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Collective Information Transmission to Improve Connectivity of Non Uniform Density Wireless Sensor Networks

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Abstract: Clustering-collective Information Transmission-routing Protocol (CCITRP) is a protocol by which information bits are shared among an array of transmitting virtual antennas. A cluster of neighboring antennas synchronously transmits the same information which coherently arrives at the receiving antenna and combines constructively in the transmission medium. A new protocol of information transmission in wireless sensor networks is investigated based on the coherent cooperative transmission of fields from closely spaced wireless nodes. CCITRP can increase the transmission distance information and can be used to address the problem of low network connectivity in case of non uniform density of wireless nodes.

Key words: Clustering, collective information transmission, connectivity, non uniform density

INTRODUCTION

Wireless sensor networks have become the new paradigm of network technologies. Such networks consist of a large number of autonomous nodes in the part of the transceiver, microprocessor, sensors and power supply. The network nodes, having a short distance from each other, gather information about the parameters of the environment and transmit it to the chain: From node to node on the point of information collection (Shan *et al*., 2011). The number of nodes in such networks can range from several to tens of thousands.

Applications of sensor networks (Liu *et al*., 2010; Wang *et al*., 2011) are very broad environmental control of large areas, the protection of various objects, monitoring of production processes, controlling complex engineering structures, collecting information on the status of agricultural, monitoring the home and health care (sensornets) (Wei *et al*., 2010) and much more.

In sensor networks, a number of new problems arise. The study of those problems has received much attention (Callaway, 2004; Akyildiz *et al*., 2002; Kawadia and Kumar, 2005; Laneman *et al*., 2004; Li *et al*., 2009; Idris *et al*., 2009). One of these problems is low connectivity which is caused by a breakup of a network into unrelated groups of nodes. In many problems, when a sufficiently large number of wireless nodes is intended to be placed to a certain extent of territory, these sites are assumed to be scattered from an airplane or helicopter (Akyildiz *et al*., 2002) while their spatial distribution is random and can be highly heterogeneous.

Nodes can be strongly non-uniform density spatial distribution, even if they are placed manually. By virtue of the fact that each node has a limited radio range, the low density of nodes can lead to partitioning of the network into groups, communication between which is absent. Even in the case of high density nodes, relief features (ponds, natural barriers, buildings, etc.) may lead to the exclusion of certain groups of nodes from the main part of the network.

Another reason for the splitting of the network into separated parts is the degradation of energy network (Yang and Zhang, 2009; Guo *et al*., 2010, 2011; Wei *et al*., 2007) which is understood as a gradual failure of sensor nodes resulting from the depletion of their limited energy reserves. The work process in a sensor network entails the formation of data-transmission channels which consist of wireless nodes in which information flows down to a given reception point.

This burden is unevenly distributed among different nodes. For example, all data channels pass through the nodes surrounding the point of collection and processing of information, so these sites have a maximum load. In case of accidental deployment of wireless nodes, the effect of uneven distribution of load between the nodes increases. For example, some sites may be a link between

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large groups of nodes. In this case, the energy in the connecting nodes is depleted more quickly than in most other sites and the failure of binding sites leads to fragmentation of the network.

In present study, a protocol of clustering-collective communication is proposed, aimed at addressing the problem of low connectivity in non-uniform densities nodes sensor networks. The idea of this protocol is close to the one in which other nodes are combined to sync data to another node or a point of information gathering.

It is assumed that the receiving device signals from the transmission nodes are added coherently, leading to a significant increase in transmission range of information within the network. The increase in transmission range allows establishment or restoration of service to isolated groups of nodes. Moreover, it should help to improve connectivity and increase the coverage area.

For the implementation of coherent addition of capacity is needed above all to ensure synchronization of the radiation of wireless nodes. Solution sync generators in wireless nodes can be achieved based on standard approach, involving the use of phase-locked systems (Tu and Pottie, 2002; Zhou *et al.*, 2009).

In this study, the cluster is considered to be a virtual antenna array with a non-regular structure. To analyze the effectiveness of the proposed method of clustering-collective communication, the outcomes of connectivity network are compared when clustering-collective communication is used and when it is not.

