A Novel Approach for Efficient Data Collection in Cluster Based Communication using Compressive Sensing and MIMO Techniques to Extend Network Lifetime

Sunanda Patne, Vinodha K
Department of Information Science, Visvesvaraya University, Karnataka-, 18
sunandapatne2009@gmail.com, mohan.vinodha@gmail.com

ABSTRACT- In Wireless Sensor Networks (WSNs) consumption of energy is a major concern. In this paper Cluster Based Communication using Compressive Sensing and Multi Input Multi Output (MIMO) Techniques for efficient data collection is proposed. This system consists of a three level framework which includes the cluster head layer, sencar (mobile collector) layer, and sensor layer. By using this framework good scalability, prolong network lifetime and low data collection delay is achieved. At cluster head layer, a distributed load balanced clustering algorithm is proposed. Our scheme generates multiple cluster head in each cluster to balance the load and provides dual data uploading. At the cluster head layer, the connectivity among the clusters is guaranteed by choosing appropriate inter-cluster transmission range. To make the system energy efficient multiple cluster head within the cluster they cooperatively communicate with each other. Before uploading, the data is compressed by the Cluster Head using compressive sensing technique to reduce data transmission time. By using compressed data sensing and dual data uploading technology the proposed system achieves over 50 percent energy saving per node and 60 percent energy saving on cluster heads comparing with data collection through multi-hop relay to the static data sink, and 20 percent shorter data collection time compared to traditional mobile data gathering.

Keywords – Mobile Collector, Polling Point, Multi Input Multi Output, Relay Node, Dual Uploading, Load Balancing.

1. Introduction

Wireless Sensor Networks (WSNs) have emerged as a new information-gathering paradigm in a wide range of applications, such as medical treatment, outer-space investigation, battlefield surveillance, emergency response, etc. where Sensor nodes are usually thrown into a large-scale sensing field without a preconfigured infrastructure. Before monitoring the environment, sensor nodes must be able to discover nearby nodes and organize themselves into a network. The measuring and monitoring of the data packets from multiple sensors are then processed and forwarded to external networks via static or mobile sink which act as gateways. This procedure is called data gathering. Sensors are used to sense, process and record conditions in different locations. Every sensor node has a power source typically in the form of a battery. The base stations are one or more components of the WSN with infinite energy and communication resources. They act as an interface between sensor nodes and the end user as they typically forward data from the WSN to a server. Clustering is particularly useful for applications with scalability

requirement and is very effective in local data aggregation, since it can reduce the collision and balances the load among sensors. The sencar (mobile collector) collects the aggregated data from the cluster heads by visiting predefined locations named as polling points through a planned trajectory.

This paper is organized as follows. Section 2 deals with the system overview, related work is presented in section 3. The detailed implementation methodology of the proposed system is discussed in section 4; the performance evaluation of the system is discussed in section 5. The result analysis is done in section 6, finally the concluding remarks and future work is presented in section 7 and 8 respectively.

2. System Overview

An overview of cluster based communication of three layer framework is shown in Fig.1, which consists of three layers: sensor layer, cluster head layer and sencar layer. The sensor layer is the bottom and basic layer. In the Initial set up phase the sensors self organize themselves into a cluster. Each individual sensor decides by itself to be a cluster head or member of the cluster. The sensor with high residual energy becomes the cluster head and each cluster has at most M cluster heads, where M is the positive integer [1]. The cluster heads act as peers to each other. The algorithm places these sensors in such a way that they are 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. To avoid collisions during data aggregation, the cluster head group (CHG) adopts time-division-multiple-access (TDMA) based technique to coordinate communications between sensor nodes. After the election of cluster heads, the nodes synchronize their local clocks via beacon messages. For example, all the nodes in a CHG adjust their local clocks based on the node with the highest residual energy.
The cluster head layer consists of all the cluster heads and member nodes. The inter-cluster forwarding is only used to send the CHG information of each cluster to sencar, which contains a list of ids of multiple cluster heads as well as the priority of the data to be sensed in a CHG. Such information must be sent before sencar departs for its data collection tour [1].Upon receiving this information; it plans the path trajectory for data collection from the CHs. To guarantee the connectivity for inter-

