An Improved Three-Layer Low-Energy Adaptive Clustering Hierarchy for Wireless Sensor Networks

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Abstract — In a wireless sensor network the topology control is used to balances the communication on sensor devices and have a response to increase the network lifetime and scalability. So conserve the energy of the sensor networks is highly concern. In this they have one approach that is Hierarchical or cluster-based design which is used to conserve the energy of the sensor networks. By this, the nodes with the higher residual energy could be used to gather data and route the information. The previous work on clustering has the two-layer hierarchy and that only few methods studied a three-layer scheme instead. But the previous work of two layer hierarchy is not efficient. Based on the three layer scheme we proposed a semi-distributed clustering approach by considering a hybrid of centralized gridding for the upper-level head selection and distributed clustering for the lower-level head selection. The simulation results show that the proposed approach is more efficient than other distributed algorithms. Therefore, the technique presented in this paper could be further applied to large-scale wireless sensor networks.

Keywords :- *fingerprint identification; Convolution Neural Network (CNN); fuzzy feature points; recognition rate.*

I. OVERVIEW

Wireless Sensor Networks (WSNs) are composed of large number of low power, small size and low cost sensor node. A sensor node typically consists of several parts including: a radio transceiver, a sensing unit, a microcontroller and power source usually a buttery. The sensor nodes might vary in cost from few to hundreds of dollars depending on the functionality of each sensor node. The constraints of cost and size of the sensor nodes led to constraints on its resources such as energy, communication and computation.

Each sensor node can communicate and exchange its data with other nodes and the base station. In this context, sensor nodes can use variable or fixed power for data transmission; as the distance between the source and destination nodes is increased, the required power is increased hop communication, the transmission power should be sufficient to deliver data to the destination node.

II. INTRODUCTION

A Wireless Sensor Network (WSN) is a network system composed of numerous wireless sensors and a few sinks which transmit data wirelessly. WSN are commonly applied in areas such as military, agriculture, disaster prevention and emergency rescue. In all these applications, sensors gather environmental information and then report the sensing data to the sink(s) wirelessly. In some applications, the mobile sink may move freely. So, the moving path of the mobile sink is unpredictable. For example, intelligence reporting in the battlefield is an application of this operation. A group of soldiers with a handheld PDAs patrolling in battlefield to gathering information from the WSN. To send the sensing data to the mobile sink, the source sensor has to locate the mobile sink first and then deliver the data via multi-hop transmission. Hence, how to improve the packet delivery ratio is a primary focus of this type of research. For example, intelligence reporting in the battlefield is an application of this operation. A group of soldiers with a handheld PDAs patrolling in battlefield to gathering information from the WSN. To send the sensing data to the mobile sink, the source sensor has to locate the mobile sink first and then deliver the data via multi-hop transmission. Hence, how to improve the packet delivery ratio is a primary focus of this type of research.

In order to enhance the packet delivery ratio, Shi et al. proposed the Data-Driven Routing Protocol (DDRP). In DDRP, sensors can be divided into three types, including One-Hop neighboring Sensor nodes of mobile sinks (OHS), Multi-Hop neighboring Sensor nodes of mobile sinks (MHS) and Infinite-Hop neighboring Sensor nodes of mobile sinks (IHS). overhearing-based route learning process, sensors without beacon packets are able to overhear the route information when their neighboring sensors with route information deliver data packets. The status of sensors which have overheard the route information will be changed from IHS to MHS. Because OHS sensors and MHS sensors possess route information, they can deliver data packets to mobile sinks by tracing beacon packets. IHS sensors do not have route information, so they need to rely on random walk to find OHS/MHS sensors. Hence, DDRP still cannot guarantee 100% delivery of data packets. that is, they cannot ensure that all data packets can be delivered to a mobile sink. Besides, as data packets are delivered by random walk and following the beacon packets, the number of times of data relay will be very high.

In this paper, we attempt to improve the above-mentioned problem. The proposed algorithms are expected to ensure 100% delivery of sensing data and also reduce energy consumption by delivering the data through a smaller number of times of data relay compared to existing algorithms.

