Compressive Data Gathering for MI Based Clustered Non-Conventional WSNs

1st Vinay Kumar
Department of Electronics and Communication Engineering
VNIT, Nagpur, India, 440010
vinayrel01@gmail.com

2nd A. Laxmi Prasanna
Department of Electronics and Communication Engineering
VNIT, Nagpur, India, 440010
akulalaxmiprasanna@gmail.com

3rd Dush Nalin K. Jayakody
School of Computer Science and Robotics Head,
Infocomm Lab, National Research Tomsk
Polytechnic University, Tomsk 634050, Russia
nalin.jayakody.@ieee.org

4th Akhilendra Pratap Singh
Department of Electronics and Communication Engineering
National Institute of Technology Meghalaya India, 793003
akhilendra.singh@nitm.ac.in

4th Indrasen Singh
Department of Electronics and Telecommunication Engineering
G H Raisoni College of Engineering, Nagpur 440016, India
indrasen.singh@raisoni.net

***Abstract*—In non-conventional media (underground and underwater environment), the wireless signal propagation is not advantageous by means of electromagnetic (EM) waves due to the problems like high path loss, size of antenna and dynamic channel conditions. Hence, an alternative communication technique of magnetic induction (MI) based communication is developed which is highly suitable for efficient communication in this media due to its promising features such as constant channel behavior, less propagation delay and stealth underwater operations. In this paper, a traditional energy efficient scheme known as compressive data gathering (CDG) is implemented on MI based communication in non-conventional wireless sensor networks (WSNs) i.e in dry soil and sea water media. In this paper we have also estimated MI sensor energy consumption (sensor sensing, sensor logging, micro-controller, radio transmission and reception electronics) and compared the results. Moreover, we perform an analytical modeling to find the total energy consumption in the network for two different media (dry soil and sea water).**

***Index Terms*—Clustered non-conventional WSN, MI communication, energy efficiency and compressive sensing.**

I. INTRODUCTION

MI based communication is currently traversed approach in non-conventional media. For non-conventional media like underground and underwater, Electro magnetic (EM) wave system is not suitable due to various losses and antenna size as constraint [1]. Hence, MI wave guide based approach for communication is proposed to reduce above losses for non-conventional media (soil, rocks and water). MI approach uses the near field of magnetic coil of low frequency to initiate the wireless communication. In MI based communication, the transmitter and receiver coils acts as primary and secondary of a transformer. Various parameters such as frequency of operation, number of turns, length of coils and medium (properties of medium) plays a key role in effective MI communication. In MI communication, magnetic field generated by a time varying current in primary (transmitter) coil induces emf in secondary (receiver) coil which is used to form communication network. In terrestrial environment, MI waves attenuate rapidly while in con-conventional mediums it achieves larger ranges. In WSNs, powered batteries are required for sustaining the sensor nodes to longer duration. To greatly reduce or compress the amount of information, compressed sensing theory play an important in either conventional or non-conventional WSNs. Hence in this paper, we have implemented a traditional technique of CDG based on compressed sensing for MI based communication in non-conventional medias such as sea water and dry soil.

In this data gathering technique, each MI sensor node collects the required data and multiplies with the projection coefficient and moves to the next preceding node and adds the weighted result from previous node. Therefore, every node transmits data in form of the total weighted sum along particular route or path.Therefore all the data collected from various nodes is transmitted to base station which helps in reconstruction of data using sensing matrix for M measurements [4]. Hence, this CDG technique based on CS theory converts the N samples into M weighted sums of the samples in non-conventional media on MI based perspective. According to proposed technique the reduced transmitted data amounts to lower energy consumption which makes communication system more efficient.

