A Cooperative Nodes Selection Scheme For Wsns Lifetime Maximization Based On Virtual Mimo

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Abstract. One of the major design requirement of the wireless sensor networks is to reduce the total energy consumption of the sensor nodes. In this paper, a new scheme is proposed to choose the cooperative nodes in virtual MIMO transmission mode in energy constrained wireless sensor networks. Transmission scheme is based on V-BLAST technique. Based on the introduced communication energy consumption model, the performance of the proposed and other schemes introduced in the literature are compared based on the overall energy consumption and number of alive nodes in different rounds. The simulation results show that the proposed scheme can decrease the energy consumption of the network and prolong the sensor network lifetime.

Keywords: Wireless sensor network, V-BLAST algorithm, Virtual MIMO, Energy efficiency

INTRODUCTION

One of the most important characteristics of the wireless sensor networks is limited energy resources of the sensor nodes. Thus, a main design requirement of the wireless sensor networks is to reduce the total energy consumption of the sensor nodes. In this way, many energy-efficiency techniques have been proposed. Some of these techniques are based on the multiple input multiple output (MIMO) mechanism. In recent years, MIMO is studied intensively in order to improve the performance of the wireless communications [1]. However, as implementing multiple antennas on small sensor nodes seem infeasible, the concept of the virtual MIMO is introduced to solve the problem. In virtual MIMO, a group of sensor nodes are selected to cooperatively transmit or receive. The researches show that the cooperative MIMO mechanisms are more energy efficient than single input single output (SISO) mechanisms. Thus, virtual MIMO is an attractive technique in WSNs. Virtual MIMO is deployed in a cluster based WSN. Cluster is a group on node that can communicate with the cluster heads. Many algorithms are introduced for clustering of the WSNs in the literatures. LEACH is one of the most well known energy efficient clustering algorithms for WSNs [2], that forms clusters based on the received signal strength and uses these local clusterheads as routers to the sink.

In [3], X. Li proposed a virtual MIMO transmission scheme based on Alamouti technique which is a simple encoding/decoding algorithm. However using the inter node cooperation makes it less feasible than V-BLAST technique [4]. Energy consumption performance of V-BLAST based virtual MIMO technique was introduced in [5] by S.K. Jayaweera. Author in this scheme donot require transmitter-side sensor cooperation unlike previously proposed virtual MIMO schemes for wireless sensor networks. But this scheme donot consider the selection of virtual V-BLAST

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MIMO technique on practical multihop transmission scheme design [4]. In [4] K. Xu et al proposed a cluster to cluster virtual V-BLAST based transmission scheme. This scheme unlike existing works that are mostly based on Alamouti scheme does not require transmitter-side cooperation therefore, it is more suitable for application in real wireless sensor networks.

In this paper, we propose a cooperative nodes selection scheme in the virtual MIMO transmission based on the V-BLAST algorithm. In the proposed mechanism, after clustering the nodes by the LEACH algorithm in each round, some of the nodes in each cluster are selected as auxiliary nodes based on the proposed criterion. These nodes are called VBN (V-BLAST nodes). Thus when a cluster head receives data packets from its cluster members, it aggregates data to remove the data redundancy and then, demultiplex it into several parts and distribute it among the preselected VBN nodes. Finally, VBN nodes simultaneously transmit the data to the sink.

Remainder of this paper is organized as follows. Proposed Scheme is presented in section 2. Section 3 develops the overall energy consumption model. Section 4 compares the introduced schemes through simulation. Finally, we conclude the paper in section 5.

Proposed Scheme

In this section, we explain the proposed scheme in three steps.

Assume that a sensor network consist of N nodes distributed over an area MxM (Fig. 1). Nodes are able to control their transmission power. In the first step, all the sensor nodes self-organized into k clusters based on the distributed LEACH algorithm. According to this algorithm, each node elects itself as a cluster head with a probability P, if its remaining energy is above the average remaining energy in the network. After selecting the cluster heads, each cluster head broadcasts a message to the other sensor nodes using CSMA protocol. Sensor nodes choose one of the cluster heads to join it based on the received signal strength.