Furthermore, to tackle the opportunistic availability of licensed channels, two sequential channel sensing and accessing schemes with the resource allocation of an accessed channel are exploited for minimizing the energy consumption in both intra- and inter-cluster data transmission. Specifically, the contributions of this work are three-fold.

(i) For both intra-cluster and inter-cluster data transmission, we determine the condition when sensor nodes should sense and switch to a licensed channel for potential energy consumption reduction.

(ii) We propose a dynamic channel accessing scheme to reduce the energy consumption for intra-cluster data transmission, which identifies the sensing and accessing sequence of the licensed channels within each cluster.

(iii) Based on the analysis of intra-cluster data transmission,
a joint power allocation and channel accessing scheme is developed for inter-cluster data transmission, which can dynamically adjust the transmission power of cluster heads and determine the channel sensing and accessing sequence to reduce energy consumption.

III. SYSTEM MODEL

A. Network Model

Consider a cognitive radio sensor network, where a set of cognitive sensor nodes N = {s1, ..., sn} are distributed to monitor the area of interest, as shown in Fig. 1. According to the application requirements, sensor nodes periodically sense the environment with different sampling rates and then report their sensed data to the sink node [21]. We divide the operation process of the network into a large number of data periods. A data period is composed of data sensing, data transmission, and sleeping durations, where sensor nodes sense the monitored area, transmit the sensed data to the sink node, and then sleep, respectively. Motivated by the benefits of hierarchical data gathering, sensor nodes form a number of clusters, denoted by L = {L1, ..., Lm}, to transmit the sensed data to the sink [22]. Denote the cluster head (CH) of Li as Hi , and the set of cluster members (CMs) in Li as Ni.

The data transmission is further divided into two phases: intra-cluster data transmission and inter-cluster data transmission. In the intra-cluster data transmission, CMs directly transmit their sensed data to the cluster heads in a Time Division Multiple Access (TDMA) manner. During the intercluster data transmission, CHs aggregate the sensed data and directly send the aggregated intra-cluster data to the sink. The inter-cluster data transmission is also based on a TDMA manner, coordinated by the sink. The sensor network operates on a license-free channel C0 for data transmission, which may occasionally suffer from uncontrolled interference causing a significant packet loss rate. Enabled by the cognitive radio technique, sensor nodes can sense the licensed channels and access the vacant ones, when the packet loss rate of C0 is fairly high. There is only one radio within each sensor node for data communication, which means sensor nodes can only access one channel at a time. Moreover, similar to most existing works [13], [23], we assume that sensor nodes use a network-wide common control channel for control signaling and channel access coordination.

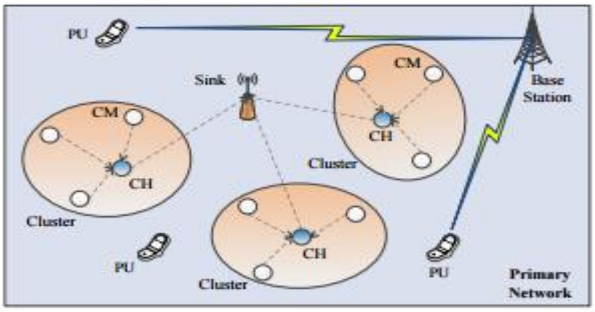


Fig. 1. The architecture of CRSN.

B. Cognitive Radio Model

Suppose that there are k different licensed data channels C = {C1, ..., Ck} with different bandwidths {B1, ..., Bk} in the primary network. The PU's behavior is assumed to be stationary and ergodic over the k channels. The cognitive sensor nodes in the primary network are secondary users (SUs) that can opportunistically access the idle channels. A fixed common control channel is considered to be available to exchange the control information among the sensor nodes and the sink. We model the PU traffic as a stationary exponential ON/OFF random process [3]. The ON state indicates that channel is occupied by PUs and the OFF state implies that the channel is idle. Let Vx and Lx be the exponential random variables, describing the idle and occupancy durations of Cx with means vx and lx, respectively. Thus, for each channel Cx, the probability of channel being idle p x of f and the probability of channel occupancy p x on are