cluster communication, the cluster heads in a CHG can cooperatively send out duplicated information to achieve spatial diversity, which provides reliable transmissions and energy saving. The top layer is the sencar layer, which mainly manages mobility of sencar. There are two issues to be addressed at this layer. First, we need to determine the positions where sencar would stop to communicate with cluster heads when it arrives at a cluster. In the proposed algorithm, sencar communicates with cluster heads via single-hop transmissions. It is equipped with two antennas while each sensor has a single antenna. The traffic pattern of data uploading in a cluster is many-to-one, where data from multiple cluster heads converge to sencar. It is equipped with two receiving antennas, for dual data uploading whenever possible, in which two cluster heads can upload data simultaneously. By processing the received signals with filters based on channel state information, sencar can successfully separate and decode the information from distinct cluster heads. To reduce the latency in collecting the data the sencar stops at predefined polling point such that it encounters maximum number of CHs that comes under its transmission range. Since sencar is mobile, it has the freedom to choose any preferred position. However, this is infeasible in practice, because it is very hard to estimate channel conditions for all possible positions. Thus, we only consider a finite set of locations. To mitigate the impact from dynamic channel conditions, sencar measures channel state information before each data collection tour to select candidate locations for data collection. We call these possible locations as polling points. Since sencar has pre-knowledge about the locations of polling points, it can find a good trajectory by seeking the shortest route to visit each selected polling point exactly once and then returns to the data sink.

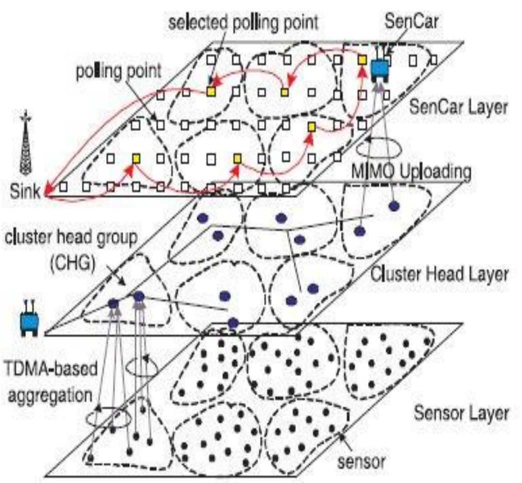

Fig. 1 Illustration of three layer framework

3. Related Work

Clustering Scheme such as a relay routing, is an effective and simple way to approach the concept of routing messages to the data sink in multi-hop fashion. Cheng et al[3] discovered the alternate route method to avoid congestions and transfer data. Wu et al. [4] studied to maximize the life time of data storage by designing an algorithm that started with a random design and ideally ended with load reduction on the bottleneck nodes. Xu et al. studied on the relay approach towards nodes to extend the lifetime of the network. The cluster tree protocol (CTP) is mainly used to work on robustness, reliability, efficiency and hardware independent. Whatever maybe, but when it comes to nodes in the critical data path, if energy depletion occurs then data collection performance will decline. Heinzelman et al. [5] provided another applicable approach using the concept of clusters called LEACH. LEACH leads to less number of relays and instead forms the cluster groups. However the performance of the cluster depends on the cluster head. Younis and Fahmy [4] proposed the concept of HEED, which helps in the cluster head selection. The combination of residual energy and cost is considered in this approach. HEED can deliver well-distributed cluster heads and compact clusters. Gong et al [6] discovered energy efficient clustering in wireless sensor networks through quality links. Amis et al [7] contributed towards another interesting concept of d-hop cluster where each node is at d hop away from the cluster head. Among all the cluster based models, clusters not only act as a local data collector, a cluster head also acts as a controller and a scheduler for in-network process. Cluster heads use the spatio-temporal concept to minimize the reading process to maximize the energy saving. Single head clustering schemes are not compatible with Multiple Uploading-Multi Input Multi Output (MU-MIMO).In this paper a load balanced; multi-head clustering algorithm is proposed to improve data collection latency and network lifetime.