In the second step, Percentage of the nodes in each cluster is chosen as V-BLAST nodes (VBN) for MIMO transmission. The VBN nodes are chosen by a threshold δ which is defined as follows.

\[ δ = \frac{E_{\text{remain}}}{d_{h\text{town}} + d_{v\text{ntos}}} \]

where \( E_{\text{remain}} \) is the remaining energy of a node, \( d_{h\text{town}} \) is distance between clusterhead and the node, \( d_{v\text{ntos}} \) is distance between the node and the sink. We choose the Ni nodes with the maximum value of δ as the VBN nodes in each cluster.

In the third step, cluster members transmit L bits data to the clusterhead by the TDMA schedule. This schedule is used to reduce the communications interference in the cluster and increase the bandwidth efficiency. After the clusterhead receives data packets from its cluster members, first, aggregates the received data to remove the data redundancy and split the data packets into Ni parts and distribute to Ni VBN nodes. Then, VBN nodes transmit their data to the sink simultaneously. The sink will receive all data with N antennas and decode them based on zero-forcing and cancelling V-BLAST detector used in [6], [7] and [8]. The detector is the decorrelating decision feedback detector (D-DFD) proposed in [9], [10] for multiuser detection in CDMA systems.

Decorrelating Decision Feedback Detector for MIMOSystems

By using the QR decomposition, we can write channel matrix \( H = UV \) where \( U \) is an \( N_t \times N_t \) matrix with orthonormal columns \( U^H U = 1 \), and \( V \) is an \( N_r \times N_t \) upper triangular matrix, and \( N_t \) and \( N_r \) are the number of transmitter and receiver antennas, respectively. Therefore, received signal in the receiver antennas can be defined as:

\[ \hat{y} = U^H y = VX + l \] where \( l = U^H n \) and \( n \sim N(0, N_0 I_{N_t}) \). Since \( V \) is upper triangular, \( \hat{y}_k \), the k-th element of \( \hat{y} \), only depends on the symbols \( x_t \) for \( t = k, \ldots, N_t \). Denoting the output decision of
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receiver for symbol $x_t$ by $\hat{x}_t$. For $t=1,...,N_t$ the decorrelating decision feedback detector decision statistic for the symbol $x_k$ is given by following equation:

$$z_k = \overline{y_k} - \sum_{t=k+1}^{N_t} t_{kt}x_k = t_{kk}x_k + \sum_{t=k+1}^{N_t} t_{kt}\hat{x}_t + \Pi_{k=k=N_t,N_t-1,...,1}$$

where $\Pi_k \sim N(0,N_0)$ is k-th element of the noise vector $\Pi$ and $\hat{x}_t = x_k - x_k$ for $t=1,...,N_t$. Next minimum distance decisions are made for $x_k$s based on the statistics $z_k$'s. This phase is called the virtual MIMO transmission. In this paper, we assume $N_t = N_r$.

![Figure 1. Cooperative Transmission System model.](image_url)

**Energy Consumption Model**

Energy consumption of our proposed mechanism consists of energy consumed by virtual MIMO transmission and by the normal and VBN nodes in the cluster. To calculate the energy of the whole network, first, the energy consumption of transmitting or receiving one bit is calculated. As described in [11] the total power consumption along a signal path can be divided into two main components: the power consumption of all circuit blocks ($P_c$) and the power consumption of all the power amplifiers ($P_{PA}$). Therefore, the transmitting energy consumption of one bit is defined as follows:

$$E_{bt} = \frac{P_{PA} + P_c}{R_b}$$

The total power consumption of the power amplifiers can be approximated as: $P_{PA} = (1 + \alpha)P_{out}$ where $P_{out}$ is the transmit power, $\alpha = \frac{\xi}{\eta} - 1$ with $\eta$ being the drain efficiency of the RF power amplifier and $\xi$ being the peak to average ratio that depends on the modulation scheme and the constellation size. For $P_{out}$ two models are considered based on the transmission distance. If the transmission distance is above a threshold free space model is considered otherwise two-ray ground reflection model is considered. Thus:
\[ P_{\text{out}} = \begin{cases} E_b R_b \frac{(4\pi)^2 M N_f}{G_t G_r \lambda^2} d^2 d \leq d_0 \\ E_b R_b \frac{M N_f}{G_t G_r h_t h_r^2} d^4 d > d_0 \end{cases} \]  

where \( d \) is the transmission distance and defined as \( \frac{4\pi h_t h_r}{\lambda} \), \( G_t \) and \( G_r \) are the transmitter and receiver antenna gains respectively. \( M_t \) is the link margin compensating the hardware process variations and other additive background noise or interference, \( N_f \) is the receiver noise figure defined as \( N_t = \frac{N_0}{N_t} \) where \( N_0 \) is the single-sided thermal noise power spectral density at room temperature and \( N_t \) is the PSD of the total effective noise at the receiver input. \( \lambda \) is the carrier wavelength.\( h_t \) and \( h_r \) are the heights of transmitter and receiver antenna, \( E_b \) is the required average energy per bit at the receiver for a given BER requirement. \( P_s \). \( R_0 \) is the system bit rate[12].

