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A Unified Approach of Augmenting the Lifetime of Cooperative Wireless Sensor Networks

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Abstract:

This paper aims to optimize the service life of the network in wireless sensor networks. In this work, the emphasis is focused on energy harvesting and energy reduction methods for the enhancement of network life in wireless sensor networks. In the wireless sensor network, using the energy harvesting nodes as the cooperative relays for scavenging energy from ambient sources can lead us to better solution. The measurements of network efficiency such as probability of successful information exchange and network lifetime gain were obtained and simulated using the MATLAB program. To have an efficient communication between two corners and to minimize the energy consumption in WSN, fading must to be reduced for which spatial diversity is the solution. In this paper, VMIMO technique is used to achieve spatial diversity in wireless sensor networks that requires the use of single omnidirectional antenna at each sensor node and decreases the power consumption by considering multiple node cooperation. In addition to energy harvesting, this paper also studies about joint virtual MIMO and energy-efficient data gathering in wireless sensor networks. D-vMDG algorithm is studied which is used for an efficient data gathering inVMIMO based communication scheme. This algorithm involves constructingtree like topology by taking specific features of VMIMO into account. D-vMDG reduces energy consumption by 81% and 31% compared to MDT and the MIMO-LEACH algorithms according to simulation study.

Index Terms— Wireless Sensor Networks(WSN), EMREH, Energy harvesting, Data gathering, Virtual MIMO, energyefficiency (EE).

I. INTRODUCTION

Wireless sensor networks, consists of community of self-organized nodes, and provide a wide advantage over a longer period of time in the field of monitoring the physical world. The key emphasis in WSN is energy efficiency. Deploying sensor nodes with limited battery capacity at inaccessible environment is a major issue. For that reason, using the energy harvester nodes as a cooperative relay renders us the better solution in the arena of WSN. A network lifetime is characterized as duration under which a device operates efficiently at a given functionality. A key constraint in WSN is energy sources may not always be available. To extend the network lifetime, we have considered two methods. One by technique of energy harvesting and other by using virtual MIMO to reduce energy consumption in WSN. Under the joint virtual MIMO and data gathering we considered the form of data gathering is data gathering without fusion.

As battery power is a critical resource the idea of reducing power consumption for data gathering is a necessity. To avoid fading in the area of communication, spatial diversity is considered as the best approach, in which each sensor node has multiple numbers of antennas to transmit/receive the data. But it is difficult to implement multiple antennas at each and every sensor node when size and complexity is considered. So to avoid this issue

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VMIMO mechanism has been introduced to achieve spatial diversity which uses only one omni-directional antenna at each sensor node. VMIMO comprises four modes, they are single-input single –output (SISO), multi-input single-output (MISO) and multi-input multi-output (MIMO) respectively. To reduce the power consumption in wireless sensor networks, a routing algorithm for energy efficient data gathering using VMIMO has been proposed. For an energy efficient data gathering using VMIMO we have two steps. Firstly, we describe the problem posed due to joint VMIMO and data gathering (vMDG), and formally prove that this issue is NP-Hard. This problem is very complex and thus it is difficult to solve optimally. We propose a distributed and heuristic algorithm called D-vMDG consisting of two steps to solve this. The first step involves selecting the set of cooperative node pairs and constructing a tree like topology by taking into account the specific features of VMIMO. Then, after this built topology, a dynamic programming based energy efficient routing protocol is proposed. Our theoretical analysis shows that the proposed algorithm can guarantee a constant approximation for the problem in terms of the optimal efficiency. Based on the simulation result analysis the lifetime of the network has been increased using the energy harvesting technique and the D-vMDG approach decreases the energy consumption by about 81% and 36% compared to the well-known MDT algorithm and MIMO-LEACH algorithmsrespectively.

This paper is organized as follows. In Section II gives an overview of its operation of Wireless sensor networks. Section III portrays the System model and network performance metrics such as Probability of successful message exchange and network lifetime using energy harvesting. Section IV describes the use of Virtual MIMO in Wireless sensor networkandprovidestheinformationaboutanalysis of different data gathering algorithms in wireless sensor networks. Section V describes about the simulation results of successful message exchange, network lifetime and different data gathering algorithms in wireless sensor networks.

II .WIRELESS SENSOR NETWORKS

A Wireless sensor network can be identified as a network of sensor nodes exchange the information collected from a geographical area via wireless links. Network purpose is to sense data from the field being monitored and forwardit to the common destination node. A Sensor node is a device that senses and detects some kind of input from both the physical or environments, such as pressure, heat, light, etc. The sensor output is an electrical signal that is forwarded to a processor for further processing. Due to least power, cost effective nature, flexibility, reliability and accuracy WSN is far superior to the conventional networks.