4. Proposed Methodology

In the applications of WSN, the sensors are densely deployed and scattered over a sensing field and left unattended once being deployed, that makes it tough to recharge or replace their batteries. Once sensors starts working, the sensors which are close to the information sink usually deplete their battery power at a faster rate compared to the other sensor node, due to additional relaying traffic. Once sensors round the information sink [2].deplete their energy, network property and coverage might not be secured. The main aim is to propose an energy efficient system that consumes energy uniformly across the sensing field to attain long network time period. Moreover, as sensing information in some applications are time-sensitive, information collection is also needed to be performed inside a fixed time-frame. Therefore, a large-scale information collection scheme aims at a smart, long network time period and low information latency scheme. Many approaches were discussed for economical information collection within the literature, in this work we discussed a Cluster Based communication using compressive sensing and MIMO techniques to extend network lifetime.

Sensor Layer – Load Balanced Clustering:

In sensor layer, the sensors self-organize themselves into clusters. The essential operation of clustering is the selection of cluster heads. The selected cluster heads are the ones with higher residual energy. Each sensor is covered by at least one cluster head inside a cluster. Clustering enables network scalability and extends the life of the network by allowing the sensors to conserve energy through communication with closer nodes and by balancing the load among the cluster head nodes. Clusters are formed based on the cost of communication and the load on the cluster heads.

The Load balanced clustering (LBC) algorithm is

comprised of four phases

· Initialization

· Status claim

· Cluster forming

· Cluster head synchronization

Initialization:

The Initialization is done at the sensor layer using LBC algorithm. The sensor informed its existence to all neighbors within its transmission range. If a sensor has no neighbor existence, it claims itself to be cluster. Otherwise sensor sets its status as tentative and its priority set by the percentage of residual energy. Then it sorts the neighbors with high residual energy as candidate peers. In the initialization phase, each sensor acquaints itself with all its near neighbors. The sensors $_{Si}$ would pick one neighbor with the highest initial priority as its candidate peer[8].

Algorithm 1. Phase I: Initialization
1: My. N ← {v | v lies in my transmission range; v € S;
2: if My. N Φ then
3: Set My. cluster_head to My.id;
4: Set My. Status to cluster_head;
5: else
6: My. init_prio ← Eres=Etot;
7: My. cluster_head ← 0;
8: My. Status ← tentative;
9: My. A ← v| v € Can_Peers (N)};
10: My. prio ← My.init_prio+∑v € My: A v:init_prio;
11: My. B, My.C _Φ;
12: Iter _ 0;

Status Claim Phase:

Each sensor determines its status by iteratively updating its local information, refraining from promptly claiming to be a cluster head. The sensors are members in the cluster. We use the node degree to control the maximum number of iterations for each sensor. The priority is partitioned into two thresholds τh(threshold of CH), τm (threshold of cluster member node) this is used to declare a sensor as either cluster head or cluster member [8].

Cluster Forming Phase:

The third phase is cluster forming that decides which cluster head a sensor should be associated with cluster consists of two cluster heads and sensors. The sensor with tentative status, or being a cluster member, is arbitrarily chosen as the cluster head from its candidate peers for load balancing purpose. If no sensor with tentative status then it chooses itself as the cluster head. The re-clustering is performed when the chosen cluster head is running on low battery. The Initialization phase is done by sending re-clustering messages to all sensors. The following algorithm explains about how clustering is done and how they receive packets from the other sensor.

Let us consider two cluster head i.e. C1, C2 whose cluster members are m1, m2, m3 and m4 respectively and τh be the threshold value. Let us assume that the initial energy of CH as xJ. Assign each cluster with energy of E and the maximum energy each cluster head is say $E_{max.}$

if $E(C1) > E_{max} (m1, m2)$

and $E\ \tau h(C1) > E_{max} (m1, m2)$

then C1 is the cluster head.