REGULAR METHOD

The regular method is categorized into application layer protocol, link layer and network layer protocol.

Application layer protocol: Application layer protocol implemented in the regular method is responsible for sending messages from nodes environmental data to the base station. While the first message to be sent is chosen randomly, each node periodically sends a message to the information obtained from the sensor.

Link layer protocol: Link layer is implemented in the regular method, an Additional Carrier Sensing (ACS) algorithm (Lee *et al.*, 2010) which allows community access to the medium of a data transmission carrier, thus resulting in the recognition and avoidance of conflict.

Network layer protocol: The network layer protocol which is implemented in the regular method, is Reliable Routing Mechanism (RRM) (Chen *et al.*, 2009). This protocol is responsible for the delivery of messages to the recipient via other nodes in the network.

CLUSTERING-COLLECTIVE INFORMATION TRANSMISSION-ROUTING PROTOCOL (CCITRP)

This protocol is based on the coherent addition of fields from closely spaced wireless nodes by using the principle of coherent cooperative transmission of information (Tu and Pottie, 2002). The neighboring nodes are combining in clusters. If a node needs to transmit information to the base station, this node sends this information to other nodes in its cluster. Then, together, they synchronously transmit the data to the next hop node. At the reception point, there are summary signal and electric field intensity that may increase as a result of interference.

MODEL DESCRIPTION

Consider the model sensory network with fixed topology (Fig. 1). Suppose that all nodes are identical and randomly distributed with non-uniform density over some flat area, meaning in one plane. Channels are between a nodes and base station, multihop network and omni-directional antenna. Assume that the communication system of nodes is arranged in such a way that each node has the same fixed radius of R (Fig. 1). Therefore, it is assumed that any two nodes, at a distance less than R, can organize a communication channel between themselves; otherwise the connection impossible (for collective communication, range of radio communication can be raised). To implement the idea of coherent addition of power, network is divided into cluster groups of nodes. Moreover, the radiation of transmitters can be synchronized in frequency and the phase can be stabilized.

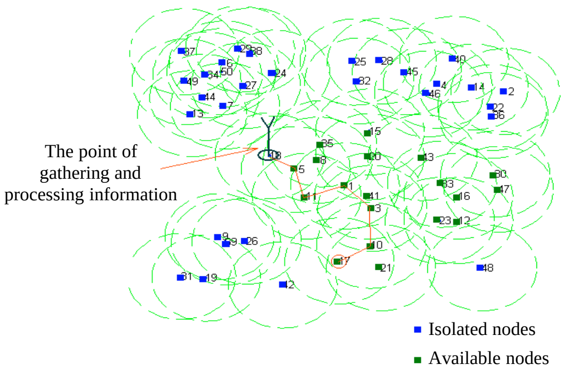


Fig. 1: Model of non uniform density sensor network

CONCENTRATE DISTRIBUTED CLUSTERING ALGORITHM (CDCA)

The realization of the presented method requires an effective clustering algorithm. It is important that a cluster combines the nodes nearest to each other. The concentration of the nodes in a cluster simplifies the data exchange and the synchronization inside the cluster. The clustering algorithm should be energy efficient because of the limited energy resource. The base of our algorithm is the clustering algorithm which is described in (Lin and Gerla, 1997). It is improved for better concentrated cluster organization. The clustering algorithm is based upon the following assumptions:

Assumption 1 : Every node has a unique identification number, ID

Assumption 2 : A message, transmitted by every node, must be received without errors in a finite period of time

Assumptions 3 : The network topology must not change during the session

Description the parts of an algorithm: It is supposed that each node has a dictionary with key (ID of one-hop neighbors and itself ID) and value (number of neighbors for corresponding node). This dictionary is called Γ and it contains unclustered neighbors of current node.

When algorithm starts, this dictionary contains all neighbors. During the algorithm execution, nodes that have already joined the cluster will be removed from this dictionary. At the end of the algorithm execution, this dictionary will be void because all nodes should be clustered. Moreover, it is supposed that each node simultaneously runs this algorithm for Γ and can broadcast message to 1-hop neighbors. The parts of the algorithm are listed and described in Table 1.