A. Motivation

Zhi Sun et al. [1] proposed MI based communication which achieve constant channel condition, very low path losses and the size of antenna in underground WSNs and also developed wave guide technique to increase the transmission range significantly. J. Qiao et al.[4] proposed two compressed data collecting techniques for equitable projection nodes based on even clustering. In this paper, even clustering is performed by dividing the sensing area into equal sized grids. Ebrahimi et al.[5] proposed compressed data acquiring technique using compressive sensing and random projection. According to it a new new CDG technique called as minimum spanning tree projection (MSTP) which generates minimum spanning trees that are embedded at arbitrarily chosen projection nodes. In this method, M nodes were randomly selected as projection nodes or cluster heads (CHs) which accumulates the weighted sum. The non-CH MI nodes denotes non-zero entries of each row of observation matrix which are given to a CH and sends the weighted sum to the CH by MSTP and then the CH node will forward the total weighted sum involving itself to the base station. The major drawback of this paper was large energy consumption because of random selection of projection nodes. Chong Luo et al. [6] explained the CDG for large sensor networks addressing the two major challenges such as effective communication, reduction in energy used by sensor network which is a cost effective measure.

Bajwa and Haupt et al.[7] introduced compressive sensing technique in WSN. This paper explains the CS theory for WSNs in which a fusion center recovers the required data or information from a group of spatially allocated MI sensor nodes. Vinay Kumar et al. [11] have explained the designing of Mi sensor nodes for non-conventional media using multi-layered sender equiped with novel energy model. This paper describes an energy model that may be more useful in formulating the features such as routing, modulation, clustering and Medium Access Control (MAC) protocol using optimal clustering technique.

The main principle of this proposed technique is, that in this the base station will gather the weighted sum of all MI nodes readings to restore the original signal. Also this paper described the theoretical analysis of capacity gain of sensor network for CDG.

B. Contributions

The important contributions of this paper were given as:

1) Analytical implementation of CDG method based on compressive sensing technique in clustered MI based non-conventional WSNs (dry soil and sea water media).
2) Evaluation of the total energy used per round of CDG based on even clustering, random walk method and over estimation of sensor energy consumption on MI based communication in dry soil and sea water medium.
3) Comparative analysis of the total energy absorbed per round by the number of clusters and number of rounds for different number of nodes for the two (dry soil and sea water) mentioned media.

The remainder of this paper are categorized as follows: In section II, CDG based on compressive sensing theory on even clustering in clustered MI non-conventional WSN has been explained. Results and analysis of the proposed model are presented in section III. Lastly, section IV concludes the paper along with the future scope.

C. Basic theory of Compressive Sensing

The phenomenon of compressive sensing (CS) in either conventional or non-conventional WSNs can be used to compress the sparse signals below the nyquist rate and also fairly reconstructed by non-linear algorithms. The sparse representation of *n* dimensional signal *x* which can be sparsely disintegrated into $n \times n$ transformation matrix θ is

$$x = \theta\psi \tag{1}$$

Where ψ is a sparse column matrix with *k* number of non-zero entries $(k \ll n)$ and let ϕ be the $m \times n$ observation matrix, where $m \ll n$. Hence, the set of *m* observation values *y* is

$$y = \phi x = S\psi \tag{2}$$

Mathematically equation (2) can be expressed as

$$\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{pmatrix} = \begin{pmatrix} \phi_{11} & \phi_{12} & \dots & \phi_{1n} \\ \phi_{21} & \phi_{22} & \dots & \phi_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \phi_{m1} & \phi_{m2} & \dots & \phi_{mn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix}$$

Tropp et al. [20] proposed a concept known as restricted isometry property (RIP) which states that for a matrix *S*, it satisfies this property if it satisfies $\epsilon \in (0,1)$, so that all the sparse signals θ will satisfy the following equation [20].

$$(1-\epsilon)\,\|\theta\|_2^2 \;\le\; \|S\theta\|_2^2 \;\le\; (1+\epsilon)\,\|\theta\|_2^2 \tag{3}$$

Hence, if the signal is compressible and the sensing matrix *S* satisfies the RIP, then the recovered signal can be acquired by l_0 norm or l_1 norm [21]. The reconstruction algorithm needs only *M* measurements to recover the original signal.

$$\theta^1 = arg\ min\,\|\theta\|_1 \tag{4}$$

The above equation represents the reconstruction of compressible signals.