$$\begin{cases} p^x_{off} = v_x/(v_x + l_x), & \mathcal{H}_{0,x} \\ p^x_{on} = l_x/(v_x + l_x), & \mathcal{H}_{1,x} \end{cases}, \qquad (1)$$

where H0,x and H1,x represent the hypothesis that Cx is idle and occupied, respectively. Sensor nodes are assumed to sense channel by the energy detection-based spectrum sensing approach [23]. When sj adopts energy detector to sense Cx, the detection probability pd,x,j (i.e., the probability of an occupied channel being determined to be occupied correctly) and the false alarm probability pf,x,j (i.e., the probability of an idle channel being determined as occupied) are defined as pd,x,j = P r(Dx ≥ δx|H1,x) and pf,x,j = P r(Dx ≥ δx|H0,x), where δx is the detection threshold and Dx is the test statistic for Cx. And the misdetection probability can be calculated as pm,x,j = P r(Dx < δx|H1,x) = 1 − pd,x,j .

C. Energy Consumption Model

The energy consumption of sensor nodes mainly includes four parts: the energy consumption for spectrum sensing, spectrum switching, data transmission and reception. For each sensor node, we use es to denote the energy consumption for sensing a licensed channel, which is fixed and the same for different channels. Meanwhile, sensor nodes need to consume energy to configure the radio and switch to a new channel. Therefore, we use ew to denote the energy consumption that a sensor node consumes for channel switching. For sj , the data transmission energy consumption Ej,t is based on the classic energy model.

D. Problem Statement

Fig. 2 shows the time flow of the CRSN to illustrate the temporal relationship of different actions. As shown in the figure, a data period consists of three phases, i.e., data sensing, data transmission and sleeping. At the beginning of each data period, sj senses the monitored area and generates Aj sensed data to report to the sink. Once the sensed data is successfully transmitted to the next hop, it will turn into sleep mode for energy saving and wait for the next data period. Since data transmission is independent among different data periods, our objective is to efficiently transmit P A = sj∈N Aj data to the sink within a data transmission period, by determining the channel sensing and accessing decision according to the channel condition of C0. As an indicator of the time-varying channel condition, the packet loss rate of C0 is measured/estimated at the beginning of each transmission period, by the RSSI (Received Signal Strength Indicator) and SNR (Signal-to-Noise Ratio) during the communications of each pair CM-CH and CH-Sink, and assumed to be stable in a data transmission period but may vary over different periods.

