Energy Efficient Virtual MIMO Communication Designed for Cluster Based on Cooperative WSN using OLEACH Protocol

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To monitor physical conditions, wireless sensor networks (WSNs) employ a large number of sensor nodes. These nodes have limited energy resources that is major issue in wireless communication systems. Virtual MIMO (vMIMO) is a technology that can enhance energy efficiency in WSNs by transmitting or receiving data from numerous nodes, enhancing signal quality, and lowering power. This research offers Energy-Efficient Virtual MIMO Communication (EE-VMC), a novel solution to addressing the energy efficiency dilemma in Wireless Sensor Networks (WSNs). EE-VMC presents a viable option for long-term deployments in cluster-based cooperative WSNs by exploiting virtual Multiple-Input Multiple-Output (MIMO) communication. The suggested method employs an optimized LEACH (OLEACH) protocol to promote energy efficiency by promoting effective communication while minimizing energy consumption. The simulation findings show that the OLEACH algorithm performs well in wireless sensor networks. At an SNR of -10dB, OLEACH has the highest Packet Delivery Ratio (PDR), showing improved performance in low signal-to-noise ratio conditions. Increasing the number of antennas also improves OLEACH's data delivery performance. When compared to state-of-the-art protocols (LEACH, HEED, BRICH, and B-LEACH), OLEACH regularly beats them in terms of PDR, SNR values, and data transfer rounds. Furthermore, OLEACH has greater remaining energy levels, indicating better energy management and increased network lifespan. The results back up the conclusion that OLEACH is a promising algorithm for optimizing energy consumption, improving packet delivery, and improving overall network performance in wireless sensor networks.

Keywords: Virtual MIMO, Clustering, LEACH, Optimization, Energy-Efficient.

1. Introduction

Wireless Sensor Networks (WSNs) are used in various applications for monitoring physical conditions. Sensor nodes collect data and transmit it to a central device for analysis. These nodes form a network over a geographic area. However, energy efficiency is a challenge due to limited node resources [1]-[4]. Multiple-Input Multiple-Output (MIMO) technology

improves system performance by using multiple antennas at the transmitter and receiver. Simple MIMO allows simultaneous transmission of multiple data streams over the same frequency band [5][6][7]. Simple MIMO technology offers advantages such as increased data rates, improved reliability, and enhanced spectral efficiency by leveraging spatial diversity and multipath propagation. However, it also brings challenges, including increased complexity in implementation, higher power consumption, and the need for accurate Channel State Information (CSI) estimation [8]. Fig 1 presents the difference between simple and virtual MIMO. Virtual MIMO, also known as Cooperative MIMO or Distributed MIMO, is a solution to the challenges of simple MIMO. It takes advantage of the spatial diversity of cooperative nodes within a network to obtain MIMO communication benefits without the need for physically separate antennas at each node. The advantages of energy efficiency, scalability through clustering, and increased network capacity are driving the adoption of Virtual MIMO in WSNs. By eliminating the requirement for several physical antennas at sensor nodes, virtual MIMO reduces energy usage. Scalability is enabled by the clustering-based architecture, which can accommodate a large number of nodes while maintaining efficient communication [9][10]. Furthermore, Virtual MIMO boosts network capacity and throughput by using the spatial diversity of cooperative nodes, allowing for the simultaneous transmission of several data streams inside a cluster. To improve energy efficiency in WSNs, the proposed EE-VMC technique employs Virtual MIMO communication. Traditional MIMO systems are impractical for sensor nodes with limited resources, whereas Virtual MIMO makes use of cooperative nodes inside clusters. The cluster head works as a virtual antenna array by establishing clusters with a cluster head and member nodes, allowing simultaneous transmission of several data streams and increasing network capacity [11][12]. In cluster-based Cooperative Wireless Sensor Networks (WSNs), virtual MIMO improves energy efficiency, network capacity, reliability, scalability, simplified hardware requirements, and cooperative data fusion. [13][14]. It saves energy, allows for faster data speeds, improves link quality, adjusts to changing network conditions, simplifies node hardware, and enables efficient data fusion. Because of these benefits, Virtual MIMO is a promising communication strategy for cluster-based Cooperative WSNs, improving their performance and application in a variety of fields. Therefore, the contributed to design an Energy-Efficient Virtual MIMO Communication (EE-VMC) as an approach to address the energy efficiency challenge in Wireless Sensor Networks (WSNs). This approach leverages virtual Multiple-Input Multiple-Output (MIMO) communication to improve energy efficiency in cluster-based cooperative WSNs. EE-VMC incorporates an optimized LEACH (OLEACH) protocol, which facilitates efficient communication and minimizes energy consumption. The paper investigated the performance of OLEACH in EE-VMC with varying antennas, SNR and packet size and proves its efficacy as compared to state-of-art models. The rest of the paper is organized as: Section 2 describes the related recent contributions of researchers; section 3 presents the proposed methodology and algorithm. Section 3 presents the result analysis of the proposed model and finally in section 5 conclusion and future work is presented.
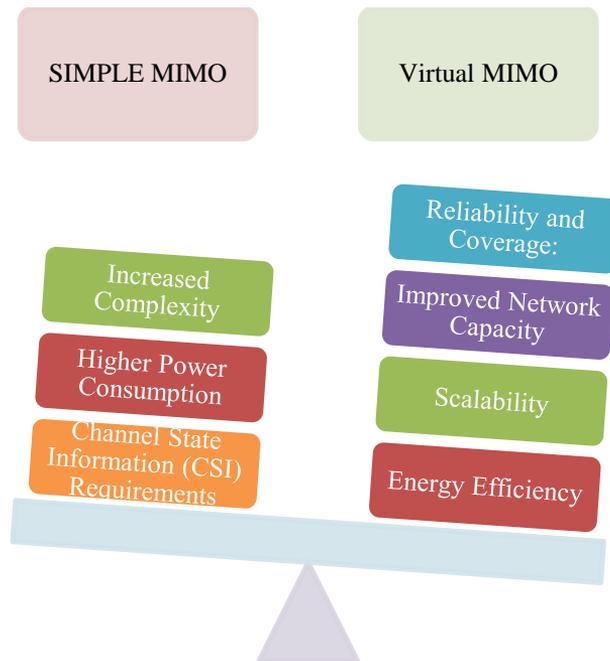
Fig. 1. Simple MIMO versus Virtual MIMO