Similarly, if $E (C2) > E_{max} (m3, m4)$

And $E\ \tau h(C2) > E_{max} (m1, m2)$

Then C2 is the cluster head.

Therefore C1 and C2 are declared as cluster head and m1, m2, m3 and m4 are the members of the cluster head.

The Cluster Formation includes the following steps:-

1. Number of clusters, vertical and horizontal end points for each of the cluster acts as an input.
2. For each of the cluster formation Step3, 4 and 5 are repeated until all clusters are formed
3. Pick appropriate x end points and y end points for the cluster.
4. Generate the cluster id for the cluster.
5. Execute the node deployment algorithm and place the nodes within the cluster.

4.1.4. Cluster Head Synchronization Phase:

To perform data collection by TDMA techniques, 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 [1]. The communication between the nodes and cluster head in the CHG is called intra cluster communication. The synchronization among cluster head is done because to perform data collection by time division. This is done by sending beacon messages to cluster heads in CHG. the message contains the local clock information and initial priority. This is done only when sencar is going to collect data.

Algorithm: Synchronization between cluster heads

Step 1: if (status=cluster_head) then

Step2: Send initial priority, clock messages, etc

Step3: Receive beacon msg b, from other cluster heads.

Step 4: Compare b msg with sent msg

Step 5: if b msg is > status msg

Step 6: Set/Adjust the beacon msg clock to my clock.

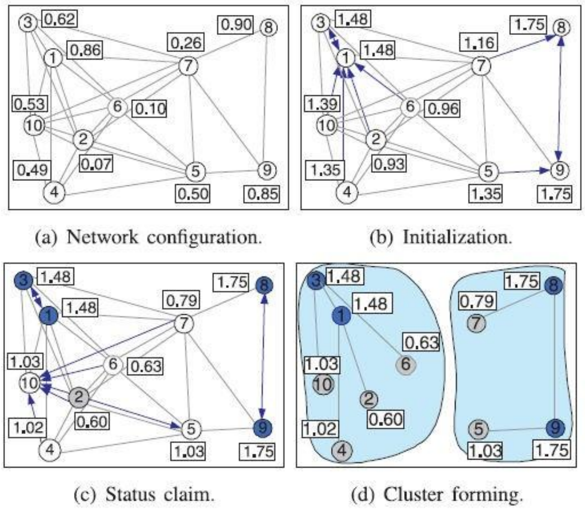

Fig. 2 An algorithm of load balanced clustering with m=2

MU-MIMO in WSN:

The feasibility of employing MIMO techniques in wireless sensor networks is envisioned [9][10][11]. Due to difficulties to mount multiple antennas on a single sensor node, MIMO is adopted in WSN to seek cooperation from multiple nodes to achieve diversity and reduce bit error rate. MIMO-based scheduling algorithm is used to coordinate transmissions. MU-MIMO can greatly speed up data collection time and reduce the overall latency. Another application scenario is in disaster rescue. For example, to combat forest fire, sensor nodes are usually deployed densely to monitor the situation. These applications usually involve hundreds of readings in a short period (a large amount of data) and are risky for human being to manually collect sensed data. A mobile collector equipped with multiple antennas overcomes these difficulties by reducing data collection latency and reaching hazard regions not accessible by human being. Although employing mobility may elongate the moving time, data collection time would become dominant or at least comparable to moving time for many high-rate or densely deployed sensing applications. In addition, using the mobile data collector can successfully obtain data even from disconnected regions and guarantee that all of the generated data is collected.

5. Implementation Methodology

Network Simulator-2 is used for the simulation, to implement the probing mechanism, congestion detection, and node placement algorithms. We create a sensor network of 50 nodes that use a single channel for communication. The nodes are configured to use the 802.11C protocol with a maximum data rate of 25Mbps and control rate of 10Mbps and a transmission range of 500mts. Based on the priority of the data sensed the sencar collects the data from the cluster heads by moving through the planned trajectory.