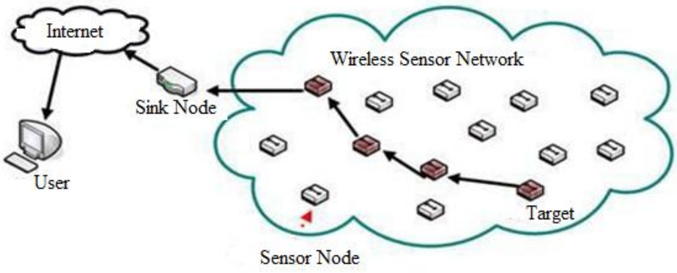

Fig: 1 Basic Model of Wireless Sensor Network

III. SYSTEM MODEL

This section portrays the measurements of network performance. A relay act as intermediate node that harvests the electromagnetic energy (EMRH) from other sources that is sending and receiving information through a series of connected nodes [1]. The time is split into m communication cycles. Fig.2 comprises three time period slots t_s. In Fig.2(a) the first time slot is depicted, in which each source S1 transmits its collected data to the intermediate relay and rest of the sources measures interference for relay that is attempting to decode the message. Simultaneously, the energy harvesting system that was attached to the relay scavenges the EMR due to the transmission of all S1sources. The second time slot in Fig.2(b) depicts the same purpose as Fig.2(a) except the source (S1) is idle and each source (S2) transmits data to nearest relay. Ultimately, each relay successfully decoded the messages from sources S1 and S2 in third time slot that was shown in Fig.2(c).

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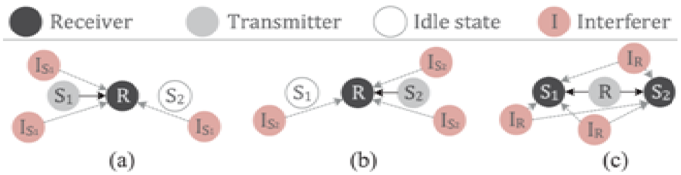

Fig:2Communication Slots

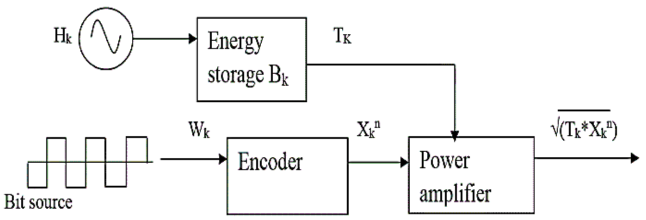

Fig.3. Over all block diagram of energy harvester module.

In the above fig.3 it is assumed that the energy harvesting system at transmitter side. In the slot k the transmitter is aware of the current channel SNR γ_k, past harvested energy H_k and current energy stored in the battery B_k .

The energy harvested from the energy harvester is stored within energy storage such as battery. The input bits are encoded as data symbols by a encoder and subsequently sent to power amplifier that uses harvested energy [4] to transmit to longer distances. At the time, packet to be transmitted by transmitter in slot k is given as $\sqrt{(T_k X_k^n)}$.

A. Distribution of WSN nodes

The sensor nodesaredistributed randomlyover a geographical region in this proposed framework.In this scenario, the sensor nodes only communicate with each other when the distance between them is within the range of communication is given as

$$d_{i,j} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \quad (1)$$

Where x_i, y_i are the first node location and x_j, y_j are the second node location.

3.1 NETWORK LIFETIME

The lifetime output of the network relies on the probability of successful information exchange between two nodes and the lifetime of energy harvesting device.

3.1.1 Successful Message Exchange Probability

This metric defines the message being decoded successfully at the receiver when the signal to noise plus interference ratio from its nearest transmitter is surpassed the threshold otherwise the message is aborted.

The signal to interference noise ratio (SINR) is defined by

$$\text{SINR} = \frac{P_t h d^{-\alpha}}{(I_d + N)} \quad (2)$$

Where, P_t=transmit power, h=amplitude of the Rayleigh fading, α=path loss exponent, I_d=interference,
N=additive Gaussian noise, d=distance between the nodes

The efficiency of the network can be improved by the probability of active data exchange (P_{ex}) between two nodes is given by

$$P_{ex} = (P_{s1\text{-}r} P_{s2\text{-}r})(P_{r\text{-}s1} P_{r\text{-}s2}) \quad (3)$$

Where **s1** and **s2** are sources and **r** is the relay.

