based on some requirements presented earlier in Fig. 3, we have devised some lemmas which are discussed below.

Lemma 1 (:). *CBCCP terminates in fixed iterations* $N\_itr = O(1)$

Proof: Probability of playing a role as a cluster head will be minimum in initial phase. If there are $n1$ nodes in each cluster then the CHprob is $1/n1$. As the number of dead nodes in each cluster increases the CHprob will also increase i.e. CHprob = $1/n1 - d$. Where $1 \leq d < n1$ and d is the number of dead nodes. Nodes with minimum energy than threshold which is assumed 0.1 J are restricted to act a CH. So nodes with minimum amount of residual energy will join the cluster. If no CHs are left with energy greater than 0.1 then nodes will directly send the data to the BS and CBCCP will terminate after the depletion of energy by all the nodes. Number of iterations are inversely proportional to the d i.e. $N\_itr \propto 1/n1 - d$ and hence $N\_itr \propto 1/d$. With the death of more number of nodes, number of iterations will become less.

Lemma 2 (:). *A node is either a cluster head or a regular node that belongs to a cluster.*

Proof: As CBCCP is completely distributed so as the probability of becoming a CH. Any node can be elected as the CH or CCO whose level of energy is greater than 0.1 J. Election of CH or CCO is done randomly. Other nodes which are not elected as the CH or CCO will join the cluster.

Lemma 3 (:). *Time complexity for n number of nodes and the number of message exchange is O(n).*

Proof: To start the working of protocol, election of CHs and CCOs is crucial step and it takes at most time n to process nodes. Number of iterations is fixed according to Lemma 1. So the total time can be computed in data communications by $N\_itr \times n$ (to transmit the data of n nodes in N_itr iterations). That is why the time complexity and the number of message exchange can be considered as the $O(n)$ for n nodes.

Lemma 4 (:). *Cluster heads are well distributed* i.e. *two nodes which are in each other's range cannot be the cluster heads.*

Proof: Two nodes $r1$ and $r2$ which are two isolated neighboring nodes will not be CHs if they will be in each other's range. In CBCCP, the area is divided into subareas which are assumed as clusters. These are assumed in rectangle shaped with Rl as length and Rb as breadth of the cell which are of size 200 m × 20 m Algorithm terminates after the election of predetermined CHs and CCOs in each of the cluster. The algorithm ensures that there is only one CH and only required number of CCOs in each cluster. In this way $r1$ and $r2$ nodes which are neighboring nodes they will be in contact with their CHs only. And if they are elected as CHs, then they will be in

```
CBCCP

1. Randomly deploy nodes with
   (N=rand()) random function
2. Initialize all nodes with same level of
   energy
3. Call Wsn_Creation Function
4. Call Wsn_sort(Norm_Node)
5. For each cluster k call min dist function
   for min distance to CH with-in cluster
6. Call to Transmission function
7. End

Wsn_creation

1. If area is 200 mt. by 200 mt. then
   election of CHs and CCOs is done in the
   following basis:
2. For all N.x<=200 and N.x>=0
   If N.y>=0 and N.y<=20 and N.energy>
   threshold level
   Elect one CH
   end

   If N.y>=20 and N.y<=40 and N.energy>
   threshold level
   Elect one CH and one CCO
   end

   If N.y>=40 and N.y<=60 and N.energy>
   threshold level
   Elect one CH and two CCOs
   end

   If N.y>=60 and N.y<=80 and
   N.energy> threshold level
   Elect one CH and three CCOs
   end

   If N.y>=80 and N.y<=100 and
   N.energy> threshold level
   Elect one CH and four CCOs
   End

   If N.y>=80 and N.y<=120 and
   N.energy> threshold level
   Elect one CH and three CCOs
   End

   And so on till the last cluster reached i.e.
   last subarea( x=0-200 mt. and y=180-
   200 mt.)

   If N.y>=180 and N.y<=200 and
   N.energy> threshold level
   Elect one CH and nine CCOs
   end

3. for all N
   if N.x and N.y is not equal to CH.x or
   CCO.x and CH.y or CCO.y
   Norm_Node.x=N.x
   Norm_Node.y=N.y
   End
4. Return to calling function

WSN_Sort
1. for i=1: 1:length(Norm_Node)
2. for j=1: 1:length(Norm_Node)
3. if(Norm_Node(j).y>
   Norm_Node(j+1).y)
   swap values
   End
   End
4. Return to calling function

Min_Dist

1. set temp_rnd=rand
2. set p with desired %age of relay
   nodes
3. G(n1)=1/(1-p(r mod1/p))
   (If n1 is member of some cluster k)
4. For all Norm_Nodes
      If temp_rnd<G(n1)
      Increment in the Relay_Node
      value
```

Fig. 3. Algorithm for inter and intra cluster communication.

```
        Compute its distance from CH
        End
5.  For all Norm_Nodes
        If dist of Relay_node from CH
        is less than dist of all other
        Relay_nodes and
        Norm_Node.Energy> Threshold
        level then
        Transmit data to that Relay
        Node
        Else
        Continue
        End

    End

6.  Return to calling function

    Transmission

    1.  Ch=true ; CCO=true
    2.  For k=1: 1:number of clusters
        If(Ch(k).energy<Threshold) Or
        (CCO(k).energy<Threshold)
        CCO=false Ch=false
        Call re-election function
        End
        Else
        While(CH or CCO not equal to
        false) and Ch_ID(k) and
        CCO_ID(K) not equal to Last
        Cluster ID
        If (Last_CH or Last_CCO)
        Transmit Data to base station
        Else
        Transmit Data to CCO of upper
        cluster
        End
        End
    3.  Continue with step 2 till all the
        nodes are dead
    4.  Return to calling function

    Re-Election

    1.  Call Wsn_creation
    2.  Call sort Wsn
    3.  Return to Calling function
```

Fig. 3. (*Continued*).

their fixed boundaries in different clusters as decided by algorithm wsn_creation (Fig. 3 or from the Block diagram in Appendix A).