2. LITERATURE REVIEW

Baniata et al. [15] introduced the MIMO-HC protocol to enhance energy efficiency in IoT applications. The protocol achieved energy-efficient longer lifetime of the network. Dogra et al. [16] presented the ESEERP protocol, which aimed to prolong the network lifetime and enhance connectivity. The protocol achieved a network longevity of 3500 rounds with improved energy utilization, data transmission rate, and packet delivery ratio. Martin et al. [17] proposed the EE-MDCHSRP routing algorithm for Underwater Sensor Networks (UWSNs). The algorithm outperformed existing protocols in terms of overall performance, leading to reduced power consumption, improved throughput, and network lifetime. Sachan et al. [18] designed a resourceful-energy-based communication network for Wireless Sensor Networks (WSNs) using the V-MIMO technique and Space-Time block coding. The technique demonstrated superior performance over aggregation in enhancing wireless communication reliability. Khan et al. [19] presented a deep Q-network (DQN)-based vertical routing scheme for a multi-plane network. The scheme improved network lifetime and reduced energy consumption and link breakages compared to traditional reinforcement learning approaches. Abushiba et al. [20] proposed the CH-leach protocol, which reduced energy consumption and improved network lifetime compared to LEACH and DEEC protocols. Midasala et al. [21] introduced the SIMHC protocol, which integrated swarm intelligence with multi-hop communication to optimize network lifetime and node energy efficiency. The protocol achieved high network lifetime, low delay, good coverage rate, high throughput, and energy efficiency. Tavakoli et al. [22] proposed a fuzzy-based clustering algorithm that was dedicated to reduce energy consumption as well as reduced the packet delivery ratio. Seyyedabbasi et al.

[23] introduced an Expanded Grey Wolf Optimization (Ex-GWO) protocol that selects optimal path on different parameters such as size, hop count, residual energy, etc. Abdulaal et al. [24] presented a modified version of LEACH called NM-LEACH that takes into account critical problems present in the network. It solves the issue by considering the energy as a weight factor while selecting the CH. These works demonstrate the effectiveness of the proposed protocols and techniques in achieving energy efficiency, prolonging network lifetime, reducing energy consumption, improving throughput, and enhancing overall network performance in wireless sensor networks. It emphasizes that communication tasks consume more energy compared to sensing and computation tasks. The design of energy-efficient WSNs is crucial for maximizing the network's longevity. Energy efficiency in WSNs involves balancing parameters such as "bandwidth, packet delivery ratio, network longevity, and energy utilization". The specific application requirements determine the trade-offs between these parameters. In applications where delays are unacceptable, minimizing data delivery delay as well as energy requirement. In contrast, other applications prioritize quality of service (QoS) parameters over network longevity. The paper aims to address the challenges of achieving energy efficiency in WSNs and proposes measures to minimize energy consumption. It provides simulation analysis and optimal solutions for energy-efficient cooperative WSNs using virtual multiple-input multiple-output (MIMO) techniques.

