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IDDR: Improved Density Controlled Divide-and-Rule Scheme for Energy Efficient Routing in Wireless Sensor Networks

F. Saleem[a], Y. Moeen[a], M. Behzad[a], M. A. Hasnat[a], Z. A. Khan[b], U. Qasim[c], N. Javaid[a,d,*]

[a]*Dept of Electrical Engineering, COMSATS Institute of Information Technology, Islamabad, Pakistan*
[b]*Internetworking Program, FE, Dalhousie University, Halifax, Canada*
[c]*University of Alberta, Alberta, Canada*
[d]*CAST, COMSATS Institute of Information Technology, Islamabad, Pakistan*

Abstract

In Wireless Sensor Networks (WSNs) unbalanced energy consumption is a major problem. As a result, energy hole is created and network lifetime is reduced. In this paper, we propose IDDR to avoid the energy hole creation through uniform energy consumption. Proposed scheme reduces coverage and energy hole by dividing the network into small segments with static number of Cluster Heads (CHs) in each round. Selection of CH in each segment is based on maximum residual energy. Simulation results prove that proposed protocol outperforms the compared protocols.

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Keywords: Coverage hole; Energy hole; Routing Protocol; Uniform Random Model; WSN

1. Introduction

WSN is a collection of small, inexpensive, low energy sensor nodes that sense the environment for a variety of applications. These applications include environment monitoring, military surveillance, fire alarms and medical applications. Sensed information is sent to the central area commonly known as sink or Base Station (BS).

WSNs face some serious energy problems They deplete energy quickly due to processing and continuous sensing of field. Therefore, energy saving is the main concern in a WSN where sensor nodes cannot be accessed easily. Another important problem for WSNs is that there is a trade-off between sensing range and energy consumption.

In order to forward the sensed data to BS, different techniques are used including direct communication, multi-hop communication or clustering. Data is directly sent to BS in direct communication whereas in multi-hop strategy, nodes use intermediate nodes. In multi-hop communication, there are areas where the energy consumption is higher than other areas due to more transmission and reception. These areas are referred as *hotspots*. The nodes in hotspot deplete their energy quicker resulting into a phenomenon called *energy hole* and cause premature death of network.

Clustering techniques can be of two types i.e.*Static Clustering* and *Dynamic Clustering*. Static clustering ensures

* Nadeem Javaid, www.njavaid.com, Tel.: +92-300-579-2728
E-mail address: nadeemjavaid@comsats.edu.pk, nadeem.javaid@univ-paris12.fr

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that nodes forward data to same CH till the end of network lifetime or their energy is fully consumed. In Dynamic Clustering, cluster size keeps on changing in eery round.

The main focus of IDDR is to minimize the effects of energy hole and increase the stability of the whole network. It overcomes energy hole by utilizing dynamic clustering, selecting CH on the basis of maximal energy and ensuring the multi-hop communication from outer region to the inner region on the basis of minimum distance.

The rest of the paper is organized as follows. Section 2 points out the Related Work. Motivation is mentioned in Section 3. Section 4 describes IDDR. Section 5 explains the energy model used in IDDR. Simulation results are detailed in Section 6. Finally, Section 7 concludes the paper.

2. Related Work

In the past years, many routing protocols have been proposed to improve the efficiency of WSNs. However, formation of energy and coverage hole reduces network lifetime.

In Low Energy Adaptive Clustering Hierarchy (LEACH) [1], CH selection is probabilistic. Random number of CHs in each round causes non-uniform distribution of load which results in creation of energy and coverage hole.

N. Amjad, *et.al.*, present a new clustering technique, DREEM-ME [2]. Authors divide the circular region into sub regions having one CH each. The cluster members have to report their cluster-specific-CH. As a result, they suffer long distance communication.

Static clustering in the form of fixed squares is presented in REECH-ME [3]. Network field is divided into regions and CH is selected on the basis of maximum residual energy. This protocol is better than LEACH in terms of network lifetime and throughput.

K. Latif, *et.al.*, give a hybrid approach of static clustering and dynamic selection of CH to enhance the network lifetime and minimize energy hole formation in Divide and Rule (DR) Scheme [4]. The scheme lacks when nodes have to report to CH of their region only irrespective of the communication distance.