The implementation phase includes three modules, they are as following:

MODULES

1. Node Construction
2. Cluster Head Formation
3. Data Transmission through sencar

Node Construction:

The NS2 simulator is used to simulate the proposed algorithm. The number of nodes considered is 50 nodes, in which each node moves around 50m/s, with transmission range of 100m, bit rate of 250bits/s, with initial energy level of 100J and then sensors are positioned. The parameters used for simulation is as listed in Table 1.

Table 1.Parameters used for simulation:

PARAMETERS	DESCRIPTION
CHANNEL	WIRELESS
RADIO PROPAGATION	TWO-RAY GROUND
DEPLOYMENT AREA	300×300m to 1000m×1000m
ANTENNA TYPE	OMNI TYPE
MAC LAYER	802.11.C
NO. OF NODES	50,100 etc
THRESHOLD	250bits/s
TOPOLOGY	FLAT GRID
TRANSMISSION RANGE	50m
ENERGY	100 Joules

Cluster Head Formation:

In this module, each sensor determines its status and the sensor which has high residual energy become a cluster head and other sensors are members in the cluster. Sensors are self organize into the cluster by the LBC algorithm. Each cluster consists of two cluster heads and sensors. The residual energy of each and every node is broadcasted to the neighbors, so which ever node is having the higher residual energy is considered as a CH. The cluster members who are at one hop distance from cluster head they become the member of that CH. The CH once it is been elected it sends it id to the sencar and also based on the priority is been sensed.

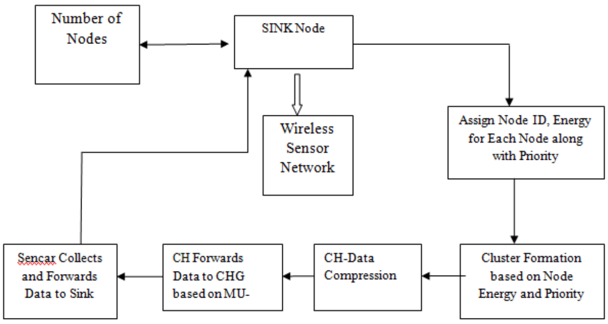

Fig 3. Proposed system architecture

Data transmission through sencar:

Source node in cluster head sends data to base station via group cluster head and sencar node. As in Fig 3, in that process, sensor nodes send data to its cluster head. Then the cluster head sends the collection of data to its group cluster head. We coordinate the mobility of sencar to fully enjoy the benefits of dual data uploading, which ultimately leads to a data collection tour with both short moving trajectory and short data uploading time. Finally sencar node collects the data from group cluster head and gives that collected data to base station.

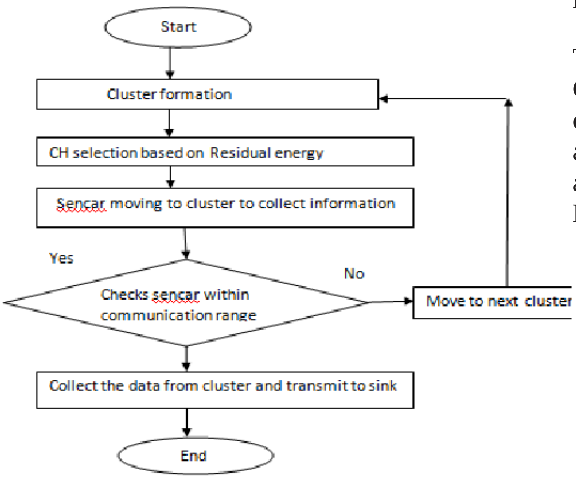

Fig 4. Flow chart for data collection by sencar

A data flow diagram (DFD) is a logical model of the flow of data through a system that shows how the system's boundaries, processes, and data entities are logically related. In above fig 4, first step is formation of the cluster(i.e. group of nodes),then we select the cluster head based on the residual energy(left out energy), the mobile collector keeps on moving for collecting the information from the cluster heads, which are within the transmission range of SenCar.