Table 1: List and describe the parts of algorithm

Part	Description
MNN	Maximum number of neighbors over its adjacent nodes
my_nn	Number of 1-hop neighbors of node that runs algorithm
my_id	Identification of node that runs algorithm
my_cid	Identification of cluster that this node plans to join or already joined
Γ	Set of unclustered neighborhood nodes
M	Temporary variable for set of nodes with maximal MNN, used for condition calculation
max_nn (Γ)	Function of search Γ for nodes with maximal number of 1-hop neighbors and returns set of this nodes
min_id (Γ)	Function of search Γ for node with minimal id and returns this id. Since id is unique number, there can be only one id in result
nn_of (id)	Function of returns MNN for cluster with identification id
broadcast_cluster (ID, CID)	Function of sends message to all neighbors of current that node with identification ID has joined cluster with identification CID
Set the cluster ID for node ID to CID	Pseudo function, no matter how, current node should remember this
On_receiving_cluster (ID, CID)	Event handler for incoming cluster messages. ID is identification of node that has joined cluster, CID is identification of cluster (actually identification of clusterhead)

Description of an algorithm: The clusterization procedure involves the following steps:

Step 1: Every node broadcasts its ID to its one-hop neighbors. Therefore, every node knows the number of its neighbors and their IDs

Step 2: Every node broadcasts the number of its neighbors to the adjacent nodes

As a result, each node forms the table (Γ) with the information about the neighboring nodes: IDs and the number of neighbors (nn). The table includes the information about the node itself. Then, every node executes the Concentrate Distributed Clustering Algorithm (CDCA) as described in Fig. 2 and 4.

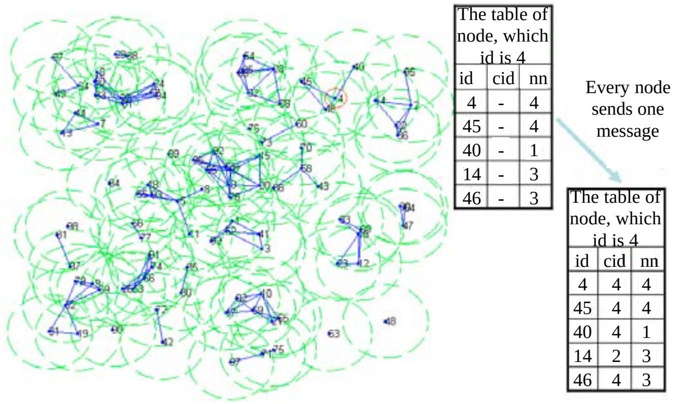
To complete clusterization, every node (i.e., node number 4, Fig. 3) should transmit only one message. After clusterization, the table in each node is supplemented with the information which describes to which cluster every neighboring node refers. The identification number of a cluster (CID) is the ID of the node which is selected to be a clusterhead.

The clusterhead is the node which has the maximum number of neighbors among the adjacent nodes. If the number of neighbors is similar in several adjacent nodes, the node with the minimum ID will be the clusterhead. The presented algorithm provides that the maximum route distance between nodes in each cluster is two hops. Therefore, the distance between each node in a cluster and the clusterhead is one hop. That is why the clusters are spatially concentrated. For real-time demonstration of this modified clustering algorithm, a modeling for parallel calculations is performed. Every parallel process represents the behavior of a single node. Nodes are randomly spread over the determined territory and function using the described algorithm.