To estimate the values of the circuit power consumption at the transmitter side, \( P_{ct} \) and at the receiver side, \( P_{cr} \), assume that the frequency synthesizer is shared among all the antenna paths in the MIMO system. Now, \( P_{ct} \) and \( P_{cr} \) can be estimated as follows:

\[ P_{ct} = P_{\text{DAC}} + P_{\text{mix}} + P_{\text{filr}} + P_{\text{syn}} \]  
\[ P_{cr} = P_{\text{LNA}} + P_{\text{ADC}} + P_{\text{mix}} + P_{\text{filr}} + P_{\text{syn}} + P_{\text{IFA}} \]

\( P_{\text{DAC}}, P_{\text{mix}}, P_{\text{filr}}, P_{\text{syn}}, P_{\text{LNA}}, P_{\text{ADC}}, P_{\text{filr}}, P_{\text{syn}}, \) and \( P_{\text{IFA}} \) are the power consumption values for the D/A converter, the mixer, the active filters at the transmitter side, the frequency synthesizer, the low noise amplifier, A/D converter, the intermediate frequency amplifier, respectively.

**Energy consumption for intra cluster communication**

For energy consumption model of intra cluster communications an AWGN channel and free space model are assumed. The energy consumption of transmitting one bit of normal nodes to clusterhead is defined as follows:

\[ E_{\text{bt}}^{\text{ntoCH}} = (n_c - 1)(1 + \alpha) E_b^{\text{ntoCH}} \frac{(4\pi)^2 M N_f}{G_t G_r \lambda^2} d_{\text{ntoCH}}^2 \]  

where \( E_{\text{bt}}^{\text{ntoCH}} \) is energy consumption of transmitting one in the cluster, \( n_c \) is the number of nodes in each cluster, \( d_{\text{ntoCH}} \) is the average distance from cluster member to the clusterhead which can be approximated as \( d_{\text{ntoCH}}^2 = \frac{M^2}{2\pi K_c} \) where \( K_c \) is number of clusters [13].

In LEACH, we assume a circle cluster area with radius \( R = \frac{M}{\sqrt{\pi K_c}} \) and the uniform density of nodes throughout the cluster area. \( E_b^{\text{ntoCH}} \) is the required energy per bit for a given BER requirement which can be estimated by \( N_0 (Q^{-1}(P_b))^2/2 \) where \( Q^{-1} \) is inverse Q-function. Thus, we obtain:

\[ E_{\text{bt}}^{\text{ntoCH}} = (n_c - 1)(1 + \alpha) E_b^{\text{ntoCH}} \frac{(4\pi)^2 M N_f}{G_t G_r \lambda^2} \frac{M^2}{2\pi K_c} \]  

The circuit blocks energy consumption of this communication can be written as:

\[ E_{\text{ct}}^{\text{ntoCH}} = \frac{(n_c - 1) P_{ct}}{BB} + \frac{P_{cr}}{BB} \]  

Where \( b \) and \( B \) are constellation size and bandwidth respectively. Assume \( E_{\text{DA}} \) is the energy consumption for data fusion per bit in cluster by clusterhead in each round [14]. Data fusion is used to reduce the total data message sent. Then the energy consumption of data fusion is expressed as:

\[ E_{\text{fus}} = E_{\text{DAL}} (n_c - 1) \]

And data length after data fusion by cluster head is expressed as:
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\[ L_{agg} = \frac{L(n_c - 1)}{f_{agg}(n_c - 1) - f_{agg} + 1} \]  

(10)

Where \( f_{agg} \in (0, 1) \) is the data fusion factor [15].

