Energy Efficient WSN using HEED Algorithm

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ABSTRACT
Analyzing system performance terms based on overall packet error rate (PER) and energy consumption. Based on system performance metrics node sleep strategy, where overall energy consumption is minimized by coordinating inter-cluster transmitting energy consumption and the number of sensor nodes in activation. Compared to existing works, our contributions are (1) random distribution of nodes and get a closed-form expression of overall PER that simplifies the energy minimization problem; (2) analyzing the trade off between overall energy consumption and nodes active rate; (3) analyzing the dead nodes in the transmission path. In simulation, the relationships among nodes active rate, inter-cluster transmitting energy consumption and the overall energy consumption and the total dead nodes affected in the transmission path. Furthermore, these parameters are affected by the nodes density, the inter-cluster transmitting distance, the cluster radius and the intra-cluster energy consumption. Finally, the proposed nodes sleep strategy has significant energy savings and this is improved to the next level as constructively changed to HEED algorithm.

Key Words: Packet Error Rate, Energy Consumption, Node Sleep Strategy, Energy Minimization, Nodes Active Rate And Inter Cluster, Intra Cluster, Heed.

INTRODUCTION
Due to the limited energy and difficulty to recharge a large number of sensors, energy efficiency and maximizing network lifetime have been the most important design goals for wireless sensor networks (WSNs). However, channel fading, interference, and radio irregularity pose big challenges on the design of energy efficient communication and routing protocols in the multi-hop WSNs.

As the MIMO technology has the potential to dramatically increase the channel capacity and reduce transmission energy consumption in fading channels [1], cooperative MIMO schemes have been proposed for WSNs to improve communication performance [2–5]. In those schemes, multiple individual single-antenna nodes
cooperate on information transmission and/or reception for energy-efficient communications. It is analyzed a cooperative MIMO scheme with Alamouti code for single-hop transmissions in WSN’s. It is proposed a delay and channel estimation scheme without transmission synchronization for decoding for such cooperative MIMO schemes. It is also proposed a STBC [6] encoded cooperative transmission scheme for WSNs without perfect synchronization. Jayaweera [8] considered the training overhead of such schemes. However, in the above proposals, the multi-hop routing and distributed operations in WSNs are not taken into consideration, which limits the practical use of the cooperative MIMO schemes in WSN. In this paper we study the feasibility of a cooperative MIMO scheme in multi hop WSNs. Radio irregularity of wireless communications and multi-hop routing is considered with the cooperative MIMO scheme. On the other hand, due to its ability of frequency reuse and efficiency in processing highly correlated data, clustering is efficient in the design of WSNs. Therefore, we incorporate the cooperative MIMO scheme[7] with the LEACH protocol, which is an efficient clustering protocol due to its energy-efficient, randomized, adaptive, and self configuring cluster formation. As only single-hop communications from cluster heads to the sink are considered in the original LEACH protocol, we modify the LEACH protocol to allow cluster heads to form a multi-hop backbone and incorporate the cooperative MIMO scheme into each single hop transmission. Based on the proposed scheme, we investigate the energy consumption of each transmission/reception. Then, the overall energy consumption model is developed, and the optimal parameters of the scheme are found such as the number of clusters and the number of cooperative nodes.

Figure 1: Cluster mimo channel for 100x100 nodes inter and intra.

SYSTEM MODEL

The multi-user MIMO concept of space-division multiple access (SDMA) was proposed by Richard Roy and Björn Ottersten, researchers at ArrayComm, in 1991. Their US patent (No. 5515378 issued in 1996[4]) emphasizes "an array of receiving antennas at the base station" and "plurality of remote users". Arogyaswami Paulraj and Thomas Kailath proposed the concept of spatial multiplexing(SM) using MIMO in 1993. Their US patent (No. 5,345,599 issued in 1994[5]) emphasized "wireless broadcast communications" applications and splitting a high-rate signal "into several low-rate signals". In 1996, Greg Raleigh, Gerard J. Foschini, and Emre Telatar refined new approaches to MIMO technology, considering a configuration where multiple transmit antennas are co-located at one transmitter
to improve the link throughput effectively. Bell Labs was the first to demonstrate a laboratory prototype of spatial multiplexing in 1998, where spatial multiplexing is a principal technology to improve the performance of MIMO communication systems.