The logic of clustering algorithm: In this study, a clustering algorithm is used, as a result of which the main (clusterhead) node becomes a node, has the largest number of neighbors (nodes at a distance smaller than R), Nodes such as number 2, 4, 28 the clusterhead nodes in their clusters (Fig. 5). The logic of the algorithm can be represented as follows:

```
        if (my_nn==max_nn (Γ) or (my_idª (M = max_nn (Γ)) and my_id==min_id (M)))
        {
    my_cid = my_id;
    broadcast_cluster(my_id, my_cid);
    Γ = Γ-my_id;
        }
        for (;;)
         {
          on_receiving_cluster (ID, CID)
          {
          set the cluster ID for node ID to CID;
     if (ID==CID and my_id ∉Γand (my_cid==UNKNOWN or nn_of  (CID)>nn_of(my_cid) or (nn_of (CID) == nn_of (my_cid) and my_cid>CID)))
     {
       my_cid=CID;
      }
        Γ = Γ-ID ;
        if (my_nn==max_nn (Γ) or (my_id ∈ (M = max_nn (Γ)) andmy_id==min_id (M)))
         {
          If (my_cid== UNKNOWN
         {
            my_cid = my_id;
          }
             broadcast_cluster (my_id, my_cid);
              Γ = Γ-my_id;
           }
     }
                if (Γ==∅)
                  {
                 stop;
                }
  }
```

Fig. 2: Concentrate Distributed Clustering Algorithm (CDCA)



The table of node, which id is 4

id	cid	nn
4	-	4
45	-	4
40	-	1
14	-	3
46	-	3

Every node sends one message

The table of node, which id is 4

id	cid	nn
4	4	4
45	4	4
40	4	1
14	2	3
46	4	3

Fig. 3: Example of applied CDCA on node number 4

- Exchange of ID between 1-hop neighbors
- Each node broadcasts count of its 1-hop neighbors
- Node that has the maximum count of 1-hop neighbors and the minimum ID. If several nodes have the same count of 1-hop neighbors, the message is broadast that it became the clusterhead. Receiving this message from one or more of its neighbors, other nodes join the cluster which the clusterhead has a maximum count of 1-hop neighbors (the minimum ID in case several nodes have the same count of 1-hop neighbors)
- Broadcasting from nodes that is not clusterhead message with node ID and ID of clusterhead of its cluster