In Density Controlled Divide-and-Rule (DDR) [5], authors further improved DR by adding a factor of density control in their protocol. Energy hole problem is addressed to a greater extent in this scheme.

Energy hole can be avoided by following different deployment guidelines as mentioned by A. Liu, *et.al.*. Authors proved that node density is proportional to the distance from sink [6]. They propose algorithms to give an optimal transmission radius for network connectivity and coverage.

A. Liu, *et.al.*, analyze that the First node Die Time (FDT) and All node Die Time (ADT) depend on transmission distances and are not related to node density [7].

V. Tran-Quang and T. Miyoshi propose an algorithm to balance the energy consumption and overcome energy hole problem. They vary transmission ranges of the nodes according to their residual energy and distance from the base station [8].

T. Liu [9] uses mixed-routing strategy and non-uniform distribution of energy to balance energy consumption over the whole network. This scheme works in both inter and intra coronal areas enhancing network lifetime reasonably.

Authors propose a mechanism to reduce frequent sensing and transmission. This balances energy depletion in the network. Furthermore, energy depletion problem is reduced by a novel sensor distribution algorithm [10].

3. Motivation

Energy hole causes a major hindrance in the network stability. In DDR and DR authors use static clustering to enhance the network lifetime and stability of the network. However, these techniques lack when nodes are bound to their respective CHs even if other CHs are at a less distance. We take DDR as the basis of our research.

We improve DDR protocol in three ways: (a) nodes are bound to their respective CHs i.e. static clustering in DDR. We change this static clustering to dynamic clustering in a way that nodes can connect to the nearest CH of any region. (b) In DDR, CH is selected on the basis of distance from reference point. We select CHs on the basis of maximum residual energy. (c) To further improve the network lifetime and stability, we consider the hybrid version of multi hop communication i.e. CHs present in the outer region will also check their distances to the CHs present in inner region and select the CH with minimum distance unlike DDR.

Table 1. Symbols used in the paper.

Symbol	**Meanings**
I_s	Inner Square
M_s	Middle Square
O_s	Outer Square
S_n	n^{th} segment
C_p	Center point of network field
$T_R^{S_n}$	Top right of n^{th} square
$T_L^{S_n}$	Top left of n^{th} square
$B_L^{S_n}$	Bottom left of n^{th} square
$B_R^{S_n}$	Bottom right of n^{th} square
S_n^{CH}	CH of segment n

4. Proposed Scheme

Efficiency of a routing protocol depends on its energy consumption and stability period. Maximization of FDT or stable region by using uniform energy consumption, is the target to be achieved. As a result, data is received from the whole field for a longer period of time. Table 1 shows the parameters used in this paper. Following are the main parts of our proposed model:

4.1. Network Model

In our model we consider a network field of 100m x 100m. BS divides the network field into rectangular segments. A fixed number of nodes are deployed in each region and one CH is selected from each segment on the basis of maximum residual energy.

4.1.1. Region Formation

Initially, network field is divided into n concentric squares which are equidistant. We take n as 3 and name these squares as: Internal Square (I_s), Middle square (M_s) and Outer Square (O_s). BS is located in the center of sensor field and its coordinates are taken as reference point in the formation of concentric squares. Coordinates of center point are represented as $C_p(x_1, y_1)$. In order to divide the sensor field into concentric squares, following equations are used:

$$T_R^{I_s}(x_2, y_2) = (x_1 + \alpha, y_1 + \alpha), \tag{1}$$

$$B_R^{I_s}(x_3, y_3) = (x_1 + \alpha, y_1 - \alpha), \tag{2}$$

$$T_L^{I_s}(x_4, y_4) = (x_1 - \alpha, y_1 + \alpha), \tag{3}$$

$$B_L^{I_s}(x_5, y_5) = (x_1 - \alpha, y_1 - \alpha). \tag{4}$$

Where, α is the distance between CP and boundary of I_S as shown in fig. 1. Following equations can be used to find out the coordinates of n^{th} square (S_n):

$$\alpha = x_1 n. \tag{5}$$

For concentric squares, α will be a multiple of 2 for M_S and similarly a multiple of 3 for O_S,

$$\alpha_2 = 2\alpha \quad and \quad \alpha_3 = 3\alpha. \tag{6}$$