II. CDG based on CS theory in MI based communication

Considering a squared platform of side 100 m with 100 MI for MI sensor nodes. According to MI based energy dissipation model, the energy that is required to process *l* bits at a distance d at transmitter and receiver, is given by [6]

$$E_{Tx}(l,d) = lE_{Tx-elec} + \frac{l\mu n_t^2 I^2 a^4}{8d^6} \tag{5}$$

$$E_{Rx}(l) = lE_{Rx-elec} \tag{6}$$

Where $E_{Tx-elec}$ and $E_{Rx-elec}$ are the dissipated energies in transmitter and receiver electronics (nJ/bit) respectively. I is the current in transmitter coil (A), a is the radius of coil (m), n_t is the number of turns of transmitter coils and d is the distance between the transmitter and receiver (m).

Even clustering technique is used to efficiently distribute the MI nodes in spatial locations. Therefore the surveying area is classified into same sized grids. In the very first stage of selecting the projection nodes, it is required to calculate the total number of clusters by dividing entire area into small grids. Select the node with highest energy in that cluster as the projection node. Transmit the status of the chosen projection node to all other projection nodes. Each node in the cluster selects it's projection node on the basis of minimum path. Now, the data collected by all the projection nodes will be send to the sink and added up accordingly.

Let K be the number of clusters in the sensing region and R is the radius of the surveying area. Assuming the shape of cluster as circular and the position of cluster head (CH) or projection node at the center of cluster. Then the average coverage area of CH nodes is $(\pi R^2)/K$. In this model, as the the is transmitted according to multi-hop criteria hence, transmission distance is considered to be D. The energy dissipation of non-CH node and CH node in a cluster to transmit l bits of data [11] are as follows respectively.

$$E_{nonCH} = lE_{elec} + l\alpha E_{MI}(d^6_{toCH}) \tag{7}$$

$$E_{CH} = l(\frac{n}{K} - 1)E_{Rx-elec} + lE_{Tx-elec} + l\alpha E_{MI}(D^6) \tag{8}$$

$$E_{MI} = \frac{\mu I^2 a^4 n_t^2}{8d^6} \tag{9}$$

$$G = e^{-\dfrac{d}{\delta}}$$

$$\delta = \frac{1}{2\pi f\sqrt{\dfrac{\mu\epsilon}{2}\left(\sqrt{1 + (\dfrac{\sigma}{2\pi f\epsilon})^2} - 1\right)}}$$

Where G is the attenuation factor, μ and ϵ are magnetic permeability and electric permittivity and σ is the conductivity of medium. The energy dissipated in a current carrying coil E_{MI} purely depends on the coil structure and circuit parameters such as total turns in of primary (sending end)and secondary (receiver end) and radius of coil. The factor α depends on the frequency of operation and attenuation factor (G) which in turn depends on the skin depth of medium. d^6_{toCH} is the distance between the non-CH nodes and CH node in a cluster. In MI communication, the received power and the sixth power of distance transmitter and receiver are inversely proportional to each other [11]. As here it is considered that all MI nodes are uniformly located, the distribution function for all the nodes is taken as $\rho = \dfrac{N}{\pi R^2}$. Therefore, the distance from non-CH node to CH node is

$$d^6_{toCH} = \frac{NR^4}{4k^4} \tag{10}$$

The overall energy consumption per round can be evaluated as

$$E_{total} = kE_{clus} \tag{11}$$

But the total energy consumption per cluster is

$$E_{clus} = E_{CH} + \left(\frac{n}{K} - 1\right)E_{nonCH} \tag{12}$$

At optimal number of clusters, the total energy consumption will be minimum. Thus, to evaluate the optimal number of clusters in the WSN, equate the first derivative of overall energy consumed (E_{total}) to zero, therefore the following equation represents the K_{opt} in MI based non-conventional WSNs.