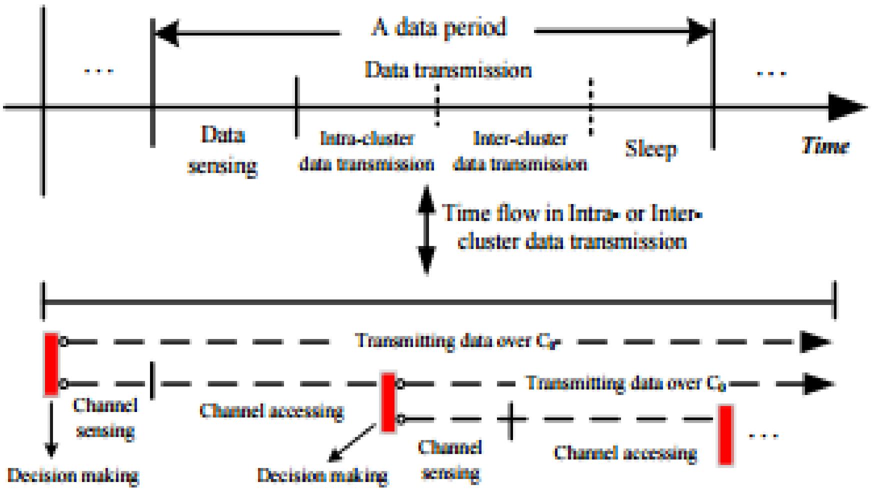


Fig. 2 time flow of the CRSN

IV. DYNAMIC CHANNEL ACCESSING FOR INTRA-CLUSTER DATA TRANSMISSION

In this section, we propose a dynamic channel access solution for intra-cluster data transmission to improve the energy efficiency, according to the temporally fluctuated packet loss rate over C0. Specifically, we adopt a four-step analysis to introduce the main ideas of the proposed solution: (1) We analyze the energy consumption E1,0(i) for intra-cluster data transmission over C0 in a cluster Li ; (2) We calculate the optimal energy consumption E1,x(i) in a cluster Li , if Li accesses a licensed channel Cx for intra-cluster data transmission; (3) Since there are different idle probabilities for the licensed channels, we further calculate the expected energy consumption E1,x(i) for the intra-cluster data transmission in Li by accessing Cx, taking the energy consumption of channel sensing and switching into consideration.

A. Initialization

The sensors are labeled with their initial priorities and the connectivity among them is shown by the links between neighboring nodes. In the initialization phase, each sensor acquaints itself with all the neighbors in its proximity. Each sensor is assumed to be able to communicate only with its neighbors, i.e., the nodes within its transmission range. During initialization, sensors are self-organized into clusters. Each sensor decides to be either a cluster head or a cluster member in a distributed manner. In the end, sensors with higher residual energy would become cluster heads and each cluster has at most M cluster heads, where M is a system parameter. For convenience, the multiple cluster heads within a cluster are called a cluster head group (CHG), with each cluster head being the peer of others. The algorithm constructs clusters such that each sensor in a cluster is one hop away from at least one cluster head. The benefit of such organization is that the intra-cluster aggregation is limited to a single hop. In the case that a sensor may be covered by multiple cluster heads in a CHG, it can be optionally affiliated With one cluster head for load balancing.

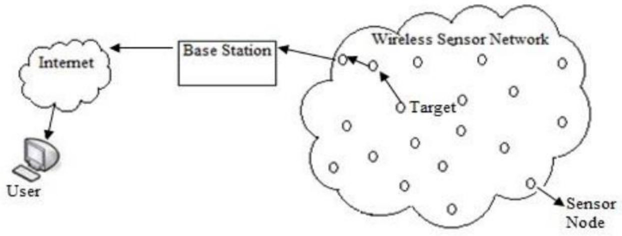


Fig.3: Initialization

B. Status claim

In this Module, each sensor determines its status by iteratively updating its local information, refraining from promptly claiming to be a cluster head. We use the node degree to control the maximum number of iterations for each sensor. Whether a sensor can finally become a cluster head primarily depends on its priority.

C. Cluster Forming

The third phase is cluster forming that decides which cluster head a sensor should be associated with. The criteria can be described as follows: for a sensor with tentative status or being a cluster member, it would randomly affiliate itself with a cluster head among its candidate peers for load balance purpose. In the rare case that there is no cluster head among the candidate peers of a sensor with tentative status, the sensor would claim itself and its current candidate peers as the cluster heads.

D. Cluster Head Synchronization

The intra cluster time synchronization among established cluster heads should be considered. The fourth phase is to synchronize local clocks among cluster heads in a CHG by beacon messages. First, each cluster head will send out a beacon message with its initial priority and local clock information to other nodes in the CHG. Then it examines the received beacon messages to see if the priority of a beacon message is higher. If yes, it adjusts its local clock according to the timestamp of the beacon message. In our framework, such synchronization among cluster heads is only performed while SenCar is collecting data. Because data collection is not very frequent inmost mobile data gathering applications, message overhead is certainly manageable within a cluster.

VI. PERFORMANCE EVALUATION

Evaluate the performance of the proposed schemes by extensive simulations on OMNET++. Setup a network consisting of 200 sensor nodes forming 10 clusters. Sensor nodes are randomly deployed in a circular area with the network radius of 250 m, and the sink is located at the center. There are 15 licensed channels in the primary network, which can be sensed and accessed by the CRSN. All the channels including the default working channel C0 are modeled as Rayleigh fading channels. For each channel Cx (Cx ∈ C ∪ {C0}), the noise spectral density is 10−14 W/Hz (i.e., σ 2 x = Bx · 10−14W), and the channel gain between si and sj is set as h 2 i,j,x = γ · d −μ i,j , where γ is an exponential random variable with mean value 1, and di,j is the distance between si and sj , and μ = 3. Instead of setting the parameters of PU traffic on different licensed channels, we directly set the probability that PU is on as p x on = 60% and the channel available duration (CAD) as Tx = N(100, 20) ms for each Cx, where N(a, b) means the normal distribution with mean value a and variance b. The other parameters, if not specified in the simulation figures, are given in Table II. To demonstrate the energy efficiency improvement, we compare the proposed.