4.4. Cooperative and chain communication

As the clusters are formed, they communicate with each other to aggregate and transmit the data via multi hop approach which is known as chain communication. Local nodes transmit their data with the help of relay nodes to CHs. This type of communication is known as cooperative communication. Both of these methods have enhanced the energy efficiency of CBCCP protocol. For inter-cluster communication in 200 m by 200 m area, the maximum transmission range between two cells must be $0 < Ac \le 40\sqrt{26}$. For intra cluster communication the required transmission range is $0 < Ac < 10\sqrt{101}$. Transmission range at intra and inter cluster communication can be set according to the area of the communication as done in HEED [6]. Any of the techniques used in [6] can be implemented in the layered architecture network. Following lemmas and theorem provide the necessary conditions for the multi hop connectivity in inter cluster overlay graph as adopted in CBCCP .

Lemma 5 (:). Let us assume that there are n nodes distributed randomly over area $A = [0,S]^2$. And it is assumed that area is divided into rectangle shaped cells known as clusters of size, $A_l \times A_b$. If $A_l \times A_b \times n = zA^2 \ln A$ for some $z > 0$ where no cell is empty and each cell has at least one node.

Proof: Proof of this lemma is same as used in [25].

Lemma 6 (:). Every cell has one CH in an area of $A_l \times A_b$.

Proof: CHs are responsible to aggregate data from all the nodes. So with the help of wsn_ creation algorithm (Fig. 3) CHs are elected in each cell. It is verified in Lemma 5, that each cell has at least one node and that node will act as CH itself, if there are no nodes in the cell to compete for the CH election. It is done with the help of re-election CH algorithm (Fig. 3). In another case when there is no CCO in the upper cell to coordinate with the lower CH node then it will send data directly to the BS by covering the distance of $^{1/2}\sqrt{A_l^2 + 4A_b^2} > 0$. (This is done to simplify the transmission process; otherwise lower CH node must search in every cell to find the CCO which complicates the process at the cost of time. Delay cannot be tolerated in real time applications. By keeping in mind this aspect complexity is avoided by transferring data directly to the BS instead of finding the CCO in other cells.)

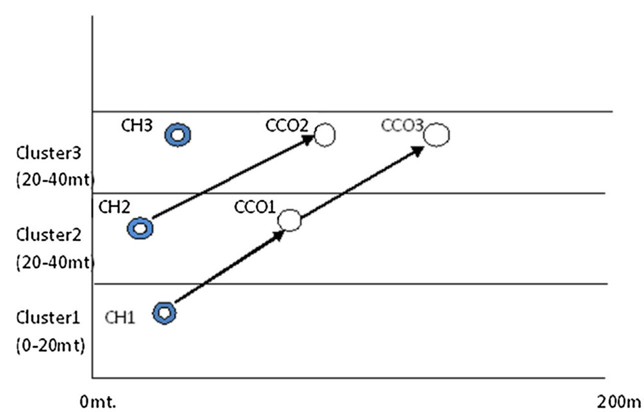

Fig. 4. Inter-cluster communication with the help of cluster coordinators.

Lemma 7 (:). Any two nodes (CH and CCO) which are in two neighboring areas each with range $\sqrt{A_l^2/4 + A_b^2/4}$ can communicate if transmission range is $Tr > \sqrt{A_l^2 + 4A_b^2}$.

Proof: In the cooperative communication (with in cluster) the required transmission range is $\sqrt{A_l^2/4 + A_b^2/4}$. And to prove the range for the chain communication, two neighboring areas $A1$ and $A2$ are shown in Fig. 5. $A1$ area has $r2$ node which needs to transmit data to the CCO i.e. $r1$ node of the upper cluster. It can be observed

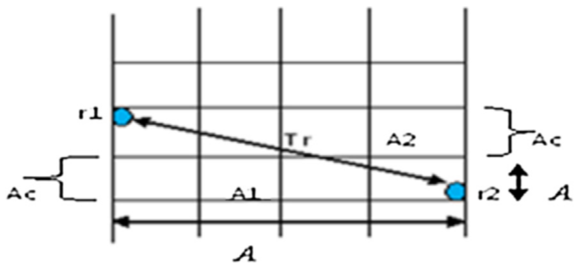

Fig. 5. Maximum distance of a node from a node in adjacent cluster.

from Fig. 5, that node $r2$ lies in the lower left corner of the area of cluster $A1$ and $r1$ lies in the top right corner of the area or cluster $A2$. Transmission range of $r2$ and $r1$ is Ac to communicate with-in cluster. It is known that distance (by using the Euclidian distance formula) between $r1$ and $r2$ is $\sqrt{A_l^2+4A_b^2}$ approximately i.e. the distance to communicate with the neighboring area for chain communication. So transmission range should be equal to or greater than defined range (Tr) for the proper communication.