$$K_{opt} = \sqrt[5]{\frac{N^2R^6}{D^6}} \tag{13}$$

Considering the sending distance as D per hop as $50\sqrt{2}$ and radius as 50 m, therefore approximating the number of grids or clusters in the sensing region to 5. In this case we have taken K as optimal number of clusters which can also be termed as the number of required CS measurements (m). Let q be the compression ratio and R is half of the side length L of the surveying area. Here, $q = \dfrac{m}{n} = \dfrac{K}{n}$ [4] and substituting in gives,

$$q^5 = \frac{n^2L^6}{32D^6}$$

and

$$N^3 = \frac{L^6}{32D^6q^5}$$

In this paper, we have compared the proposed model of MI based communication with non-uniform walk data collection method. Lets assume K be the number of random walks and τ is the length of RW. The total energy used in forwarding data to the sink is the sum of the energy consumed in transmitting and receiving data by $(\tau - 1)$ nodes and this fusion energy sends data to the sink as given in [4].

$$E_{MI-path} = (2\tau - 1)lE_{elec} + l_{DA} + lE_{MI}\alpha D^6_{BS} \tag{14}$$

According to [13], the expected distance is

$$E[d^6] = \frac{D^6}{32} \tag{15}$$

$$E[D^6_{BS}] = \frac{L^6}{12} \tag{16}$$

Now, the total energy consumption of RW [4] is

$$E_{RWtotal} = kE_{MI-path}$$

$$\begin{aligned} E_{RWtotal} = l\big[&(2n - K)E_{elec} + nE_{DA} \\ &+ E_{MI}\alpha((n - K)E[d^6] + KE[D^6_{BS}])\big] \end{aligned} \tag{17}$$

Analytical results of the two methods (CDG and RW) are expressed by equations (12) and (17) and shown in Fig. 1 and Fig. 2.

A. Evaluation over an estimation of sensor energy consumption

Here we have evaluated a comprehensive energy model for non-conventional WSNs on the basis of MI based communication. This model shows more life expectancy of the sensor nodes compared to existing models (CDG and RW), also it uses optimal clusters with increase in the free space energy fading. The total energy absorbed by non-CH MI node in a cluster per round due to various factors [7] is

$$E_{NCH} = \big[E_{sense} + E_{d-log} + lE_{elec} + ld^6 E_{amp} + T_a V_{Sup}[c_N I_a + (1 - C_N) I_s]\big] \tag{18}$$

Likewise, the total energy consumption of each CH node per round [7] is

$$E_{CH} = [h_3 E_{sense} + h_4 E_{d-log} + E_{switch} + E_{leakage} + E_{Rx} + E_{Rx-NCH} + E_{actuation} + E_{Tx-CH}] \tag{19}$$

1) Sensor sensing: The total energy consumption for sensing activity (includes signal sampling, conversion of physical signals into electric signals and ADC) for l bits of data at the MI sensor node per round [7] is

$$E_{sense} = lV_{Sup} I_{sens} T_{sens} \tag{20}$$

2) Sensor logging: The total energy consumption for sensor data logging (reading and writing l bits of data into memory) for MI sensor node per round [7] is

$$E_{d-log} = lV_{Sup}(I_w T_w + I_r T_r) \tag{21}$$

3) Micro controller processing: The total energy consumption for switching the micro controller per round [7] is

$$E_{switch} = h_1 b_1 N_{cyc} C_{avg} V_{Sup}^2 (\frac{n}{K} + 1) \tag{22}$$

This energy is wasted due to leakage current which arises when a sub-threshold leakage current flows between source and the ground [7].

$$E_{leakage} = h_1 b_1 V_{Sup} \big(I_0 e^{\frac{V_{Sup}}{n_p V_t}}\big)\big(\frac{N_{cyc}}{f}\big)(\frac{n}{K} + 1) \tag{23}$$