A. Intra-cluster Data Transmission

Evaluate the performance of the dynamic channel sensing and accessing scheme for intra-cluster data transmission in this subsection. Fig. 5 shows the energy consumption of intra-cluster data transmission by accessing a specific licensed channel. In our proposed scheme, the CAD of the accessed channel is allocated to CMs according to the optimal solution of (TAP). We compare our scheme to the average allocation scheme, in which the CAD of the accessed channel is equally allocated to the CMs with residual data. It can be seen that our scheme can achieve lower energy consumption than that of the average allocation scheme, when the CAD of the accessed channel is no large than 60 ms. After the CAD becomes larger than 60 ms, the energy consumption of two schemes converge to the same value. The reason is that a large CAD can guarantee that all the intra-cluster data are transmitted over the licensed channel, which leads to a minimum and stable energy consumption.

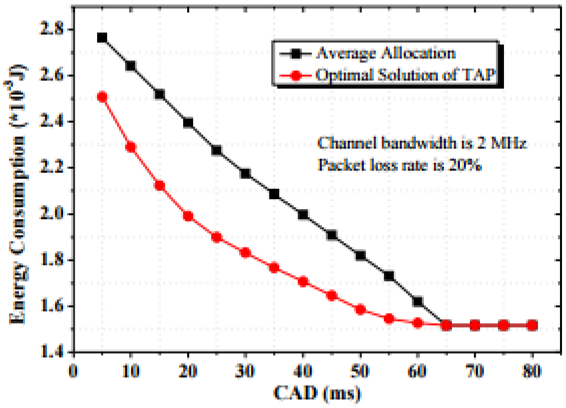


Fig. 4. Energy consumption comparison for intra-cluster data transmission by accessing a specific licensed channel.

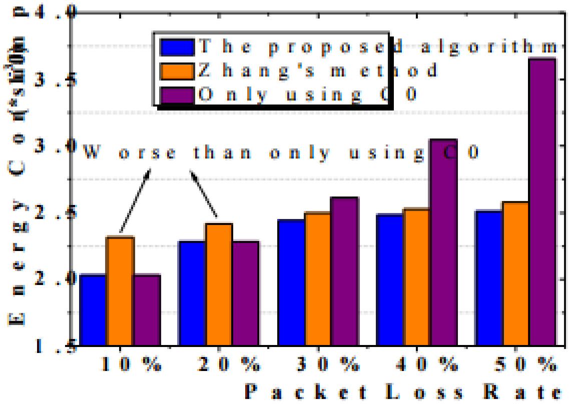


Fig.5. Energy consumption comparison for intra-cluster data transmission under different packet loss rates.

B. Inter-cluster Data Transmission

In this subsection, we aim to evaluate the performance of the joint power allocation and channel accessing scheme in inter-cluster data transmission. Fig. 7 shows the convergence speed of the ACS based algorithm for solving (PTAP), i.e., Algorithm 2. It can be seen that the algorithm can converge (or find the optimal solution) within 6 iterations, which indicates the proposed algorithm is highly efficient and can be applied to resource-limited sensor networks. Fig. 8 compares the energy consumption for inter-cluster data transmission under the proposed joint transmission power and time allocation scheme and the average allocation scheme. In the average allocation scheme, the CAD of the accessed channel is equally allocated to the CHs with residual data and CHs.