The energy consumption for transmission aggregated data from clusterhead to VBN nodes can be calculated the same as above discussion. Thus, \( E_{bt}^{CHtovn} = E_{bt}^{CHtovn} \)

\[ E_{bt}^{CHtovn} = (1 + \alpha) E_{bt}^{CHtovn} \left( \frac{4\pi^2 M N_f}{G_t G_r \lambda^2} \right) (d_{CHtovn})^2 \]  

(11)

and circuit blocks energy consumption is:

\[ E_c^{CHtovn} = \frac{p_{ct}}{2B} + \frac{N_r P_{cr}}{2B} \]  

(12)

Virtual MIMO Transmission Energy Consumption Model

For the virtual MIMO transmission a Rayleigh fading channel and a two-ray ground reflection model are assumed. The average probability of joint symbol errors of the V-BLAST receiver can be defined as:

\[ P_s \approx 1 - \prod_{k=1}^{N_t} (1 - p_k) \]  

(13)

\[ p_k = 4\left(\frac{\sqrt{2} - 1}{\sqrt{2}}\right) \left(\frac{1 - \tau}{2}\right) \sum_{i=0}^{k-1} \binom{k-1+i}{i} \left(\frac{1 + \tau}{2}\right)^i \]  

(14)

where \( k=1,\ldots,N_t \), \( \tau = \frac{\gamma}{\gamma + 1}, \gamma = E_{bimo}^{mimo} \gamma_0 \), \( E_{bimo}^{mimo} \) is required average energy per bit for a given BER \( \gamma \). As in [16]. The given average BER of the V-BLAST receiver can be estimated as:

\[ \gamma_{bimo} \approx P_s \left( N_t b + B \right) \]  

(15)

Thus the energy consumption for transmitting one bit for V-BLAST based MIMO technique is:

\[ E_{bt}^{mimo} = \frac{P_{PA} + N_t P_{ct} + N_r P_{cr}}{R_b} \]

(16)

\[ = (1 + \alpha) E_{bimo}^{mimo} \frac{M_t N_f}{G_t G_r h_t^2 h_r^2} d_{vntos}^4 + \frac{N_t P_{ct} + N_r P_{cr}}{Bb} \]

where \( d_{vntos} \) is the distance from the VBN nodes to the sink and \( R_b \) is the total bit rate of V-BLAST based MIMO system. Therefore, the total energy consumption for the whole network can be written as:

\[ E_{total} = \sum_{i=1}^{k_c} (L_{agg} E_{bt}^{mimo} + LE_{bt}^{ntoCH} + LE_{c}^{ntoCH} + L_{agg} E_{bt}^{CHtovn} + L_{agg} E_{c}^{CHtovn} + E_{fus}) \]  

(17)

SIMULATIONS AND ANALYSIS

In this section, we evaluate the performance of the proposed scheme under the system constraints. We consider 100 nodes in a 100m x 100m area with the equal initial energy for nodes. The energy consumption model used in [17] and [18] is considered for LEACH algorithm. Eq.18 represents energy consumption for k bits transmission over the distance d.
\[ E_{TX}(k, d) = E_{TX-elec}(k) + E_{TX-amp}(k, d) \] (18)

If the distance between transmitter and receiver is smaller than the threshold
\[ d_0 = \frac{\varepsilon_{fs}}{\varepsilon_{mp}} \] (19)

The model \( \varepsilon_{fs} \) is used. According to [19]
\[ E_{TX}(k, d) = \begin{cases} 
  kE_{elec} + k\varepsilon_{fs}d^2 + kE_{DA} & \text{if } d < d_0 \\
  kE_{elec} + k\varepsilon_{mp}d^4 + kE_{DA} & \text{if } d \geq d_0
\end{cases} \] (20)

The energy consumption at the receiver is calculated according to
\[ E_{RX}(k) = E_{elec}k \] (21)

The \( E_{DA} \) is data aggregation energy consumption for data aggregation and \( E_{elec} \) is consumed energy for electric circuits.

The parameters used for LEACH algorithm and primary, secondary and proposed schemes are given in Table 1 and Table 2, respectively.