3. METHOD USED

In an cooperative virtual MIMO the communication network is grouped together as clusters where it aggregates the data from other sensor nodes. The fused data is then broadcast to cooperative nodes, who send it to a sink node through many hops. The system assumes sensor nodes that are stable and time-synchronized, with the sink node having numerous antennas for cooperative receiving. The analysis disregards baseband signal processing energy consumption and assumes good SNR for efficient communication. The proposed network consists of randomly distributed nodes organized into clusters for efficient communication. Each cluster includes co-operative cluster-heads (CH), and multiple sensor nodes (SNs). The transmission within a cluster, from SNs to CHs, is referred to as local transmission, while the transmission from CHs to the sink node is termed as long-haul transmission. Here, channel propagation model is considered for both free space as well as multipath fading that is dependent on distance between receiver and transmitter. In condition of local communication, they are close to each other whereas they are far apart in long-haul transmission. The entire communication model is assumed to be effected by additive white Gaussian noise (AWGN) [25]. Then, the received signal at j_{th} node from i_{th} node with n signals are mathematically represented as:

$$r_{i,j\,(local)}(n) = \tau_{ij(local)}s(n) + \eta_j(n) \tag{1}$$

Where, $\eta_j(n)$ is AWGN samples at terminal j, $\tau_{ij(local)} = d_{ij}^{-2}$ with d_{ij} is the distance between node i and j, and $s(n)$ is the transmitted signal. Whereas in long-haul transmission, the communication model is also effected by Rayleigh fading, as nodes are far apart. Then in such communication, the received signal is represented as:

$$r_{i,j\,(local)}(n) = \tau_{ij(local)}h_{ij}s(n) + \eta_j(n) \tag{2}$$

Where, fading coefficient is termed as h_{ij} among nodes such as node i and node j and $\tau_{ij(local)} = d_{ij}^{-4}$.

1.1 Virtual MIMO Routing Algorithm

In each cycle of data transmission, the LEACH protocol [26], which serves as a model in this work, selects cluster head nodes. A probabilistic mechanism underpins the selection procedure. The LEACH protocol determines the likelihood of the ith node being elected as a cluster head node in the r_{th} round as follows:

$$"P(i) = \begin{cases} \dfrac{n}{(N - n[r \bmod (N/n)])} & \text{if } i \epsilon G \\ 0 & \text{otherwise} \end{cases} "$$ (3)

Where, set of nodes is represented as G that doesn't contain the cluster heads in round r mod (N/n). After selection of n CH nodes, the message is broadcasted for invitation to other nodes to join their respective cluster. The nodes select cluster head according to the signal strength i.e., nearby CH. Then information such as node ID, remaining energy, and the distance are communicated to their respective cluster head. This process is continued until the $N-n$ sensor nodes (remaining nodes) are selected in their respective cluster heads. This results the creation of n clusters. After cluster formation, they prepare a routing table to find the best and optimal route for data transmission. They work towards finding the optimal path to the sink node, ensuring efficient communication. This step involves ongoing optimization and adjustment by the cluster head nodes until they determine the best route to relay data to the sink node. In LEACH based cooperative virtual MIMO (presented in fig 2), the entire algorithm is divided in two phases: setup and steady state. During setup, cluster heads are selected based on a random number and a threshold calculation. In the steady state phase, data is transmitted to the base station. The threshold is evaluated as:

$$T(n) = \frac{p}{\left(1 - p\left(r \bmod\left(\frac{1}{p}\right)\right)\right)} \qquad \text{if } n \not\in G$$ (4)

Where G is number of nodes competing for CH. p is the probability of becoming CH at round r.
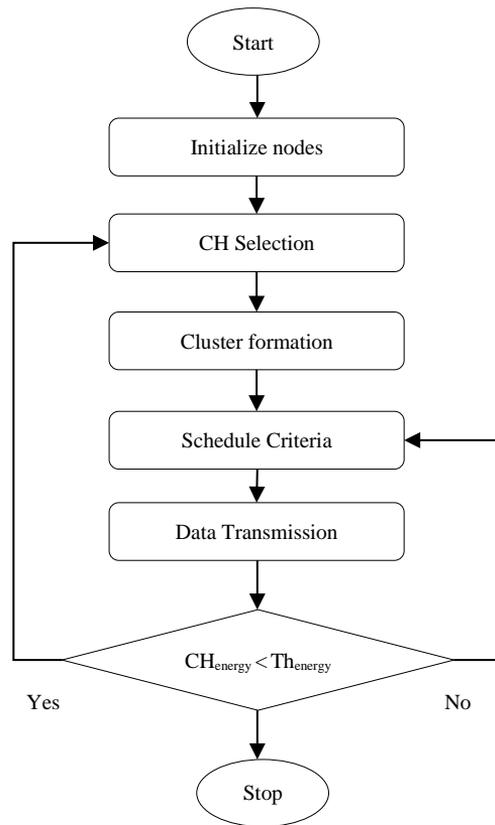
Fig 2. Flowchart of LEACH Protocol