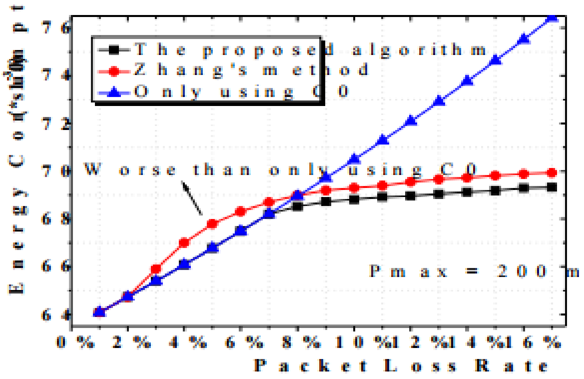


Fig. 6. Energy consumption comparison in inter-cluster data transmission under different packet loss rates.

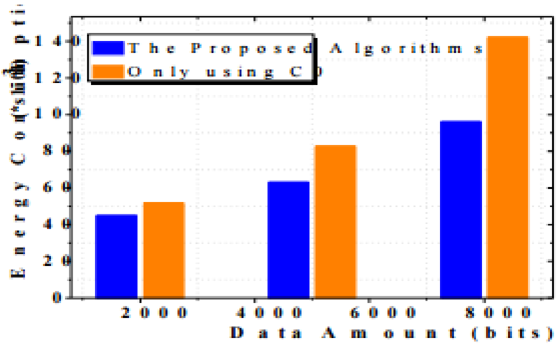
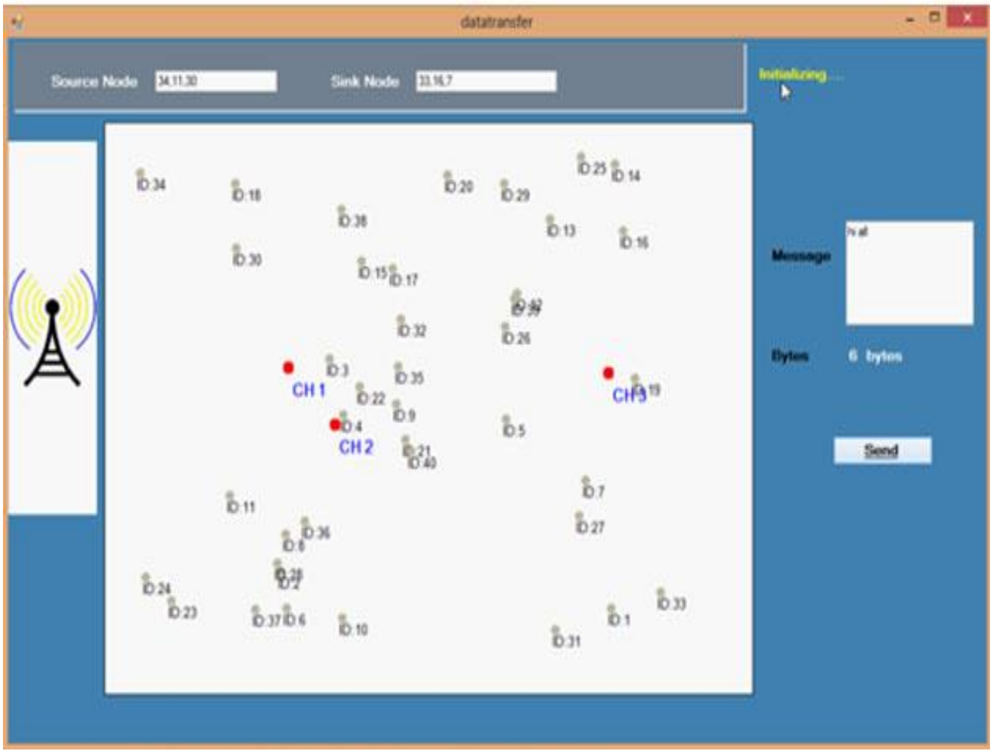


Fig. 7. Total energy consumption comparison under different amount of data traffic.

