An Energy Efficient Virtual MIMO Communication for Cluster-based Wireless Sensor Networks

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Abstract:
In this paper, a cluster-based virtual multiple-input multiple-output (MIMO) communication scheme is proposed for energy-constrained wireless sensor networks. We investigate virtual MIMO for fixed and variable rates. We propose energy efficient routing space-time block coding (STBC) based virtual MIMO technique is incorporated into low-energy adaptive clustering hierarchy (LEACH). In addition, an analysis model based on energy consumption of the whole network The simulation results show that virtual MIMO based routing is more energy efficient .

***Keywords*- energy efficiency, LEACH, MIMO, STBC, wireless sensor network**

I. INTRODUCTION

In recent years, virtual MIMO has attracted a growing interest because of its energy efficiency in large field of networks. In virtual MIMO network,a group of sensors cooperate to transmit and receive data[1]. Although the participation of multiple transmitters and receivers in a transmission save energy in long-range communications, the increase in the number of transmitters and receivers also increases the circuitry power consumption. As a result, the energy optimization techniques have to be adapted with the environment. Due to the circuitry complexity and difficulty of integrating separate antenna, virtual MIMO concepts are applied in wireless sensor networks (WSNs) for energy efficient communication to save energy and increase reliability.

A large number of protocols and methods are proposed for energy efficient communications in WSNs. In this paper, we would like to investigate cooperative virtual MIMO incorporated into LEACH[2] that provides energy efficient communication by sharing the transmission and reception of information. In virtual MIMO, multiple senders and receivers participate in long-range communication to improve data reliability in fading channels. The performance of virtual MIMO in WSNs depends on the structure of -network layer and data link layer. There are several approaches for implementing virtual antenna array in WSNs.

Although the core implementation of virtual antenna array or co-operative transmission lies on physical layer to implement this issue. In a cognitive network framework, the network components can modify the operational parameters to respond to the needs of particular environment. We propose a cluster based virtual MIMO incorporated into LEACH cognitive model with the aim of changing operational parameters (constellation size) to meet the optimum design.

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. In [2] 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 taken into account. The results show that Virtual MIMO is more energy-efficient than multiple input multiple output (MIMO) when the transmission distance is above a threshold.

Due to the physical size and energy limitation of sensor nodes, directly deployment of MIMO in one sensor node is infeasible in practice. However, through sensor nodes cooperation, virtual MIMO technique can be implemented in sensor networks. For example, a virtual MIMO based on STBC is proposed in [4], where the training overhead needed for the MIMO transmission is considered. The multi-hop with MIMO transmission, is proposed in [5], where multi-hop MIMO transmission is used to save communication energy consumption between clusters. However, in this scheme, the sink is near or inside the sensor area. In situations where the sink is far from the sensor area, since the long haul transmission energy consumption dominant the energy consumption, multi-hop MIMO transmission is unnecessary.

All these motivate us to propose a new scheme to prolong the sensor network lifetime in such situations. In the proposed scheme, instead of using cluster member as cooperative nodes, multiple cluster heads cooperate to form virtual antenna array so that STBC based MIMO technique can be implemented to achieve energy savings. Based on the communication energy consumption model, the total energy consumption of the proposed scheme is derived incorporated into LEACH under the same bit error rate (BER) requirement. Simulation results show that the proposed scheme can prolong the sensor network lifetime greatly.

The rest of this paper is organized as follows: Section 2 introduces system model and the design of the proposed scheme. Section 3 develops an analytical model for the proposed scheme based on the energy consumption of the whole network. Section 4 compares the new scheme with original LEACH scheme through simulation. Section5 gives the final conclusion of this paper.

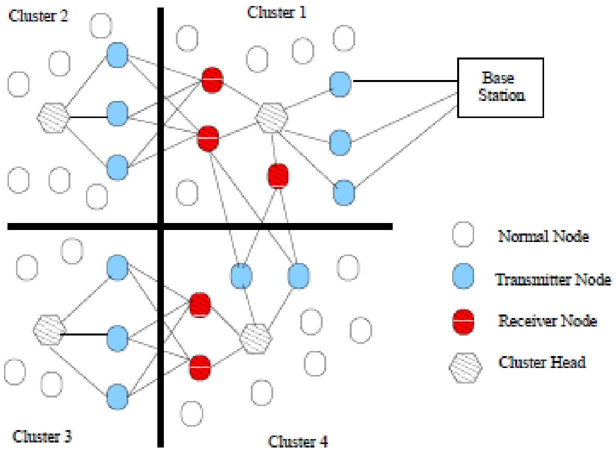

Figure 1:Cluster based Virtual MIMO

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.

B. Design of The Scheme

Figure1 shows four clusters with different transmitter and receiver nodes.For instance, Cluster 1 has three transmitter nodes that directly communicate with the base station. Cluster 2 has three transmitter nodes that communicate with 2 receiver nodes of Cluster 1. In other words, there is multi-hop communication from cluster 2 to cluster 1 and then from cluster 1 to base station. Similarly, the two transmitter nodes of Cluster 4 communicate with 2 receiver nodes of Cluster 1. It should be noted that the same receiver node of Cluster 1 is used by transmitters of both clusters 2 and 4. In other words, it is possible, that a receiver node is used by multiple transmitter nodes. Cluster 3 has two options to reach to the base station: a) Cluster 2, and b) Cluster 4. However, Cluster 4 is selected because of 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. ENERGY CONSUMPTION MODEL OF THE PROPOSED SCHEME

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.