(4a) $$C = \frac{-2\pi^2 \gamma^{\frac{2}{\alpha}}}{\alpha \sin(2\pi / \alpha)}$$

(4b) $$D = \frac{\gamma N}{P_t 2^{\alpha}} \left(\frac{1}{\lambda_1^2} + \frac{1}{\lambda_2^2} + \frac{2}{(P_{act} \lambda_R)^{\frac{\alpha}{2}}} \right)$$

Where λ_1, λ_2, λ_R are the intensities corresponding to the average number of points per unit of area and the threshold is γ.

After further modification, the probability of successful information exchange (Pex) between two nodes and given by

(4c) $$P_{ex} = \exp[C - D]$$

3.1.2 Network Lifetime Using Energy Harvesting

The relay's battery level without taking Energy Harvesting ($L_{-eh}(m)$) is given by,

Where, m=communication period, L_I= initial energy level of battery, T_{s}= time slot duration.

(5) $$L_{-eh}(m) = L_I - m t_s (2P_r + P_t P_{act})$$

P_r = the receivig power, P_t= transmission power and P_{act} is the probability of active relay.

The average power harvested by taking account of energy harvesting is given by

$$E\{P_{eh_3}\} = \frac{\in P_t P_{act} \lambda_R 2\pi}{(\alpha - 2)\left(2\sqrt{P_{act} \lambda_R}\right)^{2-\alpha}} + \in P_t \quad (6a)$$

Where ∈ = conversion efficiency of the energy harvesting system.

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The battery level of a relay with taking Energy Harvesting ($L_{+eh}(m)$) into account is given by,

(6b) $$L_{+eh}(m) = L_{-eh}(m) + mt_s\left(\sum_{i=1}^{3} E\{P_{eh_i}\}\right)$$

Where $E\{P_{ehi}\}$ is the average harvested power.

The lifetime of the relay without taking Energy Harvesting into account ($m_{max(-eh)}$) defined by,

(7) $$m_{\max_{-eh}} = \frac{L_I}{t_s(2P_r + P_t P_{act})}$$

The lifetime of the relay with taking Energy Harvesting into account ($m_{max(+eh)}$) is

(8) $$m_{\max_{+eh}} = \frac{L_I}{\left[2t_s P_r + t_s P_t P_{act} - t_s \sum_{i=1}^{3} E\{P_{eh_i}\}\right]}$$

The table below specifies the system parameters for calculating the characteristics of the network.

TABLE I SIMULATION PARAMETERS

Conversion efficiency	$\varepsilon = 0.1$
Path loss exponent	$\alpha = 3$
Transmit power	P_t =75mW
Power consumption at the reception mode	P_r= 100mW
Intensity	λ_1 , λ_2= 0.4
Relay intensity	λ_S= 0.5
Time slot duration	t_S= 1s
Initial battery level	L_I =1000J

IV.VIRTUAL MIMO IN WIRELESS SENSOR NETWORKS

Another technique that maintains the energy efficient communication in wireless networks is VMIMO. It is a robust technique that exploits the MIMO spatial diversity by implementing MIMO technology in single omni-directional antenna system. However, it is impractical to install multiple transceivers in small nodes in terms of complexity. Virtual MIMO serves the purpose of improving network lifetime with minimum energy consumption by achieving spatial diversity. Virtual MIMO has four different modes: single input and single output (SISO), single input multiple-output (SIMO), multiple-input single-output (MISO), and multiple-input and multiple-output (MIMO). A network of wireless sensors conventionally follows the topology of single input and single output (SISO) and others can be claimed asMISO as V-MISO, SIMO as V- SIMO and MIMO asV-MIMO as they can be formed virtually.

4.1 Power and Energy Consumptions in Virtual MIMO (VMIMO)

Consider a network of wireless sensors comprising several nodes spread in a planar field. As there are size and resource constraints, each node is presumedto have a single antenna system mounted. Despite that several sensor nodes can shape VMIMO network. There are four types of modes of communication: SISO, SIMO, MISO and MIMO respectively. Total power consumption of VMIMO transmission is expressed as summation of power consumption of all P_{PA} power amplifiers and power consumption of all P_C circuit blocks (that is, power consumption of all transmitter and receiver side signal processing blocks except base band signal processing blocks to simplify our analysis [10]).