Theorem 1 (:). *CBCCP produces entirely connected graph with chain (multi-hop) and cooperative communication (with-in cluster).*

Proof: Let us assume that all conditions discussed in previous seven lemmas are defined. To prove its connectivity, we assume two graphs in CBCCP, $G1=(V1,E1)$ and $G2=(V2,E2)$. If any CH in $V1$ wants to communicate with CCO of $V2$ then there must be a path between the two nodes. It is defined in the lemmas that there is always one CH in each of the cell or cluster and each cell will contain definite number of CCOs. Due to the predetermined number of CHs and CCOs in each cell according to the algorithm 1, routing path between two areas always exists. It defines the connectivity between the adjacent cells. So any node $r1 \in V1$ and $r2 \in V2$ can communicate with each other if they are elected as the CH or CCO of any cell. If a node with-in cluster of area $A_l \times A_b$ as shown in Fig. 5, wants to communicate with CH then maximum distance traveled by node can be $\sqrt{A_l^2 \times A_b^2}$ (If area is $200 \times 20\,\text{m}^2$ then max. dist is $20\sqrt{101}$ m) only when node lies on the lower left corner and CH lies on upper right corner. Energy consumption is directly proportional to the distance traveled by the node as discussed in Section 1. To reduce the distance between the CH and the local node, cooperative communication is implemented with the help of relay nodes. Then max. distance traveled by node is $\sqrt{A_l^2/4 \times A_b^2/4}$ ($10\sqrt{201}$ m in area of 200×20 m). Min_dist Algorithm (Fig. 3) is used to find the minimum distance of local node from their CH. This algorithm is called in the transmission phase. In this way, nodes within clusters are also connected to each other to transmit data to the CH.

In this way CBCCP produces entirely connected graph i.e. connection of nodes within the cluster and between the different clusters.

Theorem 2 (:). *Clustering and data aggregation are two best methods to conserve energy in the dense network.*

Proof: Let us assume that transmission starts from the lower left corner (in area of $L \times B$ as shown in Fig. 6) to the upper right corner of the area without any clustering i.e. direct transmission. Energy gain can be defined as the difference between the energy consumption by direct transmission and the energy consumption by clustering method i.e. $E_g = E_d - E_c$.

As it is defined in previous lemmas that nodes are distributed randomly and each cell has one CH. It can be shown that $E_g > 0$, if $n > 2\sqrt{2}(L \times B)/A_l A_b$.

As, $L \times B \gg A_l \times A_b$, the optimal path length from the node in the lowermost cell to the node in the uppermost cell is $\sqrt{L^2+B^2}$ (by Euclidian distance). In the clustered network the path deviates by the $2\sqrt{A_l^2+A_b^2}$ from the optimal path $2A_b$. So the suboptimal breadth path is,

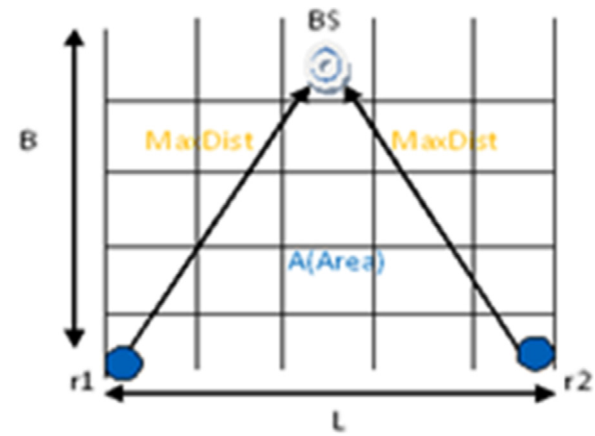

Fig. 6. Maximum distance of a node from base station.

$$S_{opt} = \left(\sqrt{A_l^2+4A_b^2} \times \sqrt{L^2+B^2}\right)/2A_b. \quad (5)$$

Average number of nodes in each cluster is

$$N_{avg} = (n \times A_l \times A_b)/2LB. \quad (6)$$

E_d is the energy consumed by all the nodes in the cell to transmit data along the path $\sqrt{L^2+B^2}$.

$$E_d = ((n \times A_l \times A_b)/2LB) \times \sqrt{L^2+B^2} \quad (7)$$

E_c is the energy consumed by all the nodes in the cluster to transmit data to the CH and energy consumed by the CHs and CCOs to transmit the data to the on the suboptimal path to the destination. Total number of CHs and CCOs is N_{tc}.

$$E_c = N_{tc}(((n \times A_l \times A_b)/2LB) - 1) \times A_b + 2B$$
$$E_c \cong ((N_{tc} \times n \times A_l \times A_b^2)/2LB) + 2B \quad (8)$$

By using Eq. (5) and Eq. (6):

$$E_g = E_d - E_c$$
$$= ((n \times A_l \times A_b)/2LB) \times \sqrt{L^2+B^2} - ((N_{tc} \times n \times A_l \times A_b^2)/2LB) - 2B > 0 \quad (9)$$

As $E_g > 0$
Therefore

$$= [((n \times A_l \times A_b)/2LB) \times \sqrt{L^2+B^2} - ((N_{tc} \times n \times A_l \times A_b^2)/2LB)] > 2B$$
$$= [(n \times A_l \times A_b)/2LB((\sqrt{L^2+B^2} - (N_{tc} \times A_b))] > 2B \quad (10)$$
$$= n > 2B(2LB/(A_l \times A_b(\sqrt{L^2+B^2} - A_b)$$
$$= n > 4LB^2/(A_l A_b(\sqrt{L^2+B^2} - A_b))$$

Since, $L > A_b$, therefore $\sqrt{L^2+B^2} > A_b$, and $n > (2\sqrt{2} \times LB)/A_l A_b$.