C. Impacts of System Parameters

Fig. 7 shows the total energy consumption comparison under different amount of data traffic. With the increasing data amount transmitted by sensor nodes, the total energy consumption increases sharply if the CRSN uses C0 for data transmission, while it only increases linearly under our proposed schemes. Moreover, higher data traffic indicates better energy consumption improvement. Fig. 11 shows the total energy consumption comparison under different numbers of licensed channels. It can be seen that the total energy consumption in our proposed schemes decreases with the increasing number of licensed channels. Fig. 12 shows the impacts of channel sensing accuracy on the performance of the proposed algorithms. It can be seen from the figure that the energy consumption of the proposed algorithms increases significantly with the increasing false alarm probability of channel sensing.

VII. SCREENSHOTS



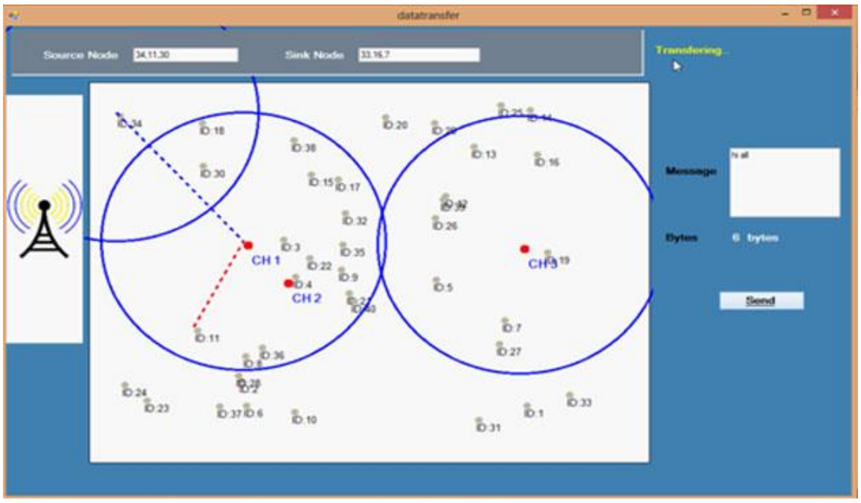
Source Node 34.11.30

Sink Node 33.16.7

Message hi all

Bytes 6 bytes

Fig 8. Data transferring is Initialized



datatransfer

Source Node 34.11.30

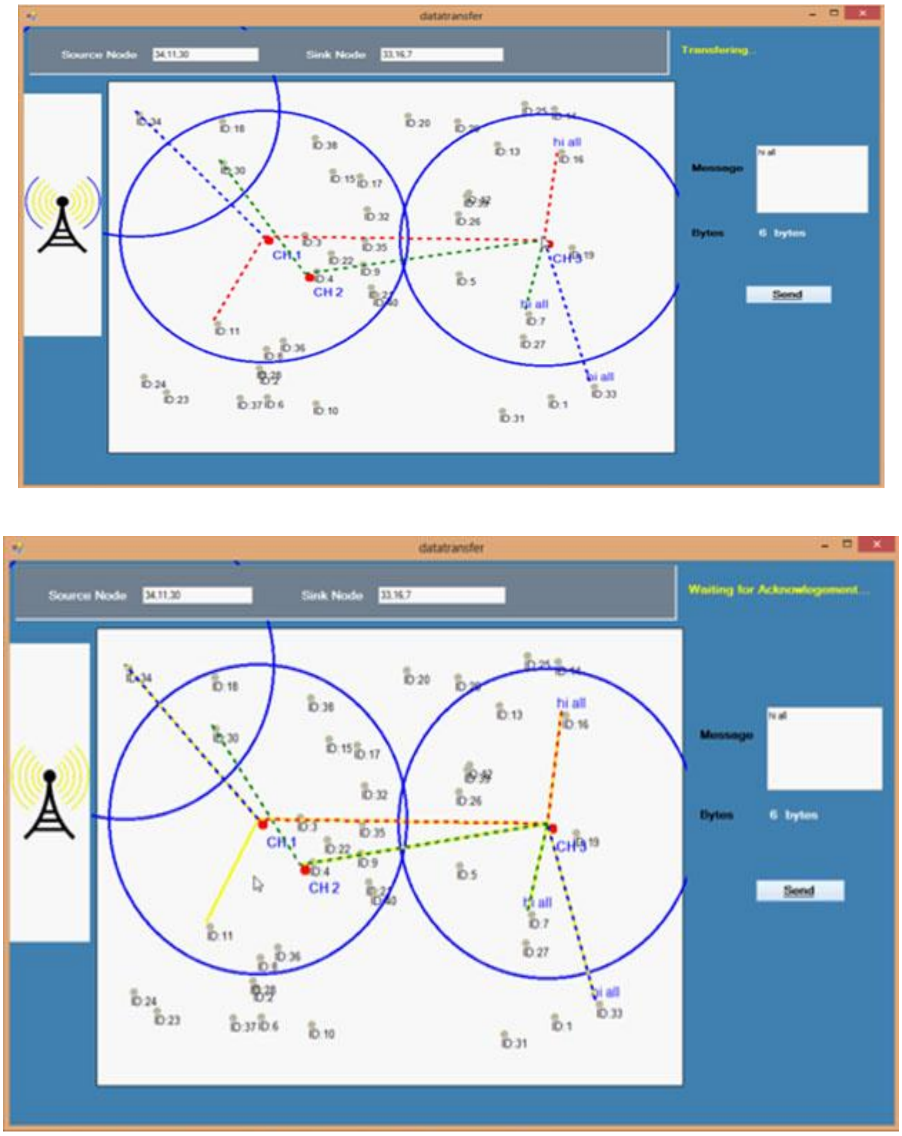
Sink Node 33.16.7

Transferring..

Message hi all

Bytes 6 bytes