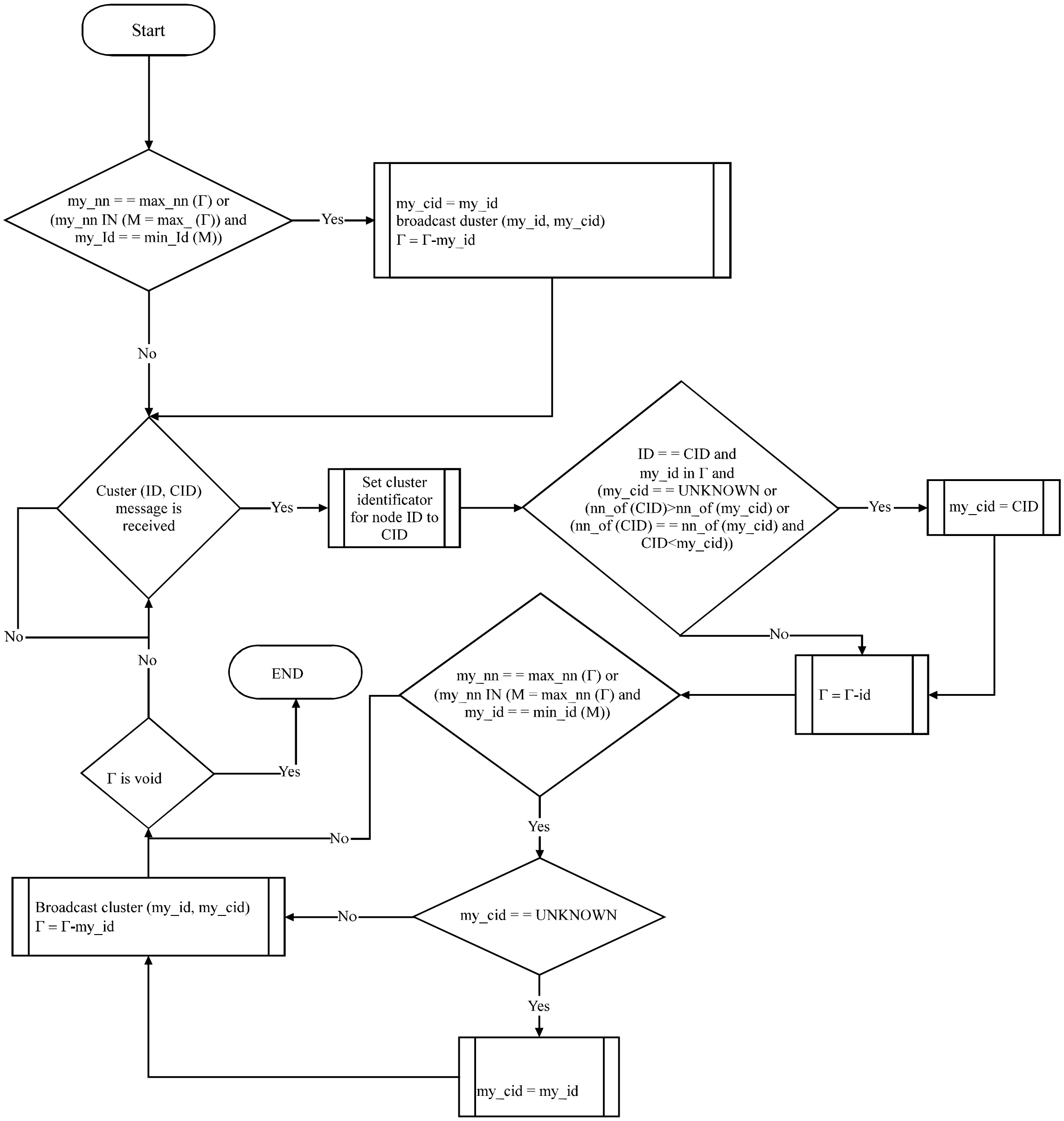


Fig. 4: Flowchart of Concentrate Distributed Clustering Algorithm (CDCA)

Thus, the clusterheads known to all nodes are included in the cluster.

As a result of the action of the algorithm, each cluster has a topology of a star. Consequently, a connection between the nodes of the cluster occurs through the clusterhead. Direct communication between the clusterhead nodes is absent.

In fact, such clusters represent virtual antenna arrays that form the general field of radiation. For the formation of clusters using an energy-efficient algorithm for the self-organization of nodes, based on the identification number which was originally assigned to each node (Gerla and Tsai, 1995; Lin and Gerla, 1997).

This algorithm allows clusters to be obtained in a compact form which is important for the organization based on these virtual antenna arrays. The node belonging to the cluster allows transfer of information prior to the distribution phase, making data between cluster nodes via a clusterhead node. Then, this information at the command of the clusterhead node is simultaneously transmitted from all cluster nodes to any of the nodes in another cluster.

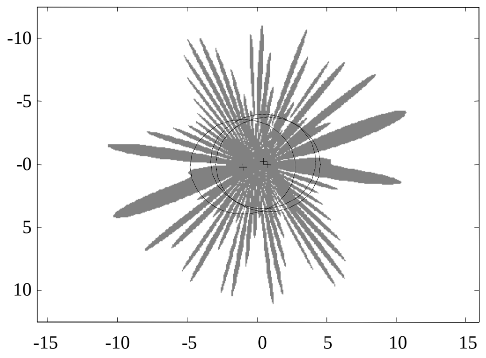


Fig. 5: Coverage of virtual antenna array, consisting of three omni-directional antennas. The dotted line marked the boundary of coverage for each node separately

