Optimized Energy Virtual Multiple-Input Multiple-Output (Mimo) Communication in Wireless Sensor Networks with Clustering

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***Abstract*—This study introduces a cluster-based virtual multiple-input multiple-output (MIMO) communication approach tailored for energy-limited wireless sensor networks. The research explores virtual MIMO under both fixed and variable data rates. An energy-efficient routing method utilizing space-time block coding (STBC) is integrated with the low-energy adaptive clustering hierarchy (LEACH) protocol. Additionally, an analytical model is developed to evaluate the energy consumption across the entire network. Simulation results demonstrate that the proposed virtual MIMO-based routing significantly enhances energy efficiency.**

***Index Terms*—"Energy efficiency, LEACH protocol, MIMO technology, STBC methods, and wireless sensor networks"**

I. INTRODUCTION

In recent years, virtual MIMO has gained significant attention due to its potential for energy-efficient communication in large-scale networks. In a virtual MIMO network, groups of sensors collaborate to transmit and receive data. While involving multiple transmitters and receivers reduces energy consumption in long-range communications, it also increases circuitry power demands. Consequently, energy optimization techniques must be tailored to the specific network environment. Given the complexities of circuit design and challenges in integrating separate antennas, virtual MIMO has been adopted in wireless sensor networks (WSNs) to enhance energy efficiency and reliability. Numerous protocols and methods have been developed to enable energy-efficient communication in WSNs. This study explores cooperative virtual MIMO integrated into the LEACH protocol, enabling energy-efficient data transmission by sharing transmission and reception tasks. In virtual MIMO, multiple transmitters and receivers collaborate for long-range communication, improving data reliability in fading environments. The performance of virtual MIMO in WSNs is influenced by the structure of the network and data link layers, with various approaches available for implementing virtual antenna arrays. While the core implementation of virtual antenna arrays and cooperative transmission lies in the physical layer, a cognitive network framework allows network components to adapt operational parameters to specific environmental needs. This paper proposes a cluster-based virtual MIMO model integrated with a cognitive LEACH approach, which dynamically adjusts operational parameters, such as constellation size, to achieve optimal performance. On the other hand, owing to its capability to exploit large potential capacity of multi-path fading channel, MIMO technique has been widely used in the wireless cellular and broadband access systems. It is an interesting issue to investigate if this technique can be used for the purpose of energy-saving in WSN. The author proposed a model to analyze the energy-efficiency of MIMO and cooperative MIMO when both the circuitry energy consumption and transmission energy consumption are considered. The results show that Virtual MIMO is more energy- efficient than multiple input multiple outputs (MIMO) when the transmission distance is above a threshold.

Proposed scheme based on the energy consumption of the whole network. Section 4 compares then ewsche me with OriginalLEACHschemethroughsimulation.Section5 gives the final conclusion of this paper.

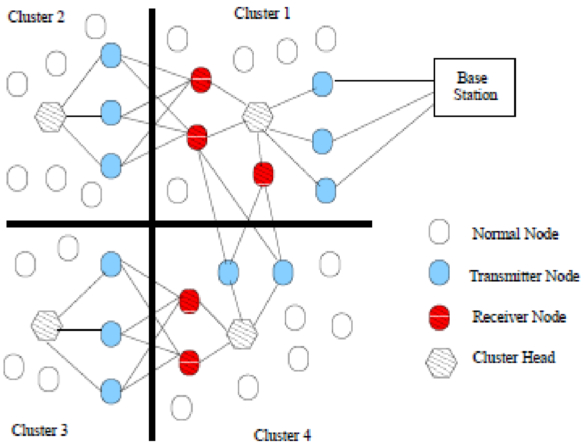

Figure1: ClusterbasedVirtual MIMO

II. SYSTEM MODEL AND SCHEME DESIGN

In this section, the STBC based cluster heads cooperative transmission (SCHCT) scheme is proposed. The system model and assumptions for the model are introduced firstly. Then the design of the SCHCT scheme is described in detail.

A. System Model

In the proposed virtual MIMO framework, there are four types of nodes: normal nodes, transmitter nodes, receiver nodes, and cluster heads. The normal nodes sense and collect data regarding the environment. The Cluster head (CHs) collect data from the normal nodes and use transmitter nodes to transmit their data to the receiver nodes of the neighboring cluster or send data directly to the base station. All the nodes in the cluster will transmit data to the CH using CSMA-CA slotted algorithm IEE (2006). CH will aggregate the packets into a single packet and will Broadcast to the transmitter nodes.

Reduced energy consumption as compared to Cluster 2, in terms of MIMO communication. The cluster heads (CHs) are selected based on their available energy and current load requirements. In our scenario, nodes with highest energy are selected as CHs. The CHs broadcast their advertisements and the other nodes will choose their cluster heads based on the received signal strength of the advertisement messages. Then, a spanning tree-based routing algorithm is used to determine the routing path between CHs.