5. Performance analysis and discussion

We assume that 1055 nodes (we have assumed 10 clusters with approx. 100 nodes in each and with one CH in each cluster i.e. total 10 and with varying number of CCOs i.e. 1 in second cluster, 2 in third cluster. . .continuing in this way 9 in last cluster i.e. total 45 cluster Coordinators. (100 (nodes) × 10 (clusters) + 10(Cluster heads) + 45(cluster coordinators) = 1055 nodes) are randomly distributed into a field with dimensions 200 m × 200 m. Every node has same probability of becoming a cluster head. Each node has same level of energy that is 0.5 J. According to the law of wireless transmission, power attenuation is proportional to the square of the covered distance (assuming fixed transmission power) as mentioned in Section 1. For the smaller distances, power attenuation is linear but in case of obstacles like noise or physical objects, receiver power gets affected. We assume absence of these factors for simplicity. Results presented here are in the average of 80 experiments. Cluster based topology is used in each experiment. We compare CBCCP with traditional protocols like LEACH, SEP and with genetic protocols HCR and ERP. Each cluster has at least one CH to gather the data from the nodes which is similar to LEACH, SEP, genetic HCR and ERP. This comparison is good baseline for the following properties: (1) clustering is based on the local information and is distributed. (2) CHs are responsible for the data transmission to the BS. (3) Each node is linked to one CH only. (4) CHs are well distributed that is, no two CHs are close neighbors. (5) No assumptions are made for the distribution of the nodes in the field that is, they are completely distributed.

We compare the above mentioned protocols in terms of: (a) iterations require to elect CHs; (b) proportion of number of clusters with respect to the number of nodes; (c) time required in data transmission; (d) communication of nodes with CHs.

5.1. Clustering iterations

We compare the iterations required for election of CHs and to decide clustering process. It is found that LEACH, SEP, Genetic HCR and ERP require six iterations for this process. According to Lemma 1, CBCCP requires only an iteration to elect CHs and to make clusters. So complexity in clustering process is less than mentioned protocols.

5.2. Clustering attributes

Number of CHs is based on the optimum formula defined in [2] which is used in comparative protocols (genetic HCR, SEP, ERP). Approximately 20 CHs are elected for 100 nodes (200 clusters for 1000 nodes) and it has been found in these protocols that if the number of clusters are increased then less energy is wasted. But in contrast to these protocols, CBCCP fixes the dimensions of the clusters which are based on the dimensions of the subareas and each subarea will have one CH according to Lemma 6. A node will act as normal node or the CH as described by Lemma 2. No other processing is required to decide the number of CHs. It is proved with CBCCP if we increase the number of clusters, more energy will be wasted. In CBCCP for 1055 nodes, 10 clusters are made by dividing the area into subareas of 200 m × 20 m. Each cluster has approx. 100 nodes. Data is transmitted through the relay nodes to the CH. And data to the BS is passed through CCOs. Data is passed through multi hop approach in CBCCP but in LEACH, SEP, genetic HCR and ERP data is transmitted through single hop approach. CHs are elected on the basis of residual energy in above mentioned protocols. But in CBCCP, CHs are elected randomly in initial phase. In re-election phase CHs are elected as CH only if they were not acted as CHs in the previous iterations. Because of this idea load is balanced on the nodes and uniform energy consumption lead to the savings in energy and hence increase the network lifetime.

5.3. Cluster characteristics

Load balancing is required in wireless sensor network for energy savings. It can be implemented in two ways: (1) energy at every node is should be consumed at the same level. (2) Clusters should be made carefully and they must have some minimum number of nodes (according to Lemma 5 no cluster is empty). If any clusters have nodes less than predefined number of nodes then that cluster should join with some other cluster. Load on each node should be balanced. In comparative protocols, load balancing is not attained in contrast to the CBCCP which has achieved this fact by first method. Percentage of clusters with one node must be minimized, after 80 experiments this is observed that this situation does not arise in CBCCP in contrast to comparative protocols.

5.4. Delay tolerance

According to Lemma 3, CBCCP takes very less time in data transmission due to the reasons: (1) reduction in traveling distance within cluster and between different clusters, so data is transported in less time. (2) Clustering process is very simple and gets complete in one iteration only, unlike to comparative protocols which again affects the time by six times in initial phase and makes CBCCP suitable for the real time applications.

CBCCP takes 23.22% less time than LEACH, 29% less time than SEP, 251% less time than genetic HCR and 272% less time than ERP.

5.5. Non-uniform distribution of nodes

CBCCB elects the nodes as the cluster heads which have energy higher than threshold level. Node distribution does not impact the election of cluster heads and clustering attributes. This happens (1) due to the factorization of the area into subareas; (2) fixed number of cluster heads and cluster coordinators in each subarea. In other comparative protocols (LEACH, SEP, genetic HCR and ERP), cluster heads are elected with higher residual energy than other nodes which need comparison of energy with all the nodes. These protocols relay on the idea that network lifetime can be increased with more number of cluster heads. But this is not true for (1) number of comparisons will be increased among the nodes which will inversely affect attributes, energy and time. (2) Direct transmissions between sink and CHs will be increased due to large number of CHs which will inversely affect the energy of nodes. Non uniform distribution of the nodes can pile up the nodes at one region. Election of optimal number of CHs in these protocols will try to form the more number of CHs in that region. Some areas may be left without CHs and they will have to join the neighboring CHs (which can increase their transmission distance.) This problem does not arise in the CBCCP, as each subarea has one CH which is responsible for the aggregation of data from that particular region. Threshold level of energy is fixed (i.e. 0.1 J in case nodes have 0.5 J initial energy) so comparison of nodes is with only threshold level, when one node with higher energy than threshold is found, other comparisons are not made (which is the cause of energy and time savings in CBCCP).