TOTAL FIELD OF THE RADIATING SYSTEM NODES

When calculating the total field of the radiating system nodes, complex field amplitude at a distance r from each node is calculated by the empirical formula obtained for the surface channels (Sohrabi *et al*., 1999):

$$E = E_s\left(\frac{r}{R}\right)^{-d} \exp\left(i(\omega t - kr + \phi)\right)$$

where E_S, sensitivity field, is the minimum field that a neighbor can detect. d, the degree of attenuation of the field, varies from d = 1 (for a model of free space) to d = 2 (for a model of propagation of radio waves over a conducting surface). ω, is angular frequency, t is time, k is wave vector in free space and ω is phase. Since all nodes in the cluster are synchronized, the common multiplier exp (ωt) can be omitted:

$$E = E_s\left(\frac{r}{R}\right)^{-d} \exp\left(i(-kr + \phi)\right)$$

Effective radius R is fixed and does not depend on the selected degree of damping d (it is assumed for different degrees of damping capacity of different emitters, ensuring consistency of the parameter R). Such a requirement is natural for the network for monitoring the parameters of the medium with a given spatial resolution. Figure 5 provides coverage of the cluster a virtual antenna array (the parameter d = 1 and $\varphi1 = \varphi2 = \varphi2 = 0$), found by summing the three fields that simultaneously emit nodes. The area inside of which the size of a field exceeds a threshold of sensitivity E_S is painted over. As seen, the area of coverage increases as compared with the total area of coverage of individual nodes (Fig. 5, the shaded area is more than twice the total area coverage of individual nodes).

Figure 5 has the following scales: the radius of each node is 50 λ, where λ is the wavelength of electromagnetic radiation. Typical frequency range for wireless sensor networks is about 2.4 GHz. For example, a wireless standard 802.15.4 (ZigBee) which among other areas of application is also designed for use in sensor networks, has a specification for a given frequency range. If the frequency of the radiation of wireless nodes is 2.4 GHz (λ = 12.5 cm), then on the figures presented by the range of nodes, it is 6.25 m.

It is important to note that the brokenness of coverage leads to the fact that the relationship between the two clusters, using the method of clustering-collective communication, can be both bidirectional and unidirectional. In the numerical simulation of the network with the collective transfer of information that will be considered bi-directional communication, it is considered that the relationship between the two clusters is possible, provided that at least one of the nodes in the cluster A is inside the coverage area of the cluster B and at least one cluster node B is within the coverage area of the cluster A.

HIGHER TO SMALLER PARAMETER ROUTING ALGORITHM (HTSPRA)

In the presented network model, it is assumed that channels exist only between a node or a cluster and the base station. Also, it is assumed that network topology is stationary. These assumptions simplify the routing problem.

A new routing algorithm (HTSPRA) is proposed which uses the concept of sequential transmission from the cluster with a higher parameter to the cluster with a smaller parameter.

The principle of this algorithm is the following. Each node has a parameter characterizing the route distance between this node and the base station. As the network begins to function, the base station initiates the valanche-like process of spreading these parameters. The base station has the minimum parameter; its neighbors have the parameter which is greater and so on. The value of this parameter in each node of the same cluster is similar. The forwarding packets are provided by sequential transmission from the cluster with a higher parameter to the cluster with a smaller parameter.

EXPERIMENTAL AND SIMULATION RESULTS

For the numerical analysis model, the sensor network described above is used. Simulation experiment is performed using Matlab, in the simulation method of clustering-collective communication, this method is implemented throughout the network. This means the whole network is divided into clusters and information is exchanged between the clusters. In the following numerical experiments, the connectivity of the network is calculated as follows:

$$\varepsilon = \frac{N_c}{N}$$

where N_c is the number of nodes available for the base station and N is the total number of nodes. The network has the following spatial scales: Territory in which the nodes are located has a size of 800×800 λ and a radius of 30 λ for each node. Nodes are distributed in non-uniform density. Coordinates of nodes in each density are chosen randomly with uniform distribution function on the grid with the step λ/2.

When calculating the connectivity of network, the number of nodes changes from 50 to 500 in steps of 10. In Fig. 6, 7 and 8, the connectivity for the network is reported and showed the results for the parameters d = 1 and d = 2 and without using CCITRP (regular method). As seen earlier, the degree of attenuation of the field significantly affects the efficiency of coherent addition of capacity. Thus, Fig. 6 and 7 show that the use of CCITRP makes gains in network connectivity. It is noted that to guarantee that all nodes can communicate with each other, the number of nodes should be more than 300 for d = 1 (Fig. 6) and more than 450 for d = 2 (Fig. 7).