The LEACH algorithm has a drawback where cluster heads are selected randomly, which may not result in the most energy-efficient nodes for data transmission. To address this limitation, a virtual MIMO routing algorithm is proposed as a solution. This algorithm aims to overcome the shortcomings of LEACH by optimizing the selection of cluster heads for efficient data transmission to the sink node, thereby improving energy savings in the network. Therefore, in this paper, energy-efficiency of the WSN network is enhanced with optimal LEACH protocol with virtual Multiple-Input Multiple-Output (MIMO) routing algorithm. The optimal LEACH protocol is designed using nature-inspired algorithm i.e., "multi-population Particle Swarm Optimizer (MPPSO)". The Multi-population Particle Swarm Optimizer (MPPSO) is an algorithm that combines different exploring methods in Particle Swarm Optimization (PSO) into a single algorithm. Here head node is selected on the basis of MPPSO. The core idea of MPPSO is to assign best particles using successful exploration method in order to take advantage of their diverse features and allocate more computing resources to enhance efficiency. MPPSO divides the population into different sub-population and one reward population. Each sib-population have small number of particles with their respective velocities. For sub-population is selected on the basis three different algorithms such as LDWPSO, UPSO, and CLPSO [26]. The MPPSO is repeated for number of learning rounds and at the end of each round an optimal population is selected. Here each sub-population

contains m particles and optimal population contains n particles. The particles in optimal population termed as POP_o with respect to POP_{sub}, wherein sub $\in$ LDWPSO, UPSO, and CLPSO, Evaluated as:

$$N_{sub} = [N * \lambda_H] \tag{3}$$

The selection criteria of POP_o by using POP_{sub} is evaluated on the parameter such as $S_{criteria}$ evaluated as:

$$S_{criteria} = N - \sum_{sub=1,2,3} N_{sub} \tag{4}$$

Fitness of POP_{sub} is evaluated as:

$$fit_{sub} = fit_{sub} + f(pbest_i) - f(x_i), \quad i \in POP_{sub} \tag{5}$$

Among the best fit population POP_o is selected as:

$$POP_o = \arg \left(\begin{array}{c} max \\ sub = 1,2,3 \end{array} \left(\frac{fit_{sub}}{[N * N_{sub}]} \right) \right) \tag{6}$$

Particles in POP_{sub} is assigned to POP_o and their velocities are updated according to increased iteration k. MPPSO improves search effectiveness with POP_o as each population can focus on different regions of the search space, increasing the likelihood of finding global and local optima together. This boosts exploration and exploitation, leading to better solution discovery. In dynamic optimization algorithms, achieving a balance between exploration and exploitation is crucial. Emphasizing exploration too much leads to random search, while focusing too heavily on exploitation results in local search. Additionally, the robustness of the algorithm's parameter settings across different problems is important. This paper introduces a new algorithm called Multi-population PSO, which aims to strike a good balance between exploration and exploitation.
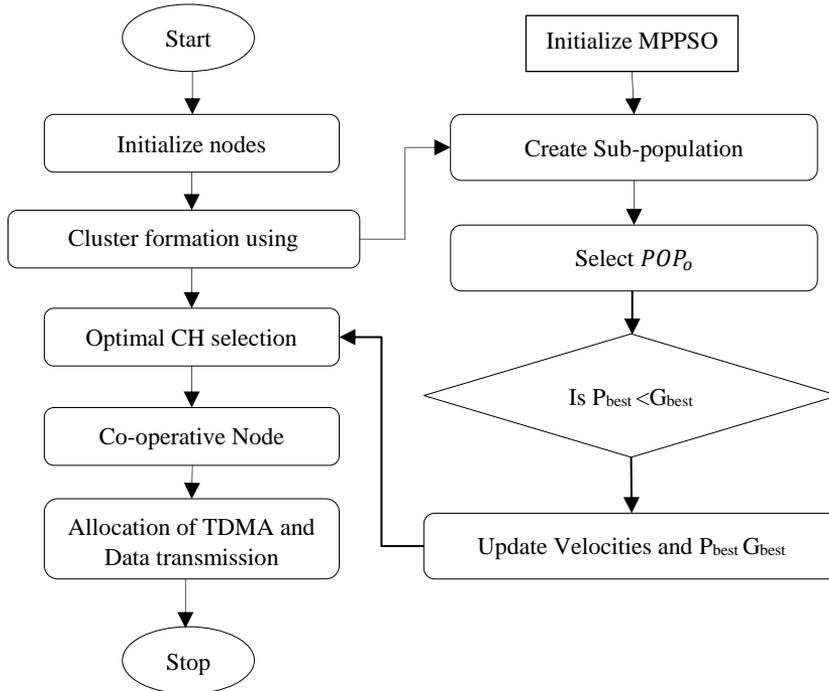
Fig 3. Flowchart of OLEACH Protocol