**Figure 2: MIMO SYSTEM MODEL**

CO-MIMO, also known as Network MIMO (Net-MIMO), or ad hoc MIMO, uses distributed antennas[9] which belong to other users, while conventional MIMO, i.e., single-user MIMO, only employs antennas belonging to the local terminal. CO-MIMO[11] improves the performance of a wireless network by introducing multiple antenna advantages, such as diversity, multiplexing and beam forming. If the main interest hinges on the diversity gain, it is known as cooperative diversity. It can be described as a form of macro-diversity, used for example in soft handover. Cooperative MIMO corresponds to transmitter macro-diversity [11] or simulcasting. A simple form that does not require any advanced signal processing is single frequency networks (SFN), used especially in wireless broadcasting. SFNs combined with channel adaptive or traffic adaptive scheduling is called dynamic single frequency networks (DSFN).

**Figure 3: Flow Chart**

Hybrid Energy-Efficient Distributed Clustering (or HEED) is a multi-hop clustering algorithm for wireless sensor networks, with a focus on efficient clustering by proper selection of clusterheads based on the physical distance between nodes. The main objectives of HEED are to [14]:

- Distribute energy consumption to prolong network lifetime;
- Minimize energy during the clusterhead selection phase;
- Minimize the control overhead of the network.

The most important aspect of HEED is the method of clusterhead selection. Clusterheads are determined based on two important parameters

1) The residual energy of each node is used to probabilistically choose the initial set of...
clusterheads. This parameter is commonly used in many other clustering schemes.

2) Intra-Cluster Communication Cost is used by nodes to determine the cluster to join. This is especially useful if a given node falls within the range of more than one clusterhead. In HEED it is important to identify what the range of a node is in terms of its power levels as a given node will have multiple discrete transmission power levels. The power level used by a node for intra-cluster announcements and during clustering is referred to as cluster power level [13]. Low cluster power levels promote an increase in spatial reuse while high cluster power levels are required for intercluster communication as they span two or more cluster areas. Therefore, when choosing a cluster, a node will communicate with the clusterhead that yields the lowest intra-cluster communication cost. The intra-cluster communication cost is measured using the Average Minimum reach-ability Power (AMRP) measurement. The AMRP is the average of all minimum power levels required for each node within a cluster range R to communicate effectively with the clusterhead i. The AMRP of a node i then become a measure of the expected intra-cluster communication energy if this node is elevated to clusterhead.

HEED: In this algorithm, network life time is prolonged through:
• Reducing the number of nodes that compete for channel access;
• Clusterhead updates, regarding cluster topology; and
• Routing through an overlay among clusterheads, which has a small network diameter.

Comparing HEED to a generic weight-based clustering (GC) protocol such as WCA
• When using a GC algorithm, the number of iterations grows quickly as the cluster radius increases, so each node has more neighbors. Implying a node has to wait longer for higher weighted nodes to decide which cluster to join. Therefore, we have more energy consumption
Clustering in GC takes 85 iterations for a cluster radius of 400. Whereas, HEED takes only 6 iterations for all cluster ranges. This means less energy consumption.
• In GC, it is guaranteed that the node with the highest residual energy will be the clusterhead, whereas in HEED, clusterheads are chosen based on their residual energy and their intra-cluster communication cost.

Cluster head probability of HEED is

\[ CH \text{ prob} = C\text{prob} \times \left( \frac{E_{\text{residual}}}{E_{\text{max}}} \right) \]  

Where, Cprob is the initial percentage of cluster heads among n nodes (it was set to 0.05), while Eresidual and Emax are residual and the maximum energy of a node.