5.6. Clustering applications

Our new approach can be used for routing protocols where energy efficiency and timely delivery of data is required, in which all the nodes (normal nodes, cluster heads and cluster coordinators) have same energy. This new design methodology can also be effective for long network lifetime of WSN, such as environmental and border monitoring applications. In this section, we consider one such application as was considered in LEACH, SEP, genetic HCR and ERP. These protocols were introduced for prolonging network lifetime. They assume, nodes are randomly distributed and continuously transmit data to the BS. We compare our protocol with LEACH, SEP, genetic HCR and ERP. In all these protocols, optimal number of CHs is elected and other nodes join the clusters in their proximity. In LEACH and SEP, CHs with more residual energy are elected for every simulation which increase the number of message exchange and hence processing. In genetic HCR and ERP, nodes with better

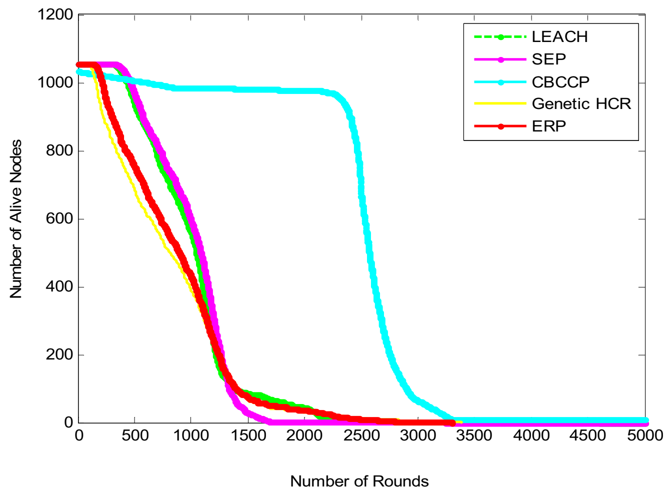

Fig. 7. Number of rounds versus number of Alive nodes.

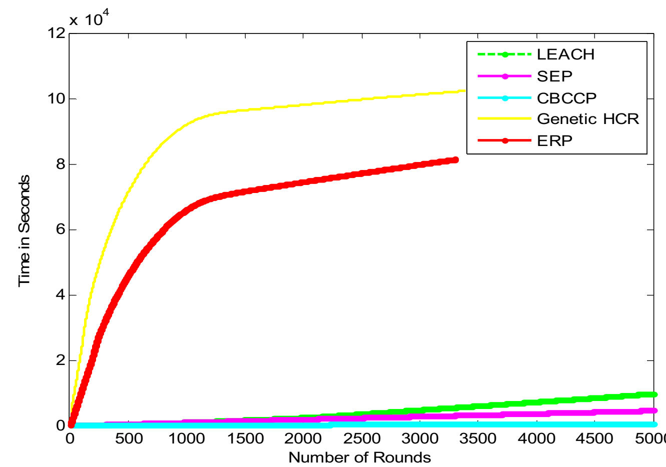

Fig. 9. Number of rounds versus transmission time.

breed are selected as CHs which results in energy efficient routing but takes a lot of time to execute.

All the four protocols proved to be energy efficient, and in their design methodology they assume sink in the center which is considered to be best, as clusters around the sink will have to follow the same distance. But in some applications, as in border surveillance, control room cannot be situated in the center. In that case, sink is situated on the corner. So in that situation, our design methodology proved to be optimal.

Comparison of all the protocols in terms of transmission time and network lifetime is made to show the effectiveness of the approach which can be observed from Figs. 7–9. In Fig. 7, it is observed that no node is alive in LEACH after 3200 rounds (transmission of data by all the nodes completes one round), in SEP after 4000 rounds, in genetic HCR after 3301 rounds, in ERP after 3390 rounds but 9 nodes are still alive in CBCCP even after 5000 rounds. In Fig. 8, dead nodes are shown over entire duration of 5000 rounds. In 500 rounds, 114 nodes are dead in LEACH, 89 nodes are dead in SEP, 302 nodes are dead in genetic HCR, 367 nodes are dead in ERP and only 49 nodes in CBCCP. LEACH, SEP. genetic HCR and ERP lost their 494,460, 626 and 662 nodes respectively in 1000 rounds but only 71 nodes are dead in CBCCP in 1000 rounds. Nodes are dying fast in all the four protocols as compared to CBCCP. Transmission time of CBBCP is 524 s, for transmitting data for 5000 times.

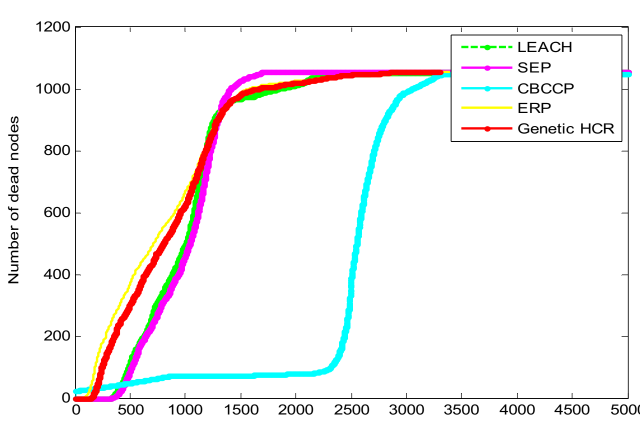

Fig. 8. Number of rounds versus number of dead nodes.