1.2 Cooperative Nodes Selection

Among the set of cluster head nodes some nodes are considered as cooperative nodes that construct a virtual MIMO communication system. The selection of co-operative node is determined on certain factors, such as:

$$\max_{node\ i\in cluster} \frac{E_{rem}(i)}{d_i}, d_{min} \le d_i \le d_{max} \tag{2}$$

The selection criteria for cooperative nodes in the virtual MIMO system are based on the remaining energy of the nodes $E_{rem}(i)$ and the distance between the cooperative node and the cluster head node is represented as d_i. There are also lower d_{min} and upper d_{max} distance limits specified. After identification of co-operative nodes according to selection criteria in virtual MIMO communication mode. Selection criteria is based on Space Time Block Code (STBC) scheme and according to their ID their roles are assigned. Finally for transmission, Time Division Multiple Access (TDMA) slots are allotted in the virtual MIMO system.

1.3 Data Transmission

In data transmission phase, the cluster head node broadcasts message to sensor nodes. Then, sensor nodes transmit their respective data to cluster head nodes within their allotted time-stamp slots. Then after transmission, the sensor node enters into sleep mode to conserve energy. Then at cluster head node, data aggregation or data fusion is performed to reduce data redundancy as well as save energy. Then they broadcast the data to the cooperative nodes. In final stage, the co-operative node creates a virtual antenna array after receiving data from CHs

and transmit according to TDMA technique. This allows for improved signal processing and transmission efficiency in the network. Therefore, the efficiency of the communication model was improvised by using the OLEACH algorithm which is described as in above section.

4. RESULT AND DISCUSSION

The proposed optimized-LEACH (OLEACH) algorithm was analyzed in this section using MATLAB [29] for experimental simulation. The simulation was conducted in a Virtual MIMO environment [30] with variable sensor nodes deployed. Simulation setup is presented in table 1.

Table 1. Simulation Parameter

Parameters	Values
"Sensor Nodes"	100
"Initial Energy of network"	10 J
"Number of Antennas"	4-12
"Energy Dissipation while transmitting bits"	0.1 nJ/bits
"Energy Dissipation while receiving bits"	0.1 nJ/bits
"Packet size"	1000-4000
"SNR"	-20dB to 20dB

The following performance parameters are used to evaluate the result:

Remaining Energy: It refers to the difference between total energy and consumed energy. It is evaluated as:

$$\text{Remaining}_{\text{energy}} = (\text{Total Energy} - \text{Energy consumed during transmission n} - \text{bit data packets}) \tag{1}$$

Packet Delivery Ratio: PDR is an important performance metric in the Virtual MIMO WSN environment, determining the reliability and efficiency of data transmission. PDR in WSN refers to the proportion of data packets that are successfully transmitted to the network's intended destination node.

$$\text{PDR} = \frac{\text{No. of packets received}}{\text{Total packets transmitted}} * 100 \tag{2}$$

The proposed Optimised LEACH (OLEACH) as well as some existing clustering protocols such as LEACH, HEED, BRICH, and B-LEACH was implemented. As the LEACH is a extensively used algorithm in wireless sensor networks (WSNs) that emphases on data collection competence and network longevity. It is based on the hierarchical clustering method in which sensor nodes form local clusters, by each cluster controlled by a cluster head (CH) who is in responsibility of data collection and their aggregation. Another WSN clustering approach that is used for optimises energy usage is HEED. It selects cluster heads dynamically on the parameters such as residual energy and communication cost. BRICH is also a hierarchical clustering protocol that is based on top-down and bottom-up strategies to select cluster head. To establish a hierarchy, it divides data points into smaller clusters and merges comparable groupings. It uses density-based approaches to strike a compromise between