Overall Energy Consumption

For comprehensive and accurate analysis of energy consumption, we consider both the transmission energy consumption and the associated circuit energy consumption. The overall energy consumption is composed of the intra-cluster energy consumption and inter-cluster energy consumption. In the intra-cluster broadcasting phase, the CH of the cluster broadcasts the packet with average energy
concentration E1 per bit. It is easily calculated by equation (1) that in average, there are \( \rho \pi R_1^2 \). Thus, the average intra-cluster energy consumption \( E_{\text{intra}} \) per packet is given by 1 node in cluster trying to receive the data.

\[
E_{\text{intra}} = L \left( (1 + \alpha)E_1 + E_{ct} + \rho \pi R_1^2 E_{cr} \right) \quad (2)
\]

Where \( \alpha \) denotes the transmission efficiency of power amplifier which can be shown as \( \alpha = (\xi/\epsilon) - 1 \), with \( \xi \) being the peak-to-average ratio (PAR) and \( \epsilon \) being the drain efficiency of the RF power amplifier \([9]\). \( E_{ct} \) and \( E_{cr} \) represent the transmitter and receiver circuit energy consumption per bit, respectively. Without loss of generality, here we assume that all nodes have the same \( E_{cr} \) and \( E_{ct} \). Just like \([12]\), during the inter-cluster cooperative transmission phase, an average of \( m + 1 \) nodes cooperatively transmit the packet to the CH of next relay cluster. Then, the average inter-cluster energy consumption \( E_{\text{inter}} \) per packet shows as

\[
E_{\text{inter}} = L \left( (1 + \alpha)(m + 1)E_2 
+ (m + 1)E_{ct} + E_{cr} \right) \quad (3)
\]

The total energy consumption \( E_{\text{all}} \) of each cooperative transmission is

\[
E_{\text{all}} = E_{\text{intra}} + E_{\text{inter}} \quad (4)
\]

RESULTS

![Figure 4: Packets Transferred, Dead Nodes, Energy Packets Transferred.](image)

The active rate \( \eta \) affects overall energy consumption \( E_{\text{all}} \), we show exhaustive numerical research result of the sensor node active rate \( \eta \) vs. the overall energy consumption \( E_{\text{all}} \) in Fig. 4. The system parameters are shown as follows: \( 1/\lambda = 2.4\text{GHz} \), \( GtGr = 5\text{dB} \), \( \alpha = 0.35 \), \( Nf = 10\text{dB} \), \( ML = 40\text{dB} \), \( N0/2 = -174\text{dBm} \), \( L = 200\text{bit} \), \( E1 = 2.5 \times 10^{-6}\text{J} \), \( R1 = 10\text{m} \), \( d = 200\text{m} \), \( \rho = 0.05 \). For the circuit energy consumption, we use the same parameters as in \([10]\) and \([11]\), and set the transmitter circuit power to be \( Pct = 150\text{mW} \), the receiver circuit power to be \( Pcr = 100\text{mW} \), and bit rate to be \( Rs = 10\text{kb/s} \). Therefore, \( E_{ct} = Pct/Rs \) and \( E_{cr} = Pcr/Rs \).

CONCLUSION

Analyzed the performance of a cooperative communication scheme in a clustered random wireless sensor network where the sensor nodes are uniformly distributed in the network. Based on the performance analysis, we get the closed form expression of overall PER and formulate an optimization problem to minimize the total energy consumption subject to the sensor nodes active...
rate. Meanwhile, we also consider how the various system constraints affect the optimization. The simulation results show that the overall energy consumption can be minimized by optimally adjusting the sensor nodes in activation. Also point out that the superiority of this sleep strategy becomes more obvious manifestation in the case of the higher node density. Then the total energy consumption can be optimized by adjusting intra-cluster broadcasting energy consumption under different overall PER requirements. Finally, validation proposed scheme has significant energy savings compared to direct transmissions. Furthermore, in future works, we can jointly optimize multiple network parameters to minimize the total energy consumption.

REFERENCES


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