LEACH and SEP take 3500 and 1750 s, respectively. Genetic HCR and ERP take much time in transmitting data that is they take 8×10^4 s and 12×10^4 s as shown in Fig. 9. All these simulations are done in the area of 200 m^2 with sink on corner (x axis = 100 m and y axis = 200 m). As a consequence, CBCCP proved itself optimized over all the four protocols which is noticeable from comparative Table 2.

5.7. Performance evaluation

CBCCP is compared with LEACH, SEP, genetic HCR and ERP in MATLAB. In all these protocols cluster head election is based on the optimized formula based on the number of nodes. But in CBCCP the number of CHs and CCOs depend upon the number of clusters. Cluster coordinators are the nodes which help in forwarding the data of CHs. It is ensured by the transmission algorithm that each CH and each CCO has the load of one cluster only to balance the load. This feature is not considered in all the comparative protocols. The protocols discussed in this paper use only CHs or the CHs hierarchy to transmit the data by multi-hop or single hop communication but CBCCP uses CCOs with CHs to co-operate in data transmission. The design and architecture proposed in this paper is new in terms of data communication. Comparative protocols have considered only network lifetime but not the other parameters. But CBCCP, shows the improvement not only in network lifetime but also in time and scalability. Scalability is achieved by the same method as discussed in [28]. If the energy of any CH or CCO falls below the threshold level i.e. 0.1 J then re-election algorithm (Fig. 4) is called to elect the new CHs and CCOs. It makes it reliable. In comparative Table 2, all the five protocols are compared on the basis of latency, reliability, energy efficiency etc. Backup nodes take place the role of CH after their energy is depleted. But one time backup CHs does not ensure the long network lifetime. Genetic HCR and ERP ensure the reliability more than SEP because mutation process of these protocols elects the best breed of the nodes as the CH. But it wastes a lot of time in mutation process. CBCCP ensures the reliability by electing the new CH and CCO for the clusters whenever the energy levels of already elected CHs or CCOs fall below threshold level. So communication of the nodes starts only after few milliseconds. This makes it more reliable and stable than other protocols.

Although CBBCP has shown improvement over the other protocols but it can be improved on the higher level by taking into account sleep and wake schedule of the nodes as considered in [27].

Table 2
Relative comparison of protocols.

Protocols and year	Network type	Data transmission and chain based architecture	Latency	Energy efficiency	Reliability	Load balancing	Scalability	Cluster communication	Fault tolerant
LEACH (2000)	Homogeneous	Single Hop, No	23.22% > CBCCP	6 times less than CBCCP	Fair	NA	NA	NA	No
SEP (2004)	Heterogeneous	Single Hop, No	29% > CBCCP	5 times less than CBCCP	Good	NA	NA	NA	No
Genetic HCR (2007)	Heterogeneous	Single Hop, No	251% > CBCCP	Approx 4 times less than CBCCP	Good	NA	NA	NA	No
ERP (2012)	Heterogeneous	Single Hop, No	272% > CBCCP	3 times less than CBBCCP	Good	NA	NA	NA	No
CBCCP (2014)	Homogeneous	Multi Hop, Yes	More efficient	Very good	Very Good	Yes	Yes	Inter and intra cluster communication	Yes

6. Conclusion

A new protocol is presented in this paper that addresses some of the major requirements imposed by wireless sensor networks such as energy-efficient connectionless communication combined with speed, fault tolerant, load balancing and scalability. Balanced energy consumption is achieved by transmission of data to the intermediate nodes at all the levels (level means subareas or clusters). Another remarkable property is that, number of nodes can be increased without any additional cost, as all the nodes can still send data with the help of relay nodes (within cluster) and cluster coordinators (inter-cluster communication). Simulation results demonstrate that CBCCP not only prolongs network lifetime but also speed up data communication. The clusters it produces exhibit several appealing characteristics like they are load balanced, fault tolerant and scalable.

This protocol is developed for the applications where control room cannot be situated in the center like border surveillance applications; we are further working on the conditions where feasibility of control room is possible in the center.

Appendix A.