The power consumption P_{PA} will be extracted from each of power amplifiers together as follows:

$$P_{PA} = (1+\alpha)P_{tr} \qquad (9)$$

Since P_{PA} is related to P_{tr}transmitter power, which can be calculated according to the link budget relationship [13]. Assuming wireless signal losses are in direction of square law, $P_{tr}$is expressed as

$$P_{tr} = \overline{E_b} \times R_b \frac{(4\pi d)^2}{G_t G_r \lambda^2} M_l N_f \text{(10a)}$$

where E_b is the required energy per bit at the receiver side for a given BER requirement, R_b is the bit rate represented by B×b(with B being the wireless connection bandwidth, and b the constellation size), d is the transmission distance, G_t and G_r are the transmitter and receiver antenna gains respectively, λ is the carrier wavelength, M_l is the link margin compensating the hardware process variations and additive background noise or interference, and N_f is the receiver noise.

The modified P_{PA} of all the power amplifiers evaluated as,

$$P_{PA} = \frac{2}{3}(1+\alpha)\left(\frac{P_b}{4}\right)^{\frac{-1}{N_r N_t}} \frac{2^b - 1}{b^{\frac{1}{N_t N_r}+1}} N_0 \sum_{i=1}^{N_t} \sum_{j=1}^{Nr} \frac{(4\pi d_{ij})^2}{G_t G_r \lambda^2} N_f M_l$$

(10b)

Where $\propto=\frac{\xi}{\eta}-1$ with η being the drain efficiency of the RF power amplifier and the Peak-to-Average Ratio(PAR) which relies on the modulation scheme and the corresponding constellation size, P_b is the average bit error rate, N_0 is the single-sided thermal noise power spectral density (PSD) at room temperature single sided noise PSD, N_t and N_r are the numbers of transmitters and receivers involved in VMIMO communication respectively, d_{ij} is the distance between node u_i in the transmitter side and v_j in the receiver side.

The total power consumption of all circuit blocks P_C is expressed as

$$P_C = N_t(P_{DAC} + P_{mix} + P_{filt}) + 2P_{syn} + N_r(P_{LNA} + P_{mix} + P_{IFA} + P_{filr} + P_{ADC}) \quad (11)$$

Finally, the total energy consumption per bit is given by (for transmission at fixed rate),

$$E_{bt} = \frac{2}{3}(1+\alpha)\left(\frac{P_b}{4}\right)^{\frac{-1}{N_r N_t}} \frac{2^b-1}{b^{\frac{1}{N_t N_r}+1}} N_0 \sum_{i=1}^{N_t}\sum_{j=1}^{Nr} \frac{(4\pi d_{ij})^2}{G_t G_r \lambda^2} N_f M_l$$

$$+\frac{N_t P_{tc} + 2P_{syn} + N_r P_{rc}}{B.b} \quad (12)$$

Below table II specifies the values of different parameters derived from [10].

TABLE II: VALUES FOR DIFFERENT PARAMETERS

η =0.35	$\xi=3\frac{\sqrt{M}-1}{\sqrt{M}+1}$, $M=2^b$	$G_t G_r$=5dBi
λ =0.12m	B=10KHz	$P_b = 10^{-3}$
P_{mix} = 30.3mw	$P_{syn} = 50\ mW$	P_{LNA}=20mW
$P_{filt} = P_{filr} =$ 2.5mw	$P_{ADC}=P_{DAC}$=15mw	$P_{IFA} = 2mW$
$M_l = 40dB$	$N_f = 10dB$	$N_0 = -171dBm/HZ$

4.2 MIMO-LEACH ALGORITHM

The energy-efficient LEACH protocol is combined with cooperative MIMO scheme for mitigating energy consumption in the network and provides the shortest path for fading channel data transmission. In the clustering process, MIMO – LEACH doesn't take into consideration of MIMO operations. MIMO-LEACH comprises single Cluster Head per cluster, that is accountable for accumulating and transmission of data to two other "cooperative nodes". These nodes are accountable for sending the data to the Cluster Header that receives clusters. As no complete MIMO communication (2x2) can be possible in MIMO-LEACH, SIMO and MISO are best transmission modes to be used.Clustering requires grouping nodes in WSN and choosing a Cluster Head to directly interact with the non-Cluster Head nodes of a cluster. Cluster Heads directly or via other cluster Heads send aggregated information to the destination. The array of Cluster Heads in the network is eventually a connected dominant group.