A. 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 [3], 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:

$$E_{bt} = (P_{PA} + P_c) / R_b \qquad (1)$$

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 expressed as [7]:

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

where μ = $1+1/(E_b/(2N_0))$, 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),

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

(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)-1 sensor members). 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, $E_{cluster}$, is given by:

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

For each cluster head, the energy consumption consists of receiving data from the cluster members, aggregating the 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:

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

where the second 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]:

$$E_s = LE_{bt\_intra} \quad (6)$$

Based on the above analysis, the overall energy consumption in one round of the SCHCT scheme can be derived as:

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

IV. NUMERICAL AND SIMULATION RESULTS

The proposed virtual MIMO network is simulated using the model described in Equation 7. The simulation details are as follows: number of nodes is 50, network area is200m × 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 = 2.5 GHz, B =1 kHz, α = 0.4706, Ml = 40 dB, Nf = 10 dB, $GtGr$ = 5 dBi, ht =hr = 1 m, $N0/2$ =-174 dBm/Hz, Pct = 98.2 mW, Pb = 10-3, EDA = 50 nJ, L = 000 bits.

Fig. 2 shows the network design for 50 nodes.

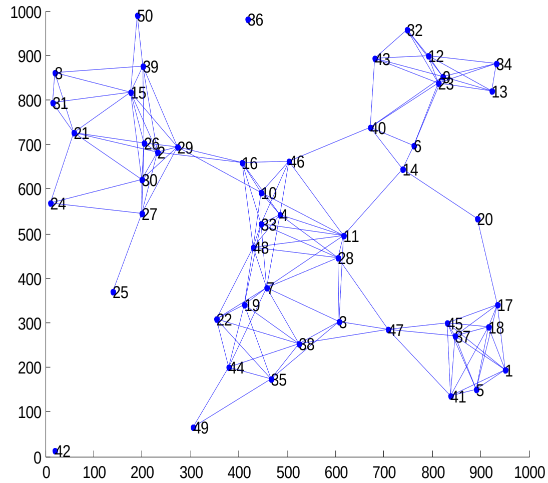

Fig:2 Sensor Network

Fig. 3 shows the total energy consumption of various virtual MIMO techniques such as 2x2, 3x3, and 4x4 using SCHCT and Shannon capacity.

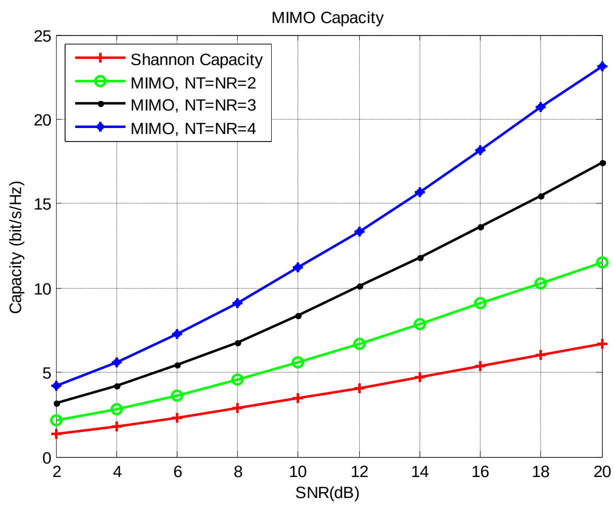

Fig.3 MIMO capacity

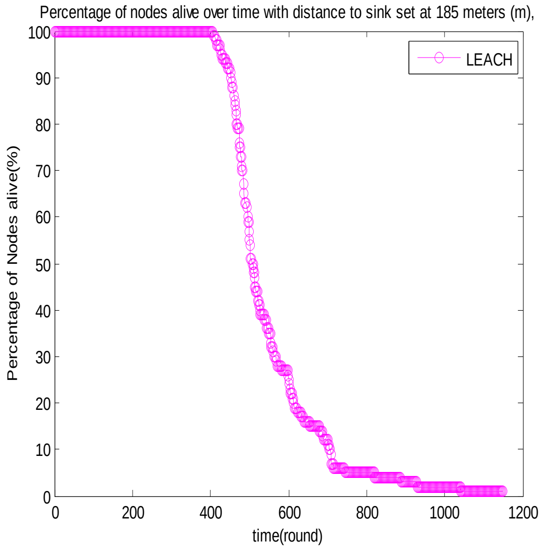

Fig.4 Energy consumption of Virtual MIMO

In Fig. 4, when *NT* is 4, the critical distance using LEACH in terms of energy efficiency is 185 meters, more cooperative cluster heads is more energy efficient. Simulation results verified the correctness of theory analysis.

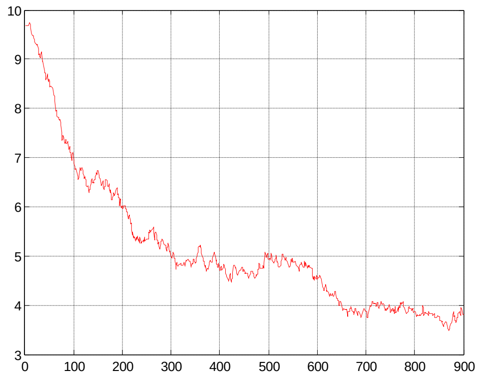

Fig. 5 Percentage of nodes alive over time with distance to sink set at 185 meters (m), Initial energy fixed as E_0=10 Joule (J)

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

In this paper, a cluster-based virtual MIMO transmission scheme is proposed to reduce energy consumption and prolong the sensor network lifetime. In the proposed scheme, instead of using cluster members as cooperative nodes, multiple cluster heads cooperate to form virtual antenna array so that STBC based MIMO technique can be implemented to achieve transmission energy savings. 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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