4) Actuation: The total energy consumption for actuation per round which is hard to estimate in general [7] is

$$E_{act} = E_{actu} N_{actu} \tag{24}$$

5) Radio transmission and reception: The total energy consumption due to the transmission of l bits of data from CH node to parent CH per round [7] is

$$E_{Tx-CH} = h_2 b_2 (1 + \gamma) E_{elec} + b_2 (1 + \gamma) d_{toBS}^6 E_{amp} \tag{25}$$

The dissipated energy due to transmission of b_1 bits of data from sensor node to CH and b_2 bits from CH to parent CH per round are [7]

$$E_{Rx} = h_2 b_1 E_{elec} (\frac{n}{K}) \tag{26}$$

$$E_{Rx-CH} = h_2 b_2 \gamma E_{elec}. \tag{27}$$

Table I: Parameters used in this paper and their values [7].

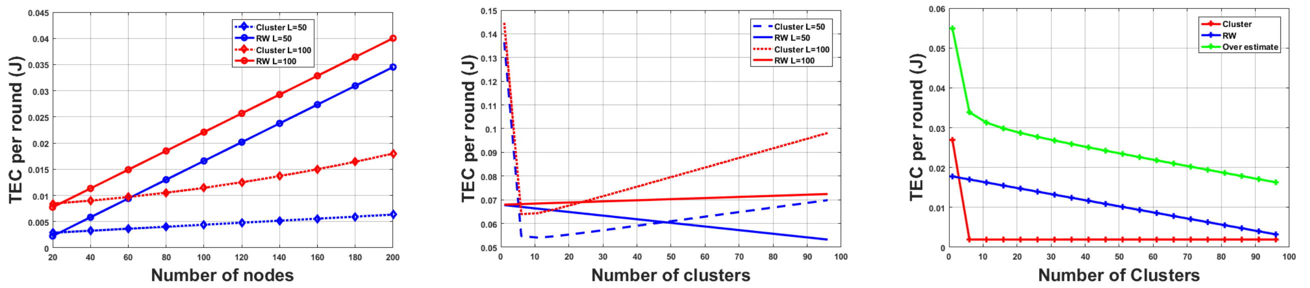
Parameter	*Defination*	*Value*
V_{Sup}	*Voltage supply to sensor*	3V
f	*Sensor frequency*	100 KHz
N_{cyc}	*Number of clock cycles*	0.4 $\times 10^4$
C_{avg}	*Avergae capacitance per cycle*	2.8 pF
I_o	*Leakage current*	0.195 mA
V_t	*Thermal voltage*	0.4 V
I_a	*Wakeup mode current*	8 mA
I_s	*sleep mode current*	16 μA
T_a	*Active time*	1 mA
T_s	*Sleeping time*	100 mA
I_{sens}	*Sensing activity current*	10 mA
T_{write}	*Time for writing*	5 ms
T_{read}	*Time for reading*	100 μs
T_{sense}	*Time for node sensing*	0.05 ms
T_{OFF}	*Idle to sleep time*	250 μs
T_{ON}	*Sleep to idle time*	2450 μJ
E_{act}	*Actuation energy*	0.02 μJ

The parameters that are used in the above sensor energy evaluation are mentioned in the below table with their corresponding values.