**Table 1. Parameters used in the simulation.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS location</td>
<td>x=100 m, y=150 m</td>
</tr>
<tr>
<td>Number of nodes(n)</td>
<td>100</td>
</tr>
<tr>
<td>Network size</td>
<td>100m x 100m</td>
</tr>
<tr>
<td>Simulation round</td>
<td>120</td>
</tr>
<tr>
<td>Initial energy</td>
<td>0.05 j</td>
</tr>
<tr>
<td>Packet size(k)</td>
<td>4000 bit</td>
</tr>
<tr>
<td>( E_{elec} )</td>
<td>50 nj</td>
</tr>
<tr>
<td>( E_{DA} )</td>
<td>50 nj</td>
</tr>
<tr>
<td>Amplifier energy free space(( \varepsilon_{fs} ))</td>
<td>10 Pj/bit/m²</td>
</tr>
<tr>
<td>Amplifier energy multipath(( \varepsilon_{mp} ))</td>
<td>0.013 Pj/bit/m⁴</td>
</tr>
</tbody>
</table>

**Table 2. The communication parameters.**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes number=100</td>
<td>Sensor area=100 x100 m</td>
</tr>
<tr>
<td>( \alpha = 0.47 )</td>
<td>( P_{bit} = P_{ifr} = 2.5 ) mw</td>
</tr>
<tr>
<td>( \lambda = 0.12 ) m</td>
<td>( P_{LNA} = 20 ) mw</td>
</tr>
<tr>
<td>( G_s G_r = 5 ) dBi</td>
<td>( P_{syn} = 50 ) mw</td>
</tr>
<tr>
<td>( N_f = 10 ) dB</td>
<td>( N_0/2 = -135 ) dB/mHZ</td>
</tr>
<tr>
<td>( P_{mix} = 30.3 ) m</td>
<td>( P_{IFA} = 20 ) mw</td>
</tr>
<tr>
<td>( R = 0.75 )</td>
<td>( B = 10 ) KHz</td>
</tr>
<tr>
<td>( R = 0.75 )</td>
<td>( f_{agg} = 0.7 )</td>
</tr>
<tr>
<td>( b = 1 )</td>
<td>( L = 4000 ) bit</td>
</tr>
<tr>
<td>( h_t = h_r = 1 ) m</td>
<td>( P_{ADC} = 20 ) mw</td>
</tr>
<tr>
<td></td>
<td>( E_{DA} = 50 ) nj</td>
</tr>
</tbody>
</table>

Now, we compare our proposed algorithm with LEACH and two other methods named as primary and secondary methods. The only difference between our scheme and two other schemes is in the auxiliary nodes selection criteria. In the primary method[6], nodes with the lowest distance to the clusterhead are reselected as VBN nodes and in the secondary method[4] the nodes with the highest residual energy are selected as auxiliary nodes. Figure 2 illustrates the systems lifetime defined by the number of alive nodes over the time. The figure compares the lifetime of the proposed virtual V-BLAST MIMO scheme with the LEACH and two other methods.
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As can be seen the proposed approach takes more time until the first node dies. In the next rounds, the number of alive nodes in the proposed method is higher than the other three methods. The number of alive nodes in the initial rounds is assumed to be the same for all the methods. In some rounds, we can observe that the lifetime of the networks based on the proposed method is three times better than the LEACH and approximately two times better than the primary and secondary methods. Figure 3 shows residual energy in networks in each round for four methods.

It can be observed that VBN nodes selection scheme based on the proposed method can reduce more energy consumption in comparison with the other methods. For example, the energy efficiency improvement can be reached to 10%.
Figure 4 and 5 shows the impact of initial energy of the nodes on the network residual energy and network lifetime, respectively.

**Figure 4.** Network residual normalized energy versus the time in different initial energy of nodes.

**Figure 5.** The number of alive nodes versus the time in different initial energy of nodes.

Figure 6 shows the residual energy in the network by changing the total number of the nodes in the network.
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![Graph](image)

**Figure 6.** Residual normalized energy in different number of nodes in the network.

It can be seen that, in the early rounds, by increasing the number of the nodes in the network, residual energy increases and the energy consumption also rapidly increase.

**CONCLUSION**

In this paper, a cluster based virtual MIMO transmission scheme is proposed to decrease total energy consumption of the network and to increase the network lifetime. This scheme is based on V-BLAST algorithm therefore does not require transmitter-side sensor cooperation. We studied the performance of proposed scheme via simulations. The results indicate the proposed scheme achieves a significant reduction in the overall energy consumption compared to LEACH and two other schemes presented in references [4],[6].

**REFERENCES**