cluster quality and computing efficiency. B-LEACH is a LEACH protocol enhancement built primarily for energy-efficient routing in WSNs. It prolongs network life by regulating energy usage among cluster heads. This is accomplished by selecting cluster heads based on residual energy and spreading cluster head roles evenly among the nodes. The Optimized LEACH (OLEACH) method was presented as an improvement to the original LEACH algorithm, with the goal of further optimizing energy consumption and improving network performance. Below results analysis was performed with respect to varying SNR and varying antennas. Fig 4 shows the performance of OLEACH with Varying SNR. For SNR -10dB the PDR is maximum. The next is remaining energy with varying SNR is presented, it is shown that the remaining energy was approx. 8J for 1000 rounds and it is almost same for signal to noise ratio - 10 to 10db. Fig 5 shows the OLEACH performance from different antenna which is 4, 8 and 12. The PDR increases with increasing antennas. Fig 6 shows the OLEACH performance from varying packet size which is 1000-4000. The PDR decreases with increasing packet size. Fig 7 shows the packet delivery ratio with SNR varied from -10 dB to 10dB comparing LEACH, HEED, BRICH, B-LEACH and OLEACH algorithm. Number of data transmission rounds varied from 0 to 1000. It is clearly visible that O-LEACH has better performance when compared to other state-of-art protocols. Fig 8 shows the remaining energy comparison with varying number of rounds with different SNR values and compared with existing state-of-art models such as LEECH, HEED, BRICH, B-LEACH and OLEACH algorithm. For O-LEACH remaining energy was higher as compared to other state-of-art models while comparing it with other techniques.
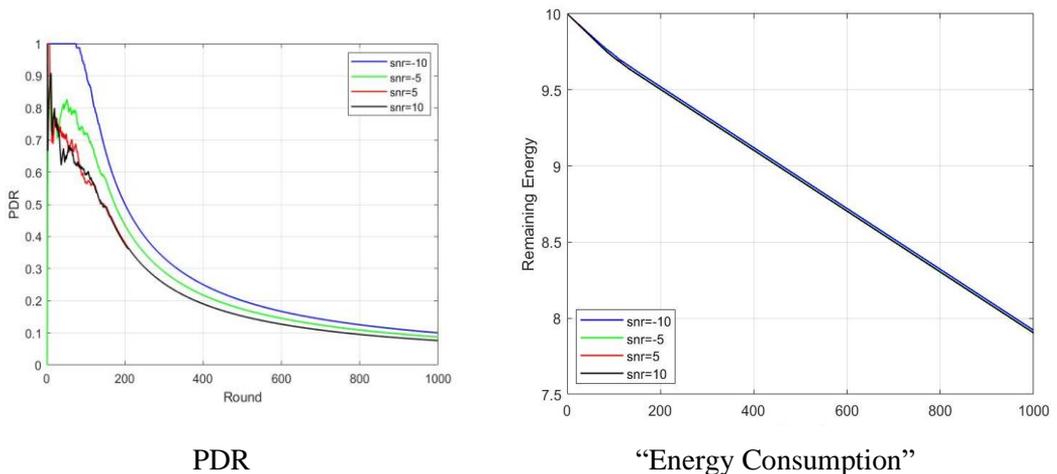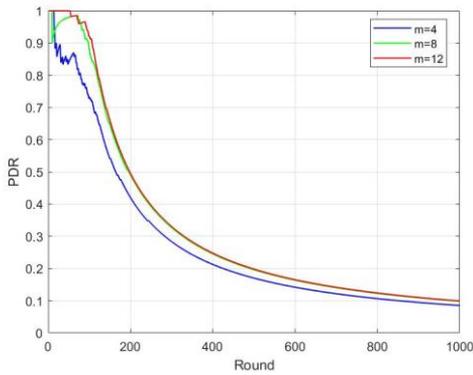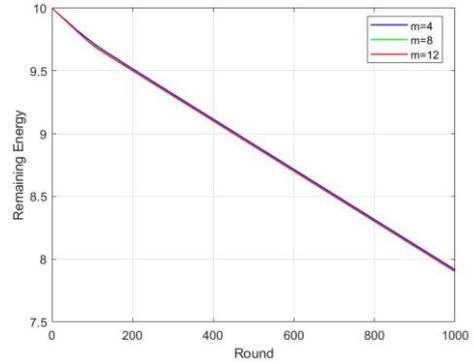

PDR   "Energy Consumption"

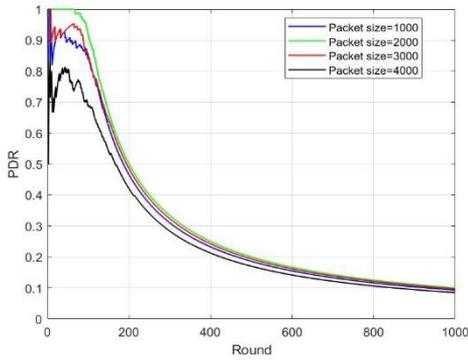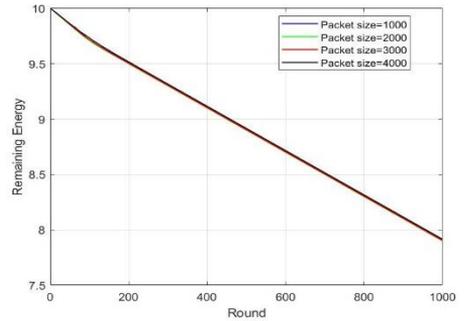Fig. 4. Performance of OLEACH with Varying SNR

PDR   "Energy Consumption"