III. ENERGYCONSUMPTIONMODELOFTHE PROPOSED SCHEME

A. Communication Energy Consumption Model

In this section, the energy consumption model for MIMO communication is derived. Then, a total energy consumption model of the proposed scheme is developed. In analysis, the sink is assumed to be energy-unconstrained as in LEACH. In addition, fixed rate QPSK is used as the modulation scheme.

Communication Energy Consumption Model In order to model the energy consumption of the whole network, the energy consumption of transmitting or receiving one bit is modeled firstly. As described in, the total power consumption of transmitting consists of two main components: the power consumption of all the power amplifiers P_{PA} and the power consumption of all other circuit blocks P_c. So, transmitting energy consumption of one bit is defined as:$E_{bt}=(P_{PA}+P_c)/R_b$(1)

Where E_{bt} is the energy consumption of transmitting one bit and $R_b$is the bit rate of the system. For the virtual MIMO transmission, a Rayleigh fading channel and a two-ray ground reflection model is used. Then the average bit error rate of the MIMO system can be [7]:

$$\bar{P}_b = \frac{4}{b}\left(1-\frac{1}{2^{\frac{b}{2}}}\right)\frac{1}{2^{N_T N_R}}\left(1-\frac{1}{\sqrt{u}}\right)^{N_T N_R}\sum_{k=0}^{N_T N_R-1}\frac{1}{2^k}\binom{N_T N_R-1+k}{k}\left(1+\frac{1}{\sqrt{u}}\right)^k \quad (2)$$

where $\mu=1+1/(E_b/(2N_0))$,b is the constellation size, for QPSK, b = 1. NT and NR denote the number of antennae at transmitter side and receiver side. For convenience, we will assume $NT=NR$ throughout this paper. The required average energy per bit E_b for a given BER requirement P_b can be got by inverting (2). Denote by E_{bt}_MIMO the energy consumption of transmitting one bit for long haul MIMO communication, communication. According to (1) and (2),

$$E_{bt\_MIMO}=(1+\alpha)E_{b\_MIMO}\frac{M_l N_f}{G_t G_r \lambda^2}d_{toS}^4+\frac{N_t P_{ct}}{R_b}$$

(3)

where d_{toS} is the distance from the cluster head to the sink, $R_b$is the bit rate of the system, which is assumed to be equal to B_b, and B is the transmission bandwidth. E_b_MIMO is the required average energy per bit for a given BER and

Can be obtained by inverting (2).

B. Total Energy Consumption Model of the Proposed Scheme

Energy consumption of the proposed SCHCT scheme consists of two terms: energy consumption for the cluster heads and energy consumption for the sensor nodes. If there are K_c clusters, there are average N/K_c nodes per cluster (one cluster head and (N/K_c)-1sensormembers). Denote by E_{CH} and E_S the energy consumption for a cluster head and energy consumption for a cluster member, respectively. Then the total energy required in one cluster,is given by:

$$E_{cluster}=\left(\frac{N}{K_c}-1\right)E_s+E_{CH} \quad (4)$$

For each cluster head, the energy consumption consists of receiving data from the cluster members, aggregatingthe received data, transmitting the aggregated data to the cooperative cluster heads, receiving aggregated data from other cooperative cluster heads in the virtual MIMO cell, transmitting the encoded data to the sink by virtual MIMO technique. Therefore, the energy consumption for the cluster head is given by:

$$E_{CH}=L\left(\frac{N}{K_c}-1\right)E_{Br}+L\left(\frac{N}{K_c}\right)E_{DA}+L(N_T-1)E_{br}+LE_{bt\_inter}+LE_{bt\_MIMO} \quad (5)$$

Where these cond term is the aggregation energy Consumption of the cluster head. For sensor nodes in clusters, the action is only transmission of data to the cluster head, so the energy consumption is given by [1]:

$$E_s=LE_{bt\_intra}$$

Based on the above analysis, the over al lenergy Consumption in one round of the SCHCT scheme can be derived as:

$$E_{total}=K_cE_{cluster}=(N-K_c)E_s+K_cE_{CH} \quad (7)$$

IV. NUMERICALANDSIMULATIONRESULTS

The proposed virtual MIMO network is simulated using the model described in Equation 7. The simulation details are asfollows:number of nodes is 50,networkareais200m×200m, base station is located at the center of the network and also moved in the horizontal direction to observe the effect of distance from the base station. Other system parameters are fc=2.5GHz,B=1kHz,α=0.4706,Ml=40dB,Nf=10dB,Gt Gr=5dBi,ht=hr=1m, $N0/2$=-174 dBm/Hz,Pct =98.2 mW,Pb= 10-3, EDA =50 nJ,L=000