Fig. 10

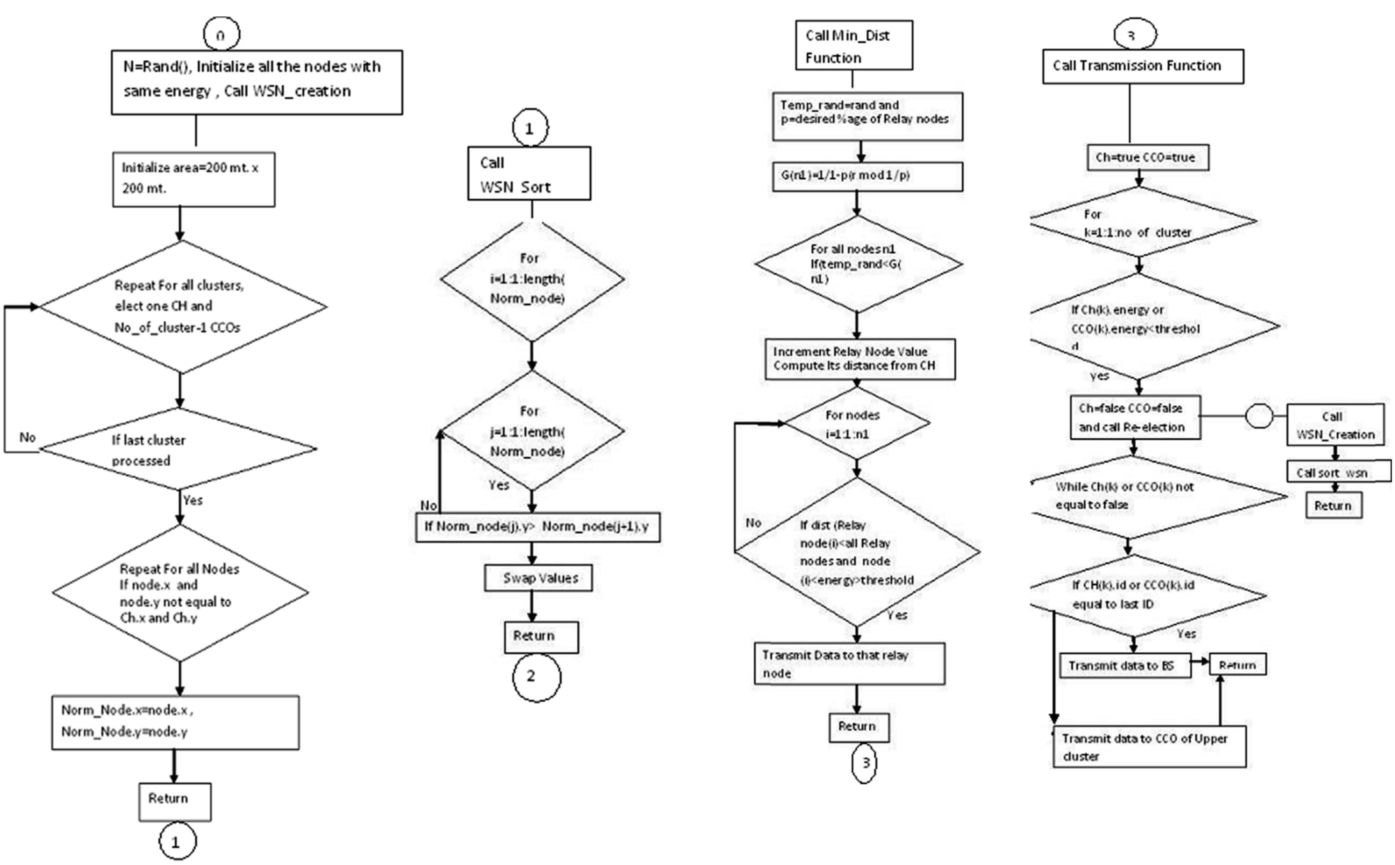

Fig. 10. Flow chart and block diagram of CBCCP.

References

[1] K. Ghosh, P.P. Bhattacharya, P. Das, Effect of multipath fading and propagation environment on performance of a fermat point based energy efficient geocast routing protocol, Int. J. Wirel. Mob. Netw. 4 (1) (2012) 215–224, http://dx.doi.org/10.5121/ijwmn.2012.4116

[2] W. Heinzelman, A. Chandrakasan, H. Balakrishnan, Energy-efficient communication protocol for wireless microsensor networks, in: Proceedings of the 33rd Hawaii International Conference on System Sciences, 4–7 January, 2000, http://dx.doi.org/10.1109/HICSS.2000.926982; E. Manjeshwar, D.P. Agrawal, TEEN: A routing protocol for enhanced efficiency in wireless sensor networks, in: Proceedings of the 15th International Parallel and Distributed Processing Symposium (IPDPS), San Francisco, CA, USA, 23–27 April, 2001, pp. 2009–2015, http://dx.doi.org/10.1109/IPDPS.2001.925197

[3] A. Manjeshwar, D.P. Agrawal, APTEEN: a hybrid protocol for efficient routing and comprehensive information retrieval in wireless, in: Proceedings of the 15th International Parallel and Distributed Processing Symposium (IPDPS), 15–19 April, 2011.

[4] S. Jung, Y. Han, T. Chung, The concentric clustering scheme for efficient energy consumption in the PEGASIS, in: Proceedings of the 9th International Conference on Advanced Communication Technology, Gangwon-Do, Korea, 12–14 February, 2007, pp. 260–265, http://dx.doi.org/10.1109/ICACT.2007.358351

[5] O. Younis, S. Fahmy, HEED: a hybrid, energy-efficient, distributed clustering approach for ad-hoc sensor networks, IEEE Trans. Mob. Comput. 3 (2004) 366–379, http://dx.doi.org/10.1109/TMC. 2004.41

[6] S. Lee, J. Yoo, T. Chung, Distance-based energy efficient clustering in wireless sensor networks, in: Proceedings of the 29th IEEE International Conference on Local Computer Networks, 2004, pp. 567–568, http://dx.doi.org/10.1109/LCN.2004.44

[7] G. Smaragdakis, I. Matta, A. Bestavros, SEP: a stable election protocol for clustered heterogeneous wireless sensor networks, in: 2nd International Workshop on Sensor and Actor Network Protocols and Applications (SANPA), 2004.

[8] S. Hussain, A.W. Matin, Energy efficient hierarchical cluster-based routing for wireless sensor networks, in: Technical Report Technical Report – TR-2005-011, Jodrey School of Computer Science Acadia University Wolfville, Nova Scotia, 2005, pp. 1–33.

[9] B.A. Attea, E.A. Khalil, A new evolutionary based routing protocol for clustered heterogeneous wireless sensor networks, Appl. Soft Comput. J. 12 (July (7)) (2012) 1950–1957.

[10] G. Xin, W.H. Yang, B. De Gang, EECHA – an energy efficient hierarchical clustering algorithm for wireless sensor networks, Inform. Technol. J. 7 (2) (2008) 245–252, http://dx.doi.org/10.3923/itj.2008.245.252

[11] J. Zheng, A. Jamalipour, Wireless Sensor Networks: A Networking Perspective, John Wiley & Sons, Hoboken, 2009.