6. Performance Evaluation and Result Analysis

In order to evaluate the performance of proposed algorithm, we performed a simulation in NS2 and collected the data. The metrics used for the comparison of existing clustered SISO with the proposed MU-MIMO are delay, over head and energy consumption. The MIMO scheme results in least energy consumption so the lifetime of the network also extended, because the sensor sends the data transmission by multi hop fashion. The low latency in data uploading is achieved by using dual data uploading technique in sencar.

The fig 5, Shows the energy consumption of MU-MIMO with compressive sensing and without compressive sensing in WSN. The data sensed by the member sensor nodes may contain redundant data. So the CHs compress the received data by using the redundancy compressive technique and upload the data to sink. This results in fast uploading of data which deals with results in less delay and less energy consumption.

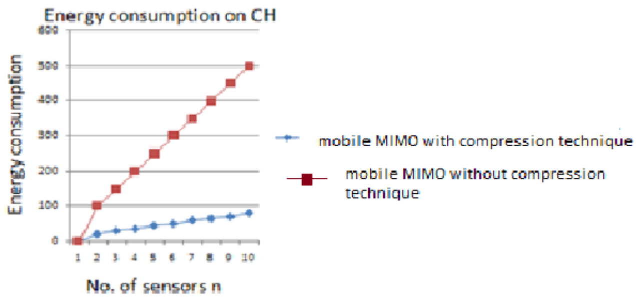

Fig. 5 Compression technique in mobile MIMO

The Fig 6. explains about the energy consumption on each CH.In clustered Single Input Single Output(SISO) each cluster has single CH, but in MU-MIMO, each cluster has atmost two CH.So the load is balanced between two CH and therefore energy consumption is reduced in MU-MIMO.

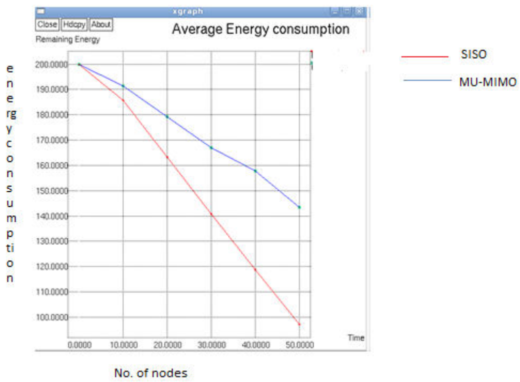

Fig.6 Energy consumption in SISO and MU-MIMO

The Fig. 7 explains about the delay. In clustered SISO the mobile collector is equipetted with one antenna hence it can receive data from one CH at a time. This increases the delay.But in MIMO, equippied with two antenna, for two CH so it can receive the data simulataneously from two CH. In order to avoid interference the uploading of data is based on time schedule

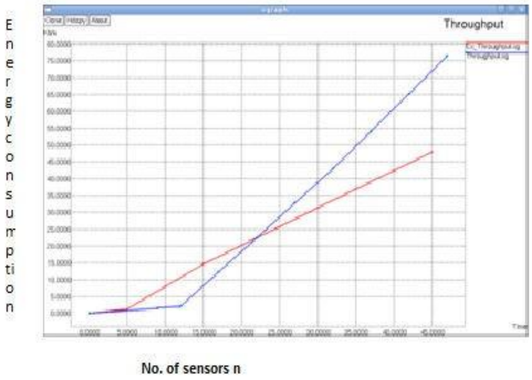

Fig.7 Delay in SISO and MU-MIMO

7. Conclusion

The cluster based communication using compressive sensing and MIMO techniques is proposed in this paper. It consists of sensor layer, cluster head layer and sencar layer. It employs distributed load balanced clustering for sensor self-organization, adopts collaborative inter-cluster communication for energy-efficient. Transmission among cluster Head Groups, uses, dual data uploading for fast data collection, and optimizes SenCar's mobility to fully enjoy the benefits of MU-MIMO. Our performance study demonstrates the effectiveness of the proposed framework in terms of packet delivery ratio, delay and energy consumption.