4.3 Joint Virtual MIMO and Data Gathering Problem

We have mentioned already that joint VMIMO and data gathering that provides an efficient communication between the sensor node and the base station and also within the sensor nodes, but the key issue comes with the selection of cooperative node pairs, in addition to to that constructing the VMIMO-aware topology and then VMIMO-aware routing of this topology, with which all the sensor nodes can forward their sensed information to their respective base stations. The leveraged objective for this problem is to mitigate the energy which is going to be used during data collection in WSN.

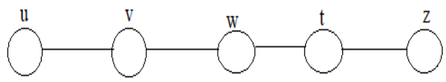

Fig.4. Data Gathering under Conventional Scheme

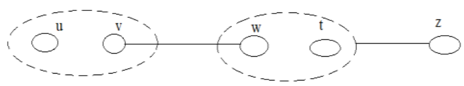

Fig.5. Partner Selection diagram for Wireless Networks

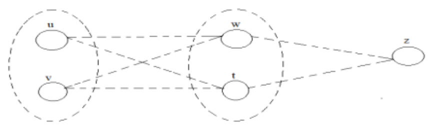

Fig.6. VMIMO-aware Topology Construction diagram

4.3.1 Illustration of the vMDG Problem

The example of a network shown in the figure above illustrates the vMDG problem. As shown in the figure we can see four sensor nodes u, v, w, t which are distributed in a linear way and the node z is the base station of these sensor nodes. Let us assume thateach sensor node has to forward 30 bytes of data to its respective base station z. we can analyze this transmission in three possible ways as shown in the figure above. Under the tradition way of communication, data gathering consists of a link set $\{l_{u,w}, l_{w,t}, l_{t,v}, l_{v,z}\}$. let us assume that $|uw|=|wt|=|tv|=|vz|=100$m. In accordance with the E_b equation, the energy consumed to forward each packet to the base station z can be determined in SISO mode of transmission is given in the table III. The energy usage in the data gathering is about 1.683J. Fig.5 reveals a tree like structure after choosing two pairs of cooperative nodes (u,w) and (t, v). In addition to it we develop a VMIMO-aware topology that shows leveraging use of VMIMO mode of transmission. The amount of energy usage from each node to its base station indicated in the table. The node w sends a packet to the node pair (v, t) in SISO transmission mode. The two nodes v and t then transfer the packet cooperatively to the base station z through MISO transmission mode. The total consumed energy in this entire process is about 0.063J. The total energy usage with VMIMO-aware topology in data gathering process is mitigated to 0.521J. That means, in comparison to the simple conventional method, the process that combines VMIMO with an suitable routing algorithm decreases the energy consumption by 69 % .

Table III Numerical illustration of the $vMDG$ problem

Node	Traditional scheme		VMIMO Scheme	
	path	Energy(J)	Path	Energy(J)
v	v-z	0.168	v-z	0.168
t	t-v-z	0.337	t-{t,v}-z	0.199
w	w-t-v-z	0.505	w-(t,v}-z	0.063
u	u-w-t-v-z	0.673	u-{t,v}-z	0.091
		1.683		0.521
Total				

4.4 D-vMDG algorithm:

The problem stated about vMDG is NP hard. It can be avoided by implementing the D-vMDG algorithm. It is mentioned below briefly in two steps.

4.4.1 Algorithm Overview

The Dijkstra's algorithm constructs a spanning tree, called Minimum Dijkstra tree or MDT, under the conventional mode of communication between sensor nodes. MDT finds the shortest path for all the sensor nodes to the base station in a given network. This topology used for data gathering is under SISO communication mode, as it determines the shortest path which consumes less energy from the sensor node to the base station. But due to the various features of the VMIMO, MDT is no longer considered as an optimal for the vMDG problem for which it is been modified.

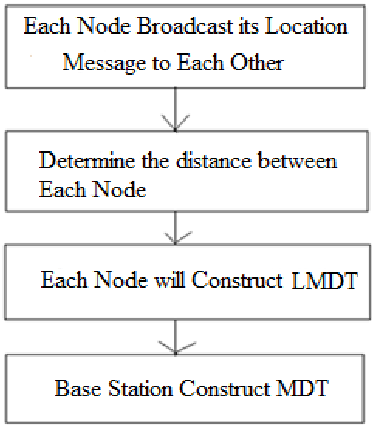

Fig.4 Flowchart for MDT Construction

The steps involved in D-vMDG algorithm are construction and route selection. It has two sub-algorithms, one for each step.