Fig 9. Information transmission



datatransfer

Source Node 34.11.30

Sink Node 33.16.7

Transferring..

Message hi all

Bytes 6 bytes

datatransfer

Source Node 34.11.30

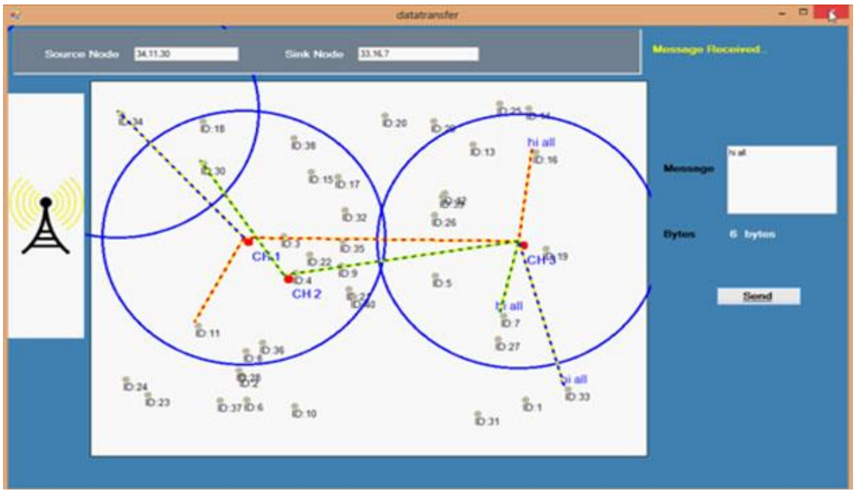
Sink Node 33.16.7

Waiting for Acknowlegement...

Message hi all

Bytes 6 bytes

Fig 10. Information received to sink nodes



Source Node 34.11.30
Sink Node 33.16.7
Message Received..
Message hi all
Bytes 6 bytes

Fig 11. Receiving Acknowledgement

VIII. CONCLUSION

Energy conservation is an important issue in wireless sensor networks. To achieve the energy efficiency, many clustering algorithms have been proposed. This paper has proposed a hybrid hierarchical clustering approach (HHCA) by considering a hybrid of centralized gridding and distributed clustering. The proposed HHCA is based on three-layer hierarchy, which can be regarded as an extensional work from previous two-layer based clustering approach. In the proposed algorithm, the grid heads are determined in a centralized manner, and then the cluster heads are determined in a distributed manner. By introducing three-layer hierarchy, the number of nodes that communicate with base station reduced, resulting in energy conservation.

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