8. Future Scope

There are some interesting problems that may be studied in our future work. The first problem is how to find polling points and compatible pairs for each cluster. A discretization scheme should be developed to partition the continuous space to locate the optimal polling point for each cluster. Then finding the compatible pairs becomes a matching problem to achieve optimal overall spatial diversity. The second problem is how to schedule MIMO uploading from multiple clusters. An algorithm that adapts to the current MIMO-based transmission scheduling algorithms should be studied in future.

REFERENCES

[1] Mobile Data Gathering with Load Balanced Clustering and Dual data gathering with load balanced clustering in wireless sensor network,Miao Zhao, member, Yuanyuan Yang, Fellow,IEEE and Yang, Fellow,IEEE and Cong Wang, *IEEE transaction on mobile computing,Vol. 14,no. 4,april 2015*

[2] A load balancing in clustering with data gathering for network prolong using sencar in wireless sensor network *International Journal for Technological Research In Engineering Volume 3,* Issue 4, December-2015

[3] W. C. Cheng, C. Chou, L. Golubchik, S. Khuller, and Y. C. Wan, ―A coordinated data collection approach: Design, evaluation, and comparison,‖ *IEEE J. Sel. Areas Commun., vol. 22, no. 10, pp. 2004–2018, Dec. 2004.*

[4] Y. Wu, Z. Mao, S. Fahmy, and N. Shroff, ―Constructing maximum- lifetime data-gathering forests in sensor networks,‖ *IEEE/ ACM Trans. Netw., vol. 18, no. 5, pp. 1571–1584, Oct. 2010.*

[5] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, ―An application-specific protocol architecture for wireless microsensor networks,‖ *IEEE Trans. Wireless Commun., vol. 1, no. 4, pp. 660– 660, Oct. 2002.*

[6] D. Gong, Y. Yang, and Z. Pan, ―Energy-efficient clustering in lossy wireless sensor networks,‖ *J. Parallel Distrib. Comput., vol. 73, no. 9, pp. 1323–1336, Sep. 2013.*

[7] A. Amis, R. Prakash, D. Huynh, and T. Vuong, ―Max-min d-cluster formation in wireless ad hoc networks,‖ in *Proc. IEEE Conf. Comput. Commun., Mar. 2000, pp. 32–41.*

[8] A load balancing in clustering with data gathering for energy efficient using sencar in wireless sensor networks. *International Conference on Explorations and Innovations in Engineering & Technology (ICEIET – 2016)***.**

[9] S. Cui, A. J. Goldsmith, and A. Bahai, ―Energy-efficiency of MIMO and cooperative MIMO techniques in sensor networks,‖ IEEE J.Sel. Areas Commun., vol. 22, no. 6, pp. 1089–1098, Aug. 2004

[10] S. Jayaweera, ―Virtual MIMO-based cooperative communication for energy-constrained wireless sensor networks,‖ *IEEE Trans. Wireless Commun., vol. 5, no. 5, pp. 984–989, May 2006.*

[11] S. Cui, A. J. Goldsmith, and A. Bahai, ―Energy-constrained modulation optimization,‖ *IEEE Trans. Wireless Commun., vol. 4, no. 5,pp. 2349–2360, Sep. 2005.*

[12] X. Tang and J. Xu, ―Adaptive data collection strategies for lifetime- constrained wireless sensor networks,‖ *IEEE Trans. Parallel Distrib. Syst., vol. 19, no. 6, pp. 721–7314, Jun. 2008.*

.**BIOGRAPHY:**

Ms. Sunanda Patne received her Bachelor of Engineering in Computer Science and Engineering in 2010. Currently she is a M.Tech student in Computer Networking Engineering from Visvesvaraya Technological University at The Oxford Collage of Engineering, Bangalore. Her research interests are Internet of Things (IOT), Computer Networks, and Network Security.

Mrs. Vinodha K received her Bachelor of Engineering in Electronics and Communication in 1998. She received her ME in Computer Science and Engineering from Anna University in 2008.She is pursuing Ph.D in Computer Science and Engineering at VTU, Belgaum. Currently she also holds a faculty position as Assistant Professor, Department of ISE, The Oxford College of Engineering. Her main research interests are Computer Networks and Distributed Networks