The first step of sub algorithm, is VMIMO-aware topology construction (or vMTC) constructs a tree-like structure which is the modified version of MDT. The second step involves another sub algorithm called VMIMO based energy-efficient routing (or vMER) will select a route by dynamic programming method for each sensor node, taking all modes of VMIMO into account.

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V. SIMULATION RESULTS

This paper focuses on improving the service life of wireless sensor networks using energy harvesting technique and how to reduce energy consumption in wireless sensor networks. This paper presents the work on three algorithms to compare the energy consumption characteristics between the proposed algorithm and existing algorithms (i.e. MDT and MIMO-LEACH algorithms). Simulation results shows network performance metrics and energy consumption characteristics of Wireless SensorNetwork is varied based on different parameters (i.e. Area size, Number of sensor nodes, Gamma value and Bit-error rate).
Fig.7 represents area of N*N, in which 50 sensor nodes are distributed randomly in a planar field. The each sensor node is localized and connected to neighboring node. The communication between them is illustrated from (1).

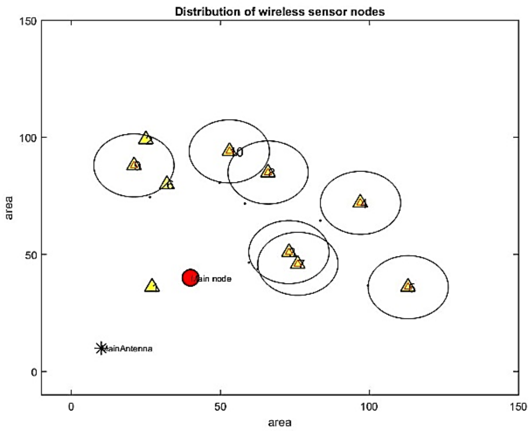

Fig.7. Distribution of sensor nodes

Fig.8 signifies the probability at which the message is successfully exchanged. The probability decreases as the threshold (db) increases and reaches zero at lower thresholds. It is observed that at low noise level (N=40dbm) the message is successfully decoded despite that probability is higher which compared with the high noise level (N=10dbm). At low noise environments augmenting relay strength benefits the network lifetime without compromising on quality of service.

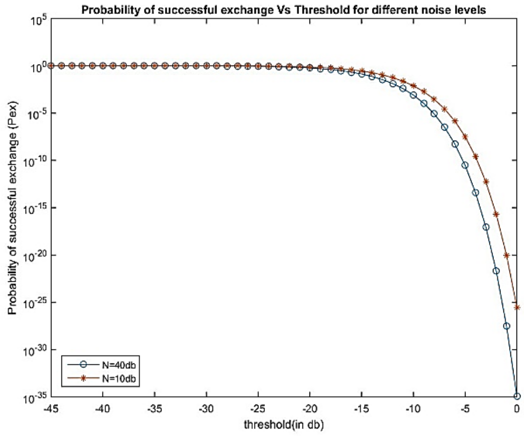

Fig.8.Probability of successful exchange Vs Threshold for different noise levels

Fig.9 depicts that threshold for different noise levels with reference to the communication slots. A shown in Fig.9, the need for communication slots relative to threshold decreases when considering without energy harvesting system in contrast to with energy harvesting system with relay intensities 0.4 and 0.5 .This indicates network lifetime has been improved with energy harvesting system.

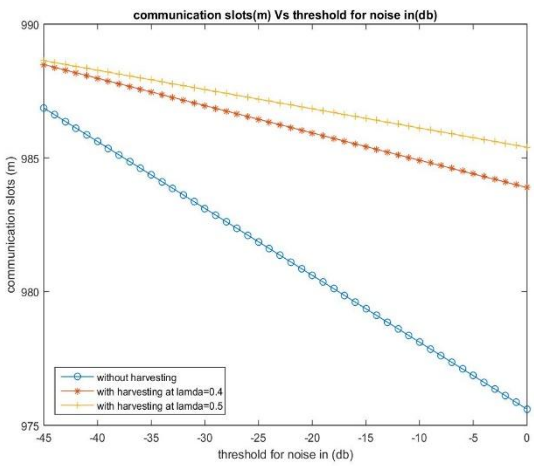

Fig.9. Communication slots vs threshold in (db)

Simulation results of Fig.10a and 10b illustrates the energy consumption characteristics for three different algorithms where 100 sensor nodes are distributed in an area size of 600x600m and 1000 ×1000m respectively. Fig.10a presents total energy consumption of three algorithms over an area of size 600mx600m. Output of Fig.10a shows the proposed algorithm save the energy consumption by about 81.6 percent and 36.6 percent in contrast to MDT and LMIMO

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algorithms under first case. Under second case (b) proposed algorithm will mitigate the energy consumption further by about 89.0 and 62.4 percent in contrast to the other two algorithms in the area size of 1000m×1000m. From the Equations (9) and (10b), the energy consumption P_{PA} is thus higher in second case whereas P_C remains the same in the both cases.