III. RESULTS AND ANALYSIS

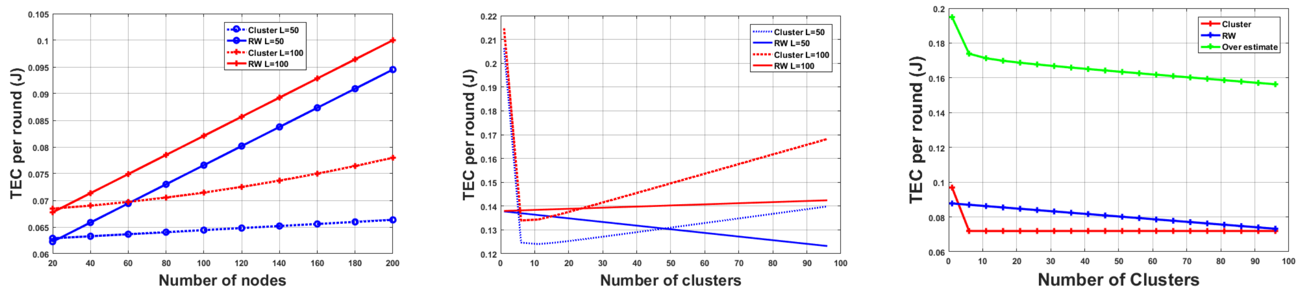
In this section, the analytical results acquired by applying the compressive data gathering technique based on even clustering on MI based non-conventional media are explained and the evaluations are performed through MATLAB software. This CDG technique based on even clustering on MI based communication is implemented in two media i.e., dry soil (DS) and sea water (SW). From the analytical results, Fig. 1 and Fig. 2 show that among the two considered media, DS medium exhibits good performance in terms of overall energy consumption of the sensor network per round. Because, the skin depth is inversely proportional to the conductivity of medium i.e., as the conductivity of medium increases, skin depth of the respective medium decreases gradually. This decrease in skin depth results in decrease of the attenuation factor. Thus, this decrease in attenuation in turn decrease the amount of energy consumption and hence among the two media, DS medium performs well than sea water medium due to less attenuation for the wireless propagation through wave guides. Also, the dissipation energy at transmitter side depends on the coil and circuit parameters such as the number of turns of transmitter and receiver coils, radius of coil and distance between the transceivers.

Fig. 1(a), 1(b), 1(c) shows the total energy absorbed per round with respect to number of nodes and clusters of CDG even clustering and random walk methods in non- conventional applications (dry soil and sea water) on MI based communications. Fig. 1(a) and 1(b) shows that for two different values of lengths of monitoring area (L = 50 and 100) in a sensor network with 100 MI nodes, RW method exhibits more energy consumption than CDG based even clustering method



(a) TEC per round Vs no. of nodes (soil) (b) TEC per round Vs no. of clusters (soil) (c) TEC Vs no. of clusters for 3 models (soil)

Figure 1: Comparitive analysis of total energy, no. of nodes and clusters for different L values in dry soil medium.



(a) TEC per round Vs no. of nodes (water) (b) TEC per round Vs no. of clusters (water) (c) TEC Vs no. of clusters for 3 models (water)

Figure 2: Comparitive analysis of total energy, no. of nodes and clusters for different L values in sea water medium.

with increase in the number of nodes and clusters in dry soil medium.

A. *Estimation of sensor energy consumption*

Fig. 1(c) and 2(c) explains the total energy consumption per round for three different methods on MI based communication in dry soil and sea water media respectively. In this case, we considered the various energy consumption sources which are neglected by CDG based on even clustering and RW methods. Such sources are energy consumption due to sensor sensing, sensor logging, micro-controller processing, radio transmission and reception, transition between operating modes and actuation. The results conclude that CDG and RW methods over estimate the real sensor lifetime in non-conventional applications. This express the significance of using such a novel energy model by comparing this to other models (CDG and RW) in terms of energy consumption of MI sensor.

IV. CONCLUSION

In this paper, we have effectively implemented an energy-efficient technique of CDG based on compressed sensing theory on even clustering in MI based communication in non-conventional applications. A comparative analysis between total energy consumed and number of clusters, nodes is performed. The above analysis of the results show that, the energy consumption in random walk method in dry soil medium decreases monotonically with increase in the number of nodes and clusters than in sea water medium. Also, CDG and RW methods based on even clustering over estimate the network sensor lifetime (considering the real sensor energy consumption) in non-conventional MI based communication.

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