[12] W.R. Heinzelman, A. Chandrakasan, H. Balakrishnan, An application-specific protocol architecture for wireless microsensor networks, IEEE Trans. Wirel. Commun. (2002) 660–670, http://dx.doi.org/10.1109/TWC.2002.804190

[13] P. Ding, J. Holliday, A. Celik, Distributed energy efficient hierarchical clustering for wireless sensor networks, in: Proceedings of the 8th IEEE International Conference on Distributed Computing in Sensor Systems (DCOSS), Marina Del Rey, CA, USA, 8–10 June, 2005, pp. 322–339, http://dx.doi.org/10.1007/11502593_25

[14] M. Ye, C. Li, EECS: an energy efficient clustering scheme in wireless sensor networks, in: Proceedings of the 24th IEEE International Performance, Computing and Communications Conference (IPCCC), Phoenix, AZ, USA, 7–9 April, 2005, pp. 535–540, http://dx.doi.org/10.1109/PCCC.2005.1460630

[15] C.F. Li, M. Ye, G.H. Chen, J. Wu, An energy-efficient unequal clustering mechanism for wireless sensor networks, in: Proceedings of the 2nd IEEE International Conference on Mobile Ad-hoc and Sensor Systems Conference (MASS), Washington, DC, 7–10 November, 2005, pp. 596–604, http://dx.doi.org/10.1109/MAHSS.2005.1542849

[16] Yueyang Liu, Hong Ji, Guangxin Yue, An Energy-Efficient PEGASIS-Based Enhanced Algorithm in Wireless Sensor Networks, China Communications, August 2006, pp. 91–97.

[17] L. Buttyan, P. Schaffer, PANEL: position-based aggregator node election in wireless sensor networks, Int. J. Distrib. Sens. Netw. 2010 (2010) 1–16, http://dx.doi.org/10.1155/2010/679205

[18] S. Jung, Y. Han, T. Chung, The concentric clustering scheme for efficient energy consumption in the PEGASIS, in: Proceedings of the 9th International Conference on Advanced Communication Technology, Gangwon-Do, Korea, 12–14 February, 2007, pp. 260–265, http://dx.doi.org/10.1109/ICACT.2007.358351

[19] S. Hussain, A.W. Matin, O. Islam, Genetic algorithm for hierarchical wireless sensor networks, J. Netw. 2 (September (5)) (2007) 87–97, http://dx.doi.org/10.4304/jnw.2.5.87-97

[20] S.D. Murugunathan, D.C.F. Ma, R.I. Bhasin, A.O. Fapajuwo, A centralized energy-efficient routing protocol for wireless sensor networks, IEEE Radio Commun. 43 (2005) S8–S13, http://dx.doi.org/10.1109/MCOM. 2005.1404592

[21] J. Liu, C.V. Ravishankar, LEACH-GA: genetic algorithm-based energy-efficient adaptive clustering protocol for wireless sensor networks, Int. J. Mach. Learn. Comput. 1 (April (1)) (2011), doi:10.7763/IJMLC.

[22] A. Norouzi, F.S. Babmir, A.H. Zaim, A new clustering protocol for wireless sensor networks using genetic algorithm approach, J. Wirel. Sens. Netw. (2012), http://dx.doi.org/10.4236/wsn.2011.311042

[23] Y. Bennani, L. Dehni, Power control and clustering in wireless sensor networks, in: Proceedings of the ICACT, 2012, http://dx.doi.org/10.1007/0-387-31173-4_4

[24] D.M. Blough, P. Santi, Investigating upper bounds on network lifetime extension for cell-based energy conservation techniques in stationary ad hoc networks, in: Proceedings of the ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM), 2002, http://dx.doi.org/10.1145/570645.570668

[25] S. Tyagi, N. Kumar, A systematic review on clustering and routing techniques based upon LEACH protocol for wireless sensor networks, J. Netw. Comput. Appl. 36 (2) (2012) 623–645, http://dx.doi.org/10.1016/j.jnca.2012.12.001

[26] K. Holger, A. Willig, Protocols and Architectures for Wireless Sensor Networks, John Wiley & Sons, 2007.

[27] Y. Kang, B. Hu, Y. Ding, J. Tan, A hybrid node scheduling approach based on energy efficient chain routing for WSN, Adv. Mech. Eng. 2014 (2014), Article ID 254761.

[28] S. Rani, J. Malhotra, R. Talwar, Energy efficient protocol for densely deployed homogeneous network, in: Issues and Challenges in Intelligent Computing Techniques (ICICT), International Conference on. IEEE, February 2014, pp. 292–298.

[29] Shuai Li, Guo Yi, Distributed source seeking by cooperative robots: all-to-all and limited communications, in: 2012 IEEE International Conference on Robotics and Automation (ICRA), IEEE, 2012.

[30] R. Marcelín-Jiménez, E. Rodriguez-Colina, M. Pascoe-Chalke, C. Moreno-Escobar, J.L. Marzo, Cluster-based localisation method for dense WSN: a distributed balance between accuracy and complexity fixed by cluster size, Int. J. Distrib. Sens. Netw. (2014) 2014.

Shalli Rani is an Assistant Professor with the S.S.D Women's Institute of Technology, Bathinda (Punjab). She received the MCA degree from Maharishi Dyanand University, Rohtak in 2004.and the M. Tech. degree in Computer Science from Janardan Rai Nagar Vidyapeeth University, Udaipur in 2007 and is currently pursuing the Ph.D. degree in Computer applications from Punjab Technical University, Jalandhar. Her main area of interest and research is wireless sensor networks. She received a young scientist award in February 2014 from Punjab Science Congress, in the same field.