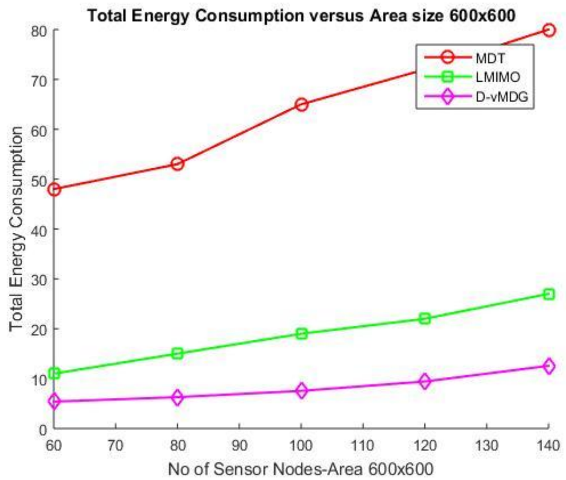

Fig.10a. Total Energy consumption versus Area size

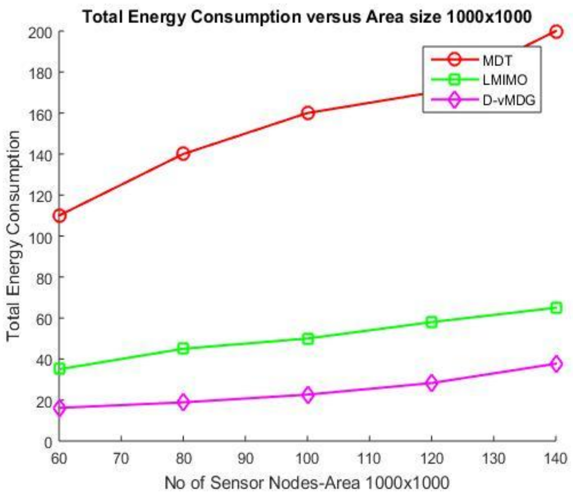

Fig.10b. Total Energy consumption versus Area size

The Fig.11 shows how the area size affects the energy consumption. This simulation result deals with 100 sensor nodes are distributed over area sizes varying from 25 m × 25 m to 1000 m ×1000 m respectively. As average transmission distance increases, overall energy usage increases with area size as seen in Fig 10b. The energy consumption rate of D-vMDG is significantly lower than that with the other two algorithms. However, when area size is bigger the proposed algorithm performs better than MDT [10]. From the simulation analysis, the proposed algorithm can save about 74.6 and 46.3 percent of energy than other two algorithms in the area sizes 50m x 50m and 1000m x 1000m.

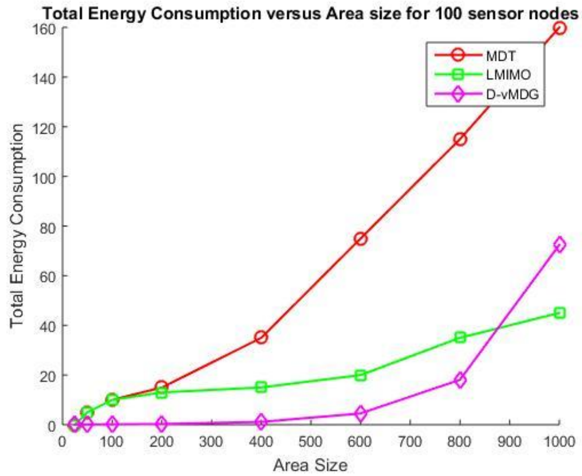

Fig.11 Total Energy consumption versus Area size for 100 sensor nodes

The simulation output of Fig.12 shows the impact of parameter P_b(bit error probability) on total energy consumption. Assuming 100 sensor nodes are distributed over an area of 800m x 800m and total energy consumption increases when the bit error probability decreases in all the three algorithms. In this scenario, the proposed algorithm can minimize energy consumption of about 80.5 and 54.2 percent in contrast to other two algorithms (MDT and MIMO-LEACH).

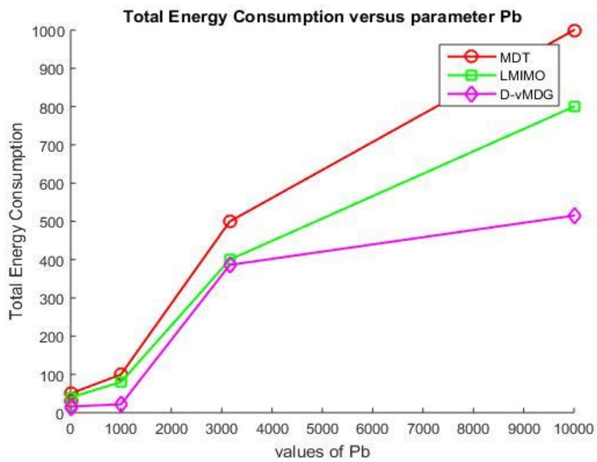

Fig.12. Total Energy consumption versus parameter P_b

The simulation outputs of Fig.13 and Fig.14 follows the number of hops corresponds to number of sensor. Assuming 100 sensor nodes are distributed over an area of 800m x 800m. Due to LMIMO is a two layer cluster structure i.e. one hop inter cluster and intra cluster topology, it is not applicable for large-scope networks (multi-hop scene). Consequently, Fig.13 and 14 compares only the MDT with D-vMDG. Both average number of hops and maximum number of hops increases with intermediate nodes (number of sensors deployed).However, D-vMDG algorithm decreases average number of hops by at least 31.1 percent when compared with MDT.

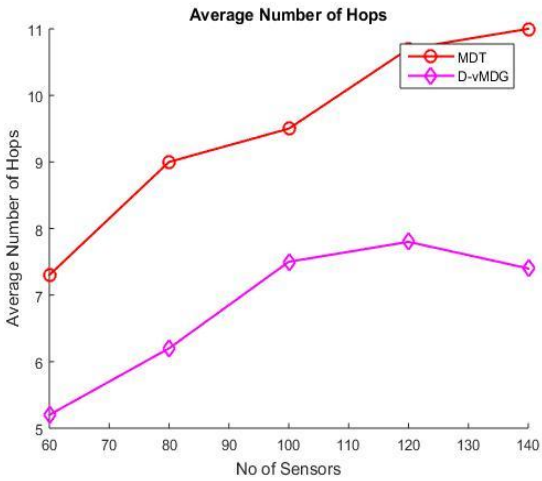

Fig.13.Average number of hops

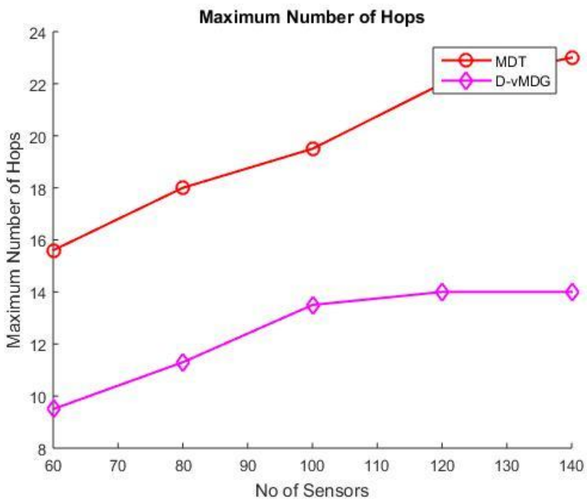

Fig.14 Maximum number of hops

V. CONCLUSION

In this paper, energy harvesting technique has been proposed to augment the network lifetime of cooperative wireless sensor networks. Also D-VMDG algorithm is proposed for energy –efficient data gathering for wireless sensor networks by using VMIMO based communication scheme. VMIMO based communication scheme is used to achieve spatial diversity and reduce the energy consumption in wireless communication. The Proposed algorithm consists of two steps (1.VMIMO–aware Topology construction and 2.VMIMO aware energy efficient route selection). The measurements of network efficiency characteristics such as the successful message exchange, network lifetime gain and also energy consumption characteristics of a WSN by using different data gathering algorithms (i.e. MDT, MIMO-LEACH and D-VMDG algorithm) has been analyzed for cooperative wireless sensor network using MATLAB R15a. Simulation results shows that the network lifetime has been improved by using energy harvesting technique and also the proposed algorithm decreases the energy consumption by 81%and 36% compared with the MDT and MIMO-LEACH algorithms respectively.

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