Fig.2 shows the network design for 50 nodes

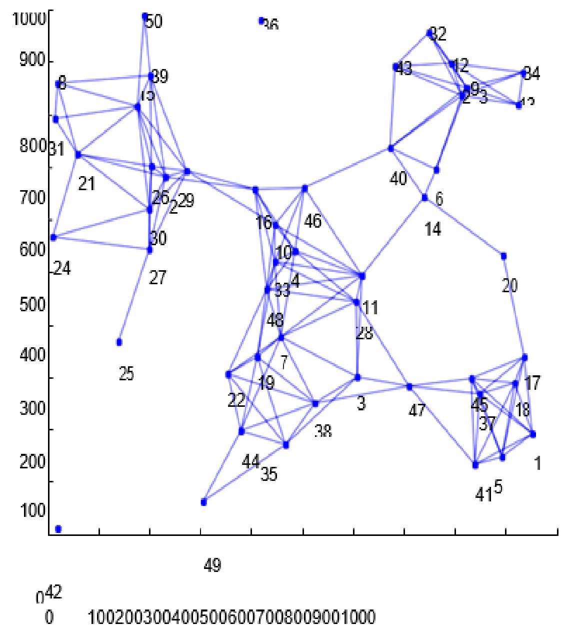

Fig: 2Sensor Network

Fig. 3 shows the total energy consumption of various virtualMIMOtechniquessuchas2x2,3x3, and4x4 using SCHCT and Shannon capacity.

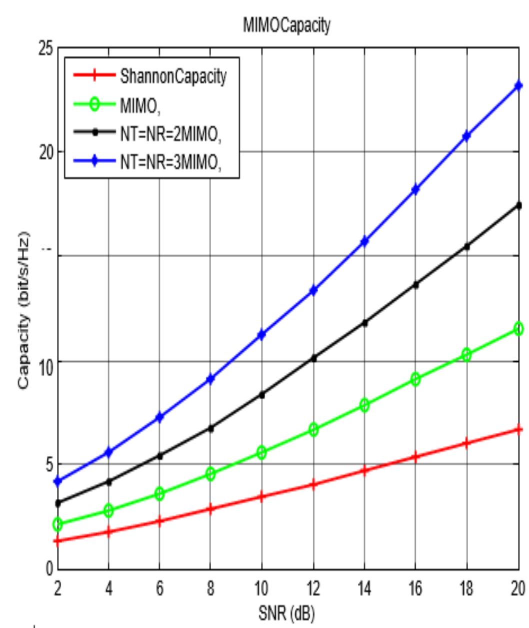

Fig.3MIMOcapacity

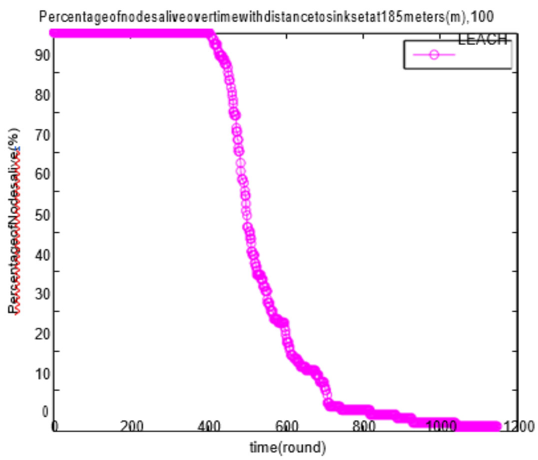

Fig.4EnergyconsumptionofVirtualMIMO

InFig.4, when *NT*is4, the criticaldistanceusingLEACH in terms of energy efficiency is 185 meters, more cooperative cluster heads is more energy efficient. Simulation results verified the correctness of theory analysis.

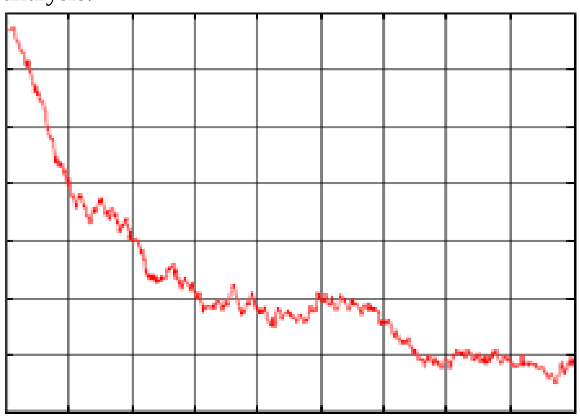

Fig.5Percentage of nods alive over time with distance to sinksetat 185 meters (m), Initial energy fixed as E0=10 Joule (J)

Fig.5 shows the percentage of sensor nodes alive over time with *dtoS* set. In this Fig, *dtoS* is set at 185 meters, which is close to but below the threshold of SCHCT with *NT* = 4. It is clear that the LEACH scheme is more energy efficient than SCHCT scheme. Simulation results verified the correctness of theory analysis.

V. CONCLUSIONS

This paper proposes a cluster-based virtual MIMO transmission scheme aimed at minimizing energy consumption and extending the lifespan of sensor networks. Unlike traditional methods that use cluster members as cooperative nodes, the proposed approach leverages multiple cluster heads to form a virtual antenna array, enabling the implementation of STBC-based MIMO techniques for enhanced energy efficiency during transmissions.

Compared to MIMO Virtual MIMO provides more efficiency, simulation results show that the proposed scheme can provide efficient energy without any break in the sensor network, especially in situations where the sink is far from the sensor area.

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