Figure 8 shows that without using CCITRP, the regular method makes the worst case, furthermore, it is noted that the maximum connectivity for the network is 90% with the maximum number of nodes which is 500 nodes.

Recall that the radius of the single node R is fixed and does not depend on d and so the connectivity of the network with a regular method does not depend on the parameter d. As mentioned above, it is assumed that the relationship between the clusters must be bidirectional. When a cluster message is sent, cluster head node waits for confirmation of acceptance of this message by other clusters. Information confirming the correct reception can be taken directly to the cluster head node or any other nodes in the cluster. It initiates a transfer of data and is transferred to the central node.

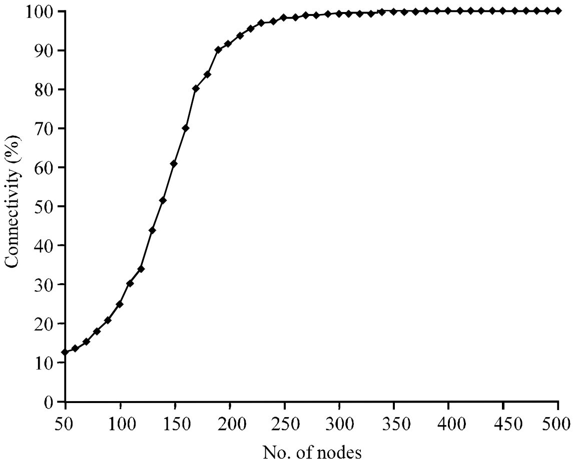


Fig. 6: The dependence of the network connectivity of the total number of nodes for CCITRP when d = 1

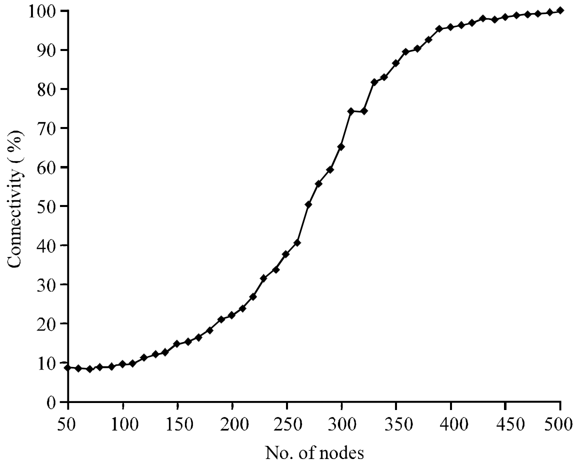


Fig. 7: The dependence of the network connectivity of the total number of nodes for CCITRP when d = 2

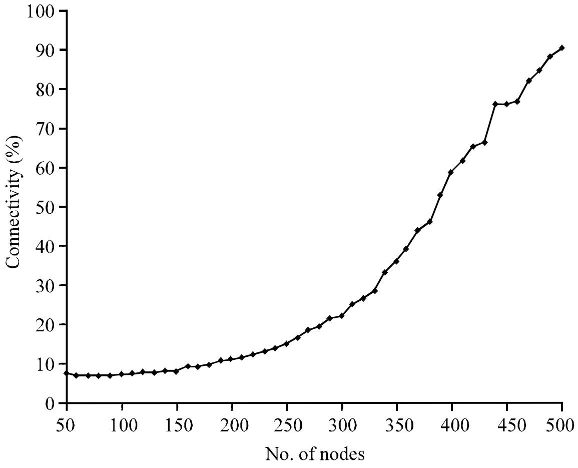


Fig. 8: The dependence of the network connectivity of the total number of nodes for regular method

CONCLUSIONS

In this study, the clustering-collective information transmission-routing protocol for non-uniform density wireless sensor networks is proposed and analyzed. The criterion is used for the analysis of characteristics of network connectivity. The results of computer simulations show that the implementation of the CCITRP improves the connectivity of the network, specially when the degree of attenuation of electromagnetic field d = 1. One problem has not been observed in this study, as it deserves to be considered specially. The main problem for future investigations is the synchronization inside the clusters.

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