Fig. 5. Performance of OLEACH with Varying Antennas

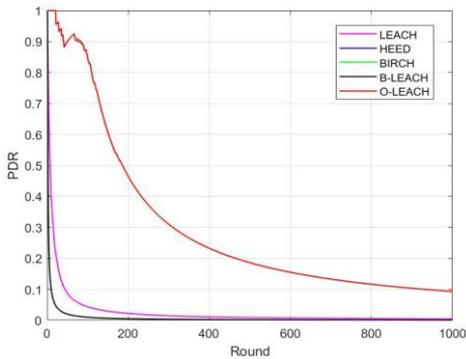PDR   "Energy Consumption"

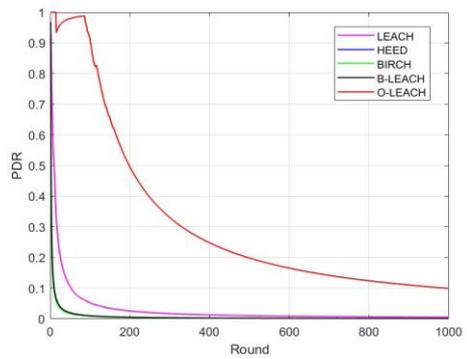Fig. 6. Performance of OLEACH with Varying Packet Size
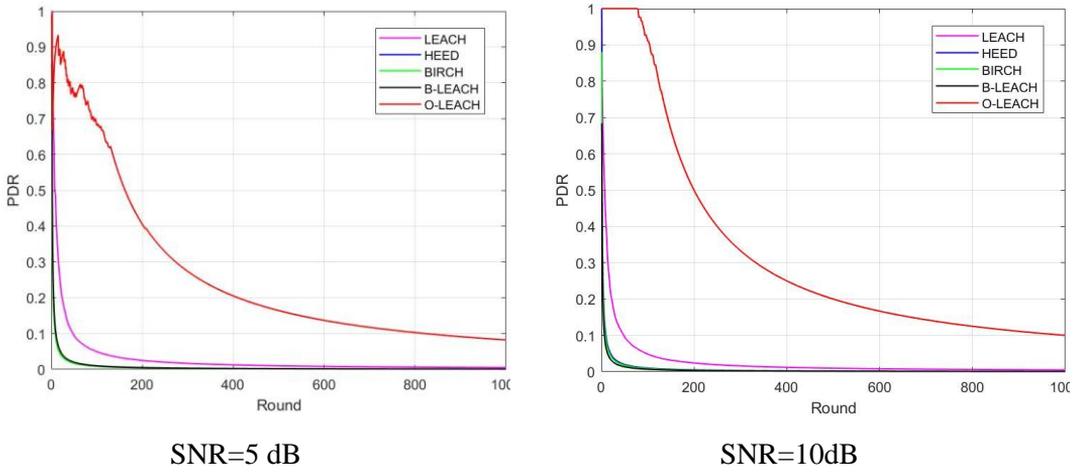

