Clustering based Multihop Cooperative Protocol for Wireless Sensor Network

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Abstract- **Now a days energy efficiency of sensor nodes is one of the most critical as well as important issues for sensor networks due to their restricted energy resources. In some applications, it is difficult to replace or recharge their batteries once they are fixed in particular location. Therefore, in order to reduce the energy consumption of sensor nodes, sensor networks must work energy efficiently and use some scalable clustering technique as a method for organizing the Sensor networks. In the Routing process, communication costs play a great role. For this purpose the effective routing technique must be used. In some scenarios, it becomes more energy efficient to transmit a message via multihop communications over short distances instead of a single hop long distance transmission to sink. In this paper, a protocol for clustered based energy efficient multihop cooperative communications for WSNs is presented and analyzed. In the presented approach, Sensor nodes form cooperative groups or clusters. Within each cluster, Sensor nodes communicate with each other over multihop links and the Sensor nodes at the last hop communicates with the Sink. Thus, cooperation between Sensor nodes is exploited for the benefit of energy efficiency.**

Keywords- Wireless Sensor Network (WSN), Sensor nodes (SNs), Cooperative communication, Cluster Head (CH), Sending Cluster Head (SCH), Receiving Cluster Head (RCH)

I. INTRODUCTION

Wireless Sensor networks consisting of nodes with limited battery power and while considering Sensor networks applications many times for wireless communications Sensor nodes are deployed to collect useful information from the particular field. Gathering sensed information in an energy efficient manner is critical to operate the Sensor network for a longer time. Wireless communications consume significant amounts of battery power so Sensor nodes should spend as little energy as possible receiving and transmitting data. Recent surveys are focusing on energy efficiency because energy efficiency is a dominant consideration no matter what the problem is. This is because sensor nodes only have a small and finite source of energy.

Cooperative networking has great importance as an emerging network design strategy for wireless Sensor networks. The cooperative communication in WSN provides the inherent advantages of minimizing the overall transmission energy consumption. In this approach number of cluster heads is along path from source to sink is formed. Clustering is performed based on link cost criteria and calculation and comparison of residual energy approach is adopted for the selection of cluster heads along the path. In the path setup, the connection is initiated to discover all the intermediate nodes between the source and the sink and their cost of remaining energy levels are considered in building up the routing tables. The high-energy nodes are added in the path and they are forwarding table to next chosen neighbor node on the path. A cluster head selection is done based on more residual energy since the cluster-head is in charge of transmitting sensing data from its own local cluster, as well as collecting and encoding data before sending them to a next node. Since cluster heads needs to perform the additional tasks as compare to other sensor nodes thus they consume more energy than other nodes in the cluster. This protocol provides energy sufficient path from source to Sink. Within each cooperating cluster, the data is delivered from the source to the intermediate nodes in the clusters and then to the Sink using multihop communications.

In the cooperation process, recruitment policy helps the nodes to co-operate each other in the network. Cluster head along the path recruit neighboring nodes to assist in communication. Here a cooperative transmission link between the nodes in wireless networks is formed between a transmitter cluster and a receiver cluster also optimal number of minimum link cost nodes is added as cluster members. A clustered cooperative protocol establishes these clusters for cooperative transmission of data. In this clustered cooperative protocol various factors such as capacity, end-to-end delivery of the protocol, energy consumption of node as well as overall energy consumption and error rate are analysed, the analysis results are used to show the energy savings and the end-to-end robustness of protocol. In this protocol sender node uses average of total transmission power which reduces the power and energy consumption. The reduction in energy consumption results in increased lifetime of cooperative sensor networks. Channel state information (CSI) is exploited here in order to build the energy efficient routes from SNs to the sink.

The paper is organized as follows. Related work is presented and different proposed approach related to clustering and multihop communications are outlined in Section 2. The proposed system model is presented in Section 3. The methodology is discussed in Section 4. Performance analysis is shown in Section 5. Future work is explained in Section 6. Simulation results for the multihop and clustering scenarios are shown in Section 7. Finally, conclusions are drawn in Section 8.

II. RELATED WORK

In the paper [10] Multihop communications are studied, and remarkable energy savings are achieved even with the 2-hop scenario, corresponding to a clustering framework where a single SN, the cluster head (CH), is in charge of directly receiving the measurement data from each SN in the cluster on the SR. Higher rates can be achieved over Short Range (SR) communications between Sensor nodes (SNs) that are relatively close from each other in a single cooperating cluster. This leads to shorter transmission and reception times and hence less energy consumption from the batteries of the SNs. [11] Geographic and Energy Aware Routing (GEAR) technique uses energy aware and geographically informed neighbor selection heuristics to route a packet towards the target region. Each control packet has a *target region* specified in some Way. Each node knows its own location and remaining energy level, through a simple neighbor hello protocol. Link is bi-directional, i.e., if a node hears from a neighbor Ni, then its transmission range can reach Ni. An energy efficient routing technique in multihop wireless sensor networks is presented in [12]. For each node, the energies consumed during reception, transmission, and sensing are considered in the analysis. In the model of [12], frame nodes relay the content of the source to the destination. If the communication fails between the source and a frame node, or between two frame nodes, assistant nodes come into play and relay the data to the next frame node. Hence the use of opportunistic transmissions depending on the fading conditions of the channel. The optimal number of nodes that should be included in a path is determined. The purpose is to reduce the energy consumption by reducing the number of nodes relaying the data from source to destination. In the paper [13] energy efficiency is studied in wireless sensor networks. Sensors having data to transmit should relay this data to a single source using multihop. Nodes that do not have data to transmit or that are not relaying the data of other nodes can be put to sleep. Energy efficiency is achieved by reducing the number of active-nodes. In the paper [14] optimization on the number of cluster heads between sources to sink is done. In the LEACH protocol [16], the election of cluster head node in LEACH has some deficiencies such as, Ignores residual energy, geographic location and other information, due to which lead to cluster head node can be fail early.

III. CLUSTERED COOPERATIVE PROTOCOL

In the Cooperative transmission a sensor network, multiple nodes simultaneously receive, decode, and retransmit data packets. A clustered cooperative model is having multiple nodes on both ends of a hop and with each data packet being transmitted only once per hop. Cooperation takes place with the task of recruiting other nodes and coordinating their transmissions. The route from a source node to a sink node is replaced with a multihop cooperative path and the point-to-point communication is replaced with many-to-many cooperative communication. Thus the Cooperative transmission provides the benefits of achieving energy savings. One of the goals of efficient cooperative protocol is to achieve the energy savings through cooperation, to increase the reliability of packet delivery also to increase capacity of protocol [1].

In this model there are multiple nodes on both ends of a hop and each data packet is being transmitted only once per hop. Every node on the path from the source node to the destination node becomes a *cluster head*, which performs the task of recruiting other nodes in its neighborhood and coordinating their transmissions. Hence replacing the classical route from a source node to a sink node with a multi-hop cooperative path and also replacing classical point-to-point communication with many-to-many cooperative communication. Figure 1(a) shows Network scenario of Clustered cooperative multihop communication model while in figure 1(b) single hop scenario is shown.

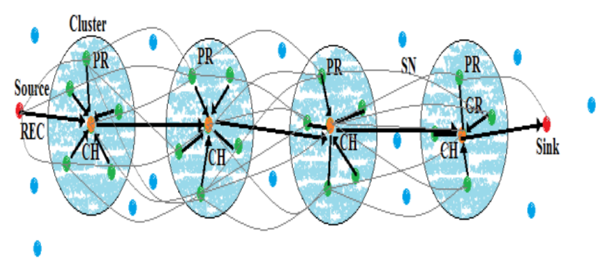


Fig 1(a) Network scenario of Clustered Cooperative multihop model

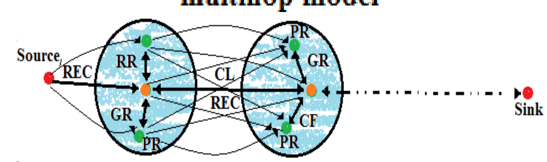


Fig 1(b) One hop scenario

It has been found that use of multipath routing is to increase the probability of reliable data delivery. In these approaches multiple copies of the data are sent along different paths allowing for resilience to failure of a certain number of paths. These are biggest Advantages of multi to multi transmission [7].

This clustered cooperative protocol basically consist of three phases: *Routing phase*, *cluster forming phase* and *Transmitting phase*

1. Routing phase

This phase is responsible for finds a route from the source node to the sink node. Initially path between the source and the sink nodes is discovered first. Next in the *Clustering phase and transmitting phase* the path becomes multi path. During the routing phase, information about the residual energy of a node and energy required for transmission to neighboring nodes is computed. This information is then used for cluster establishment. In this phase, the nodes on the initial path become cluster heads, which recruit additional adjacent nodes from their neighborhood. The inter-clusters distances are significantly larger than the distances between nodes in the same cluster because the cluster heads recruit nodes from their immediate neighborhood. *Recruiting* is done dynamically and per packet as the packet traverses the path. When a packet is received by a cluster head of the receiving cluster, the cluster head initiates the cluster forming by the next node on the routing path. Once this recruiting is completed and the receiving cluster is established, the packet is *transmitted* from the sending cluster to the newly established receiving cluster. Routing phase consist of 2 sub phases: *Path finding phase* and *Cluster Head selection phase.*

a. Path finding phase

Some modifications to routing phase [8] [9] is done in the Path construction phase that it is finding sufficient energy path rather than finding minimum energy cost paths. This phase is composed of two messages namely route request message (RREQ) and route reply message (RREP). For path construction in Path finding phase route request message is transmitted in the network to execute the neighbor discovery process during the network start-up source performs this and establish a route to the destination and route reply message is initiated when the given sink node is reached and to create a new entry in the local neighbor table.

Initially the source node starts the path construction phase to create a set of neighbors that is the address of all nodes that are able to transmit data from the sink. During this process route request messages are exchanged between the nodes. Each sensor node broadcast the route request packet once and maintains its own routing table. When sensor node disseminates a data packet, it only needs to know its neighboring node to transfer, don't need to maintain the whole path information. Since the paths are formed whenever it is required unlike proactive routing protocols where it is necessary to store the routing information, it reduces the overhead of sensor node. Although the multipath routing protocol has to compute some information to record in the routing table of sensor node, the energy expense is less than transmit and receive. Furthermore, it supports multipath data forwarding, not using the fixed path. So the energy consumption will be distributed and the lifetime of network is prolonged.

The format of RREQ message is shown in Figure 2.The ***Source ID*** contains the node ID which broadcasts the route request packet. ***SeqNumber*** field is a packet sequence. The ***HopCount*** field is the numbers of hops from the source node, nodes that can receive the radio signal of source are defined as one-hop nodes,

Energy threshold field provides the minimum required energy level for a node to be selected for data transmission, ***Signal Strength threshold*** to indicate the minimum distance the node has to be located in order to receive all the data's transmitted to that node and ***Sink ID*** indicates the ID of the sink of the message destination;

Source ID	Sequence number	Hop Count	Threshold Energy	Signal Strength Threshold	Sink ID

Fig. 2 Frame format of RREQ message

Fig 2: Route Request Message frame format

Figure 3 shows flowchart of Path finding phase.

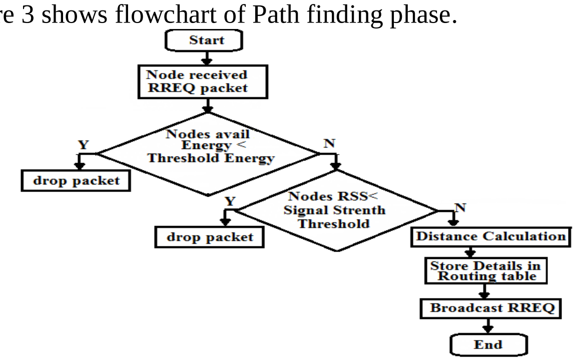


Fig 3: Flowchart of Path finding phase

The major activities in this phase are routing path formation for each node and neighbor table creation. Initially the Source node broadcasts the route request packet to discover the one hop nodes, the nodes which are receiving them first. After a route request message is sent by source node, the hop count records how many hops it has travelled from the source. The hop count field is increased by one each time when a node receives the route request message.

The broadcasting of the route request message is received by all the nodes within the radio range of "TR". The nodes after reception of the RREQ message increments the hop count field to "1", the node processes the message further i.e., it starts to check the residual energy and the received signal strength e.g. When the source initially broadcast the message, the nodes 1, 2, 3 and 4 receive the route request message. Assume that the available energy at1 and4 are larger than at 2 and 3 , and also 1 and 4 are within the required signal strength threshold, hence nodes 1 and 4 are selected and again comparison between residual energy of node 1 and node 4 is done. The node with more residual energy is selected as next node on the routing path and is recruited as Cluster Head to broadcasts the route request message to their neighboring nodes. Again some next nodes within the radio range of selected cluster head will receive the route request packet from it. This process continues till destination node (sink) comes into picture. The sink, when it receives a route request message it compares the *Sink ID* field from the request message matches its own ID, it reply's back with the route reply message. The route reply message passes through the paths through which the node received the route request and creates an entry in the neighbor table of each node. After establishing the path between the network nodes, the path is stored in a routing table. This routing table is formed with the nodes which are having required energy level and required received signal strength threshold. The routing table is used to store information about the path from source to sink that can be used to direct the recruit packet (REC) and verify the validity of each table record. The next hop address field in the routing table shown consists of address of all the nodes which can be used to route packets to the sink.

After one hop path is discovered and next hop cluster can be established, then the cluster establishment process starts and once the cluster establishment completes for one hop the source node(initially)/ previous cluster(in the further steps) begins to transmit data packets with the assigned rates on path to the selected nodes in the next cluster. At the sink, it updates the path in its routing table each time a data message is received.

b. Cluster Head Selection phase

In the this phase, the cluster head is selected according to node's residual energy .It uses the primary parameter, i.e. residual energy, to select an initial set of cluster heads $1 \leq i \leq M$, to communicate with previous cluster head, and M is the number of nodes within the communication range i.e. nodes which receives and process RREQ.

Cluster Head Selection is done on basis [5] that the greater the energy in the node and farther the node from the previous one, is the more likely to be selected as the next hop CH.

2. Clustering phase

In this phase, the receiving cluster is formed by the cluster head recruiting neighbor nodes through exchange of short control packets such as RR, REC, GR, CL CF. Then, the sending cluster head synchronizes its nodes, at which time the nodes transmit the data packet to the nodes of the receiving cluster. Medium access control is done in the *"clustering phase* and *transmitting* phase through exchanges of short control packets between the nodes on the path and their neighbor nodes.

State	Description	
CH	The node is selected as cluster head	
PR	The node is asked for recruitment by CH	
SR	The node is recruited as cluster member by CH	
Messsage	**Description**	**tuple**
REC	Recruitment	Sender(id), Receiver(id), Sink(id), t(channel avail), t(trans)
RR	Request to Recruit	Sender(id), Receiver(id), Next node(id), MTR
GR	Grant	REC originator(id), LC
CL	Clear	SR(id), tnew(channel avail), tnew(trans)
CF	Confirm	SR(id), WTS, Pt

Table 1. Different states of node and Control packets structure

Table 1 shows different states of node with control packets structure. Figure 4 shows the behaviour of Cluster Head and Figure 5 shows the behaviour of potential recruit.

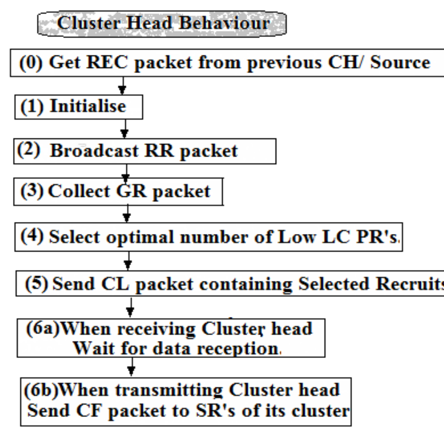


Fig. 4 Behaviour of Cluster Head

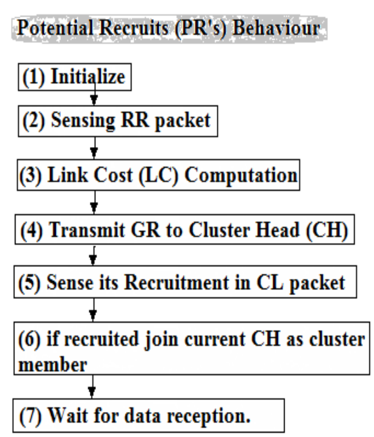


Fig. 4 Behaviour of PRs

In the current hop, the sending cluster head has a packet to be sent to next selected node on the path. *SCH* sends a request-to-recruit (RR) packet to that selected node, which after receiving RR packet will act as a cluster head i.e. RCH and starts forming receiving cluster as: it broadcasts a recruit (REC) packet to its neighbors. Each node receiving REC packet, is called as *potential recruits* (PRs). PRs will compute the sum of the link costs of two links: a link from the sending cluster head to itself (the *receiving link*) and a link from itself to the next node, such as the receiving cluster head or the sink node (the *sending link*) and will reply that cost to CH with a grant (GR) packet. *CH* waits for time *T* and collects some defined number of grants; the cluster head selects *m-1* cooperating nodes with the smallest reported cost to form the receiving cluster of *m* nodes. Here *m* is protocol-selectable parameter and we called selected m cooperating nodes as *Selected Recruits* (SRs). *CH* then sends a clear (CL) packet to the previous *CH* of current hop which sends confirm (CF) packet to the selected cooperative nodes (SRs) in its sending cluster to synchronize their transmission of the data packet.

3. *Transmitting phase*

Every node in the receiving cluster receives from every node in the sending cluster. Sending nodes are synchronized, and the power level of the sending signal at a sending node is the Average of sum of all the signal powers coming from all the sender nodes. Here it is assumed that some mechanism for error detection is incorporated into the packet format, so a node that does not receive a packet correctly will not transmit on the next hop in the path. And thus it reduces the likelihood of a packet being received in error. Now from the routing phase current *RCH* comes to know about next-hop node on the path. Route maintenance is possible through the techniques such as Localized flooding is performed from the destination to the source now and then to keep the paths alive.

Clustering and *transmitting* is done dynamically per hop, starting from the source node and progressing, hop by hop, as the packet moves along the path to the sink node. Once a data packet is received at a receiving cluster of the previous hop along the path, the receiving cluster now becomes the sending cluster, and the new receiving cluster will start forming. The next node on the path becomes the cluster head of the receiving cluster.

IV. METHODOLOGY

Clustered Cooperative Protocol:

1. Calculation of failure probability

Failure probability, that the packet does not reach the sink due to reception error(s) along the path, it can be calculated based on BER and SNR [1].

$$B_{CwR}^{h} = \sum_{k=1}^{h} A_{v(0)k}$$

Where B_{CwR}^{h}: the probability of failure of a packet to reach any node by the k^{th} hop and vector v (i) be the binary representation of integer *i*.

2. Calculation of the Links Cost

The Link Cost from node *i* to node *j*, $C_{i,j}$ calculated by node *i* as:

$$C_{i,j} = \frac{(e_{i,j})}{R_i / R_{avg}}$$

Where, $e_{i,j}$: energy cost of the link.

R_i: residual battery energy of node *i*.

R_{AVG}: average residual battery energy of the neighbors of node. Energy cost of a link is the transmission power required for reception at a particular bit error rate. Nodes determine the energy costs of links by overhearing transmissions during the routing phase. The protocol-selectable parameter which controls the weight of each factor in the total cost is kept 1. Thus from above equation, nodes with small residual battery capacity are less likely to be recruited here.

3. *Calculation of Node energy consumption $e_{(i)}$*

The *node energy consumption* measures the energy dissipated by the node in order to transmit a control or data packet on single hop. To determine the energy efficiency level of WSNs. It is calculated as follows:

$$e_i = (e_{i(INITIAL)} - e_{i(RESIDUAL)})/(data)_h$$

Where $(data)_h$ is number of data bits transmitted in one hop, and $e_{i(INITIAL)}$ and $e_{i(RESIDUAL)}$ are respectively the initial and residual energy levels of node *i*,

4. *Calculation of e(i , j)*

A node *j* that is within the transmission range from node *i* is assumed to be connected to node *i* by a link (*i*, *j*). Energy consumption to transmit packet from node *i* to node *j* can be expressed as

$$e_{i,j} = (d_{i,j}/maxTR)^{\alpha}.e_0$$

Where *maxTR* is the maximum transmission range of a node with its maximum transmission power, *di,j* is the distance between node *i* and *j*, and *α* is a loss constant in the range between 2 and 4.

Total Energy consumption

Method 1: one-hop energy consumption of the transmissions of the control and data packets between two cooperative clusters of nodes, with m cooperating nodes in each, is analyzed. For making energy consumption of this cooperative scheme meaningful, we assume some failure probability as P_f and the probability of bit error is a function of the *SNR* of the received signal. For every value of the failure probability P_f, we calculate the needed transmission power of a single node P_t from (2) to (5). We assume that the power consumption for the cooperative protocol is $m^{2} \cdot P_t$ because we need m transmissions per hop, with each transmission being of the type *m-to-1*.

Method 2: Here one-hop energy consumption of the transmissions of the control and data packets with m cooperating nodes in each cluster is analyzed. Consider *T (i)* is set of total number of nodes included in cluster for transmission of control and data packet. Then the total Energy consumption of one cluster is:

$$Etotal_{cluster} = \sum_{T(i)=1}^{m} e_i$$

3. Error calculation in Cooperative transmission

Here, the Cooperative transmission model is similar to MISO case and protocol selectable parameter m is the number of cooperating nodes in the network. Considering, a known SNR at the receiver, the probability of an error at the receiver is given by:

$$P(error) = f(SNR, m) = (1+(SNR/2))^{-m} \quad (4)$$

It is assumed that the power attenuation due to distance is carried out by $d\text{-}\gamma i,j$.
Where, di,j: the distance between node i to node and γ : the attenuation exponent. The bit error probability is calculated by (4). We assume that for a packet to be successfully received, all the bits in the packet must be successfully received.

V. PERFORMANCE ANALYSIS

In this section, the performance is characterized in terms of energy efficiency for cooperative scenario to achieve the energy savings, gained by applying cooperative transmission.The performance of protocol is evaluated in terms of the end-to-end robustness to data loss, the energy consumption, and the capacity. The analytical results such as Robustness to data loss, energy savings are analysed and the capacity bounds are derived.

1. *Protocol robustness*

We compute the *failure probability* that a packet does not reach the sink due to reception error(s) along the path.

2. *Capacity*

The capacity measures the total capacity of all the nodes in the network. Here capacity upper bounds of a single flow are analysed and compared. To determine the capacity upper bound for one hop, the number of data bits in the data packet transmitted in one hop are divided by the minimum delay needed to complete this transmission.

3. *Average Packet Delay*

It measures the delay from the reception of the data packet at the sender node of the current hop until the reception of the data packet at the receiver node of the same hop. Lost packets are ignored in this calculation of delay, *Failure Probability* is analysed here.

4. *Total Energy Consumption*

The energy consumption measures the sum of the energy used for all control and data packet transmissions. The one-hop energy consumption of the transmissions of the control and data packets between two cooperative clusters of nodes, each with cooperating nodes is analysed.

5. *Node energy consumption*

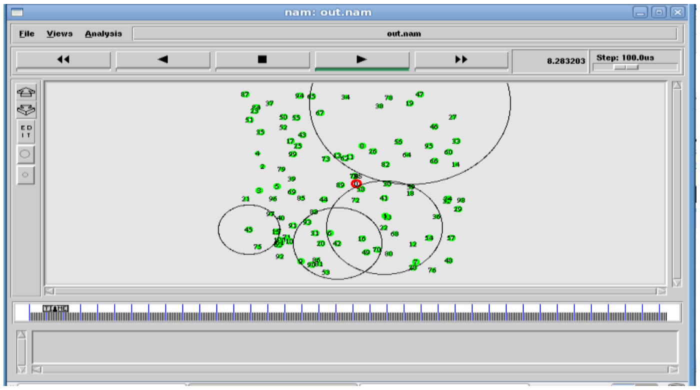
The node energy consumption measures the energy dissipated by the node in order to transmit a data packet on single hop.

VI. FUTURE WORK

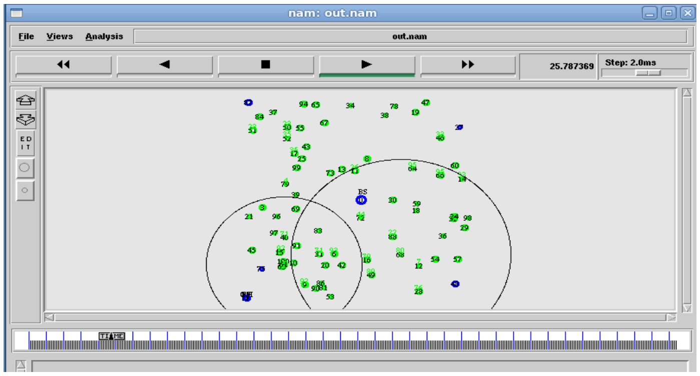
The limitation in this scheme is the fading and interference caused by wireless environments are not taken into consideration this poses a limitation on identifying the network performance in real world scenario. There is one more future work to be focus on such as contention problem. Algorithm can be improved with the help of integration of data aggregation.

VII. SIMULATION RESULTS

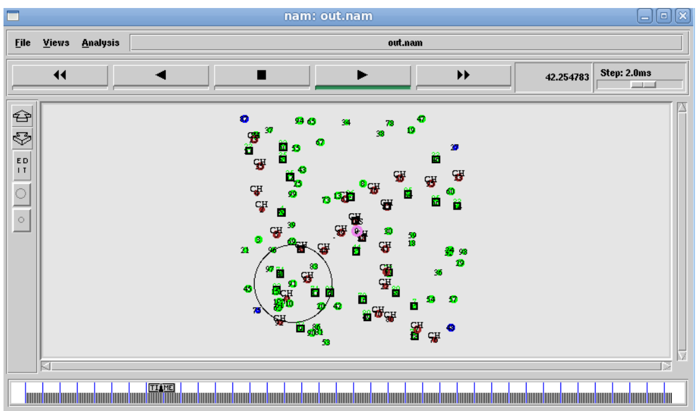
Simulation is used to evaluate the performance of Clustered cooperative protocol. Network simulator ns2 is used for simulating the results and multi-hop scenario. The x-dimension of topography is taken as 500 and y-dimension of topography is taken as 500 with simulation time of 200sec. By considering total 100 nodes in the network with initial energy of 100J are randomly distributed between (x=0, y=0) and (x=500, y=500) For scenario of 100 nodes we took the snapshots of simulation shown in following figures. Nodes are placed randomly. When we have number of cooperating nodes m=5this clustered cooperative transmission protocol has larger energy consumption. Assuming the interference power is constant at all time in analytical equations with all the transmissions are synchronized and their powers are combined at the receiving nodes, with no other interference present.



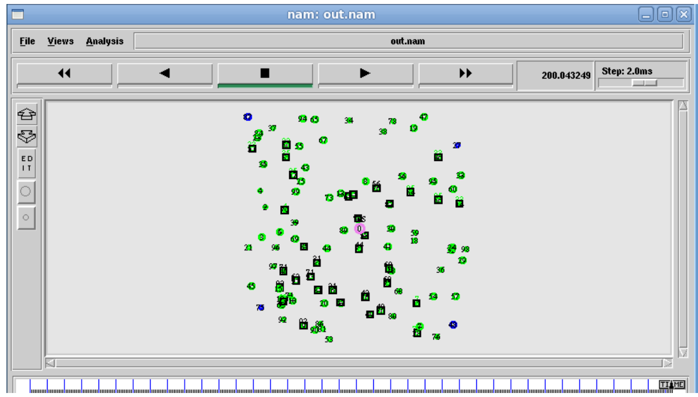
Scenario 1. Node acting as a Source.



Scenario 2. nodes within communication range



Scenario 3. Cluster Heads



Scenario 4. Minimum energy path.

VIII. CONCLUSION

Energy resource limitations are of priority concern in sensor networks. Routing protocol is capable to searching energy sufficient path as well as considers optimum number of transmissions along each path. With the help of Simulation results it can be shown that this proposed scheme has high energy efficiency. This scheme uses energy aware Cluster Head selection to route a packet towards the Sink. With the help of numerical results, it can be shown that the total energy consumption considerably reduced by using Cooperative factors of the Clustered Cooperative transmission protocol. Ultimately the energy savings translate into increased lifetime of cooperative sensor networks.

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