SNR=-10 dB   SNR=-5dB

SNR=5 dB   SNR=10dB

Fig. 7. Packet Delivery Ratio with Different SNR Values

SNR=-10 dB   SNR=-5dB

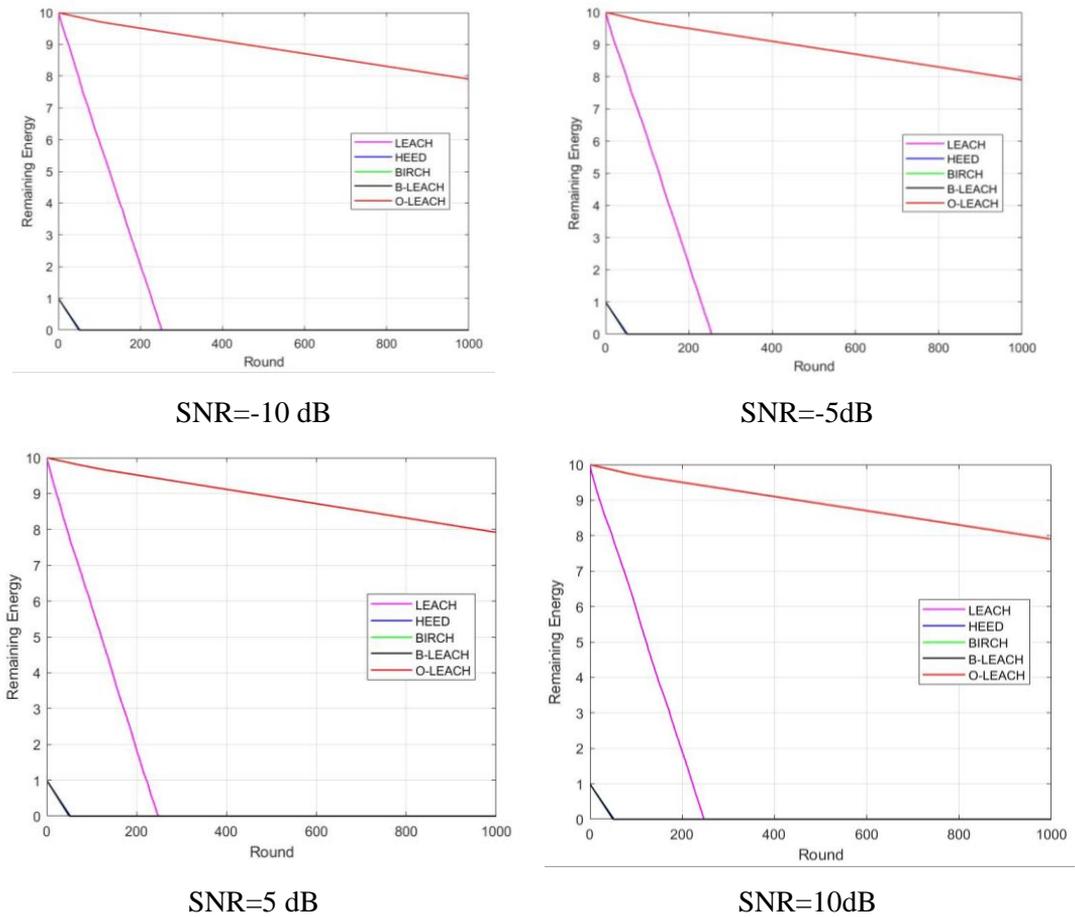SNR=5 dB   SNR=10dB

Fig. 8. Remaining Energy with Different SNR Values

Table 2 provides a comparison of different protocols in terms of Packet Delivery Ratio (PDR) and Energy Efficiency. The Ex-GWO protocol [23], achieved a PDR of 85% and an energy efficiency of 90%. The ESEERP protocol [16], achieved a higher PDR of 96%. The SIMHC protocol [21], achieved a higher energy efficiency of 95%. Finally, the OLEACH protocol achieved the highest PDR of 98% and energy efficiency of 99%.

Table 2. Comparative State-of-Art

Ref	Year	Protocol	PDR	Energy Efficiency
[23]	2023	Ex-GWO	85%	90%
[16]	2022	ESEERP	96%	-
[21]	2022	SIMHC	-	95%
OLEACH (Ours)			98%	99%

5. CONCLUSION

This paper focuses on addressing the energy efficiency challenge in Wireless Sensor Networks (WSNs) by proposing a novel approach called Energy-Efficient Virtual MIMO Communication (EE-VMC) for cluster-based cooperative WSNs using optimized LEACH protocol. EE-VMC leverages virtual Multiple-Input Multiple-Output (MIMO) communication to enhance energy efficiency in WSNs, offering a promising solution for sustainable and long-lasting deployments. The proposed OLEACH protocol designed for Virtual MIMO proved its vital role in attaining energy efficiency by facilitating optimal communication and minimalizing energy consumption. The simulation result analysis proved that the Optimized LEACH (OLEACH) algorithm performs well in WSN. OLEACH showed the highest Packet Delivery Ratio (PDR) at an SNR of -10dB, indicating its effectiveness in low signal-to-noise ratio scenarios. With increasing the number of antennas improved OLEACH's data delivery performance. OLEACH is compared with some existing clustering protocols such as LEACH, HEED, BRICH, and B-LEACH and outperformed them in terms of PDR, SNR values, and rounds of data transmission. OLEACH demonstrated higher remaining energy levels, indicating more efficient energy management and increased network longevity. The results support the conclusion that OLEACH is a promising algorithm for optimizing energy consumption, improving packet delivery, and enhancing network performance in wireless sensor networks. Future research should concentrate on exploring energy harvesting techniques and developing efficient power management mechanisms to further enhance energy efficiency. Additionally, ensuring the security and reliability of Virtual MIMO based cooperative WSNs requires the development of secure communication protocols, authentication mechanisms, and intrusion detection techniques. By addressing these areas, Virtual MIMO can contribute to energy-efficient, secure and robust WSN deployments.

ABBREVIATIONS

WSNs   Wireless Sensor Networks

MIMO   Multiple-Input Multiple-Output

vMIMO	Virtual Multiple-Input Multiple-Output
CSI	Channel State Information
EE-VMC	Energy-Efficient Virtual MIMO Communication
DQN	Deep Q-network
UWSNs	Underwater Sensor Networks
Ex-GWO	Expanded Grey Wolf
QoS	Quality of Service
AWGN	Additive White Gaussian Noise
MPPSO	Multi-population Particle Swarm Optimizer
TDMA	Time Division Multiple Access
PDR	Packet Delivery Ratio
SNR	Signal to Noise Ratio
CH	Cluster Head
SNs	Sensor Nodes
STBC	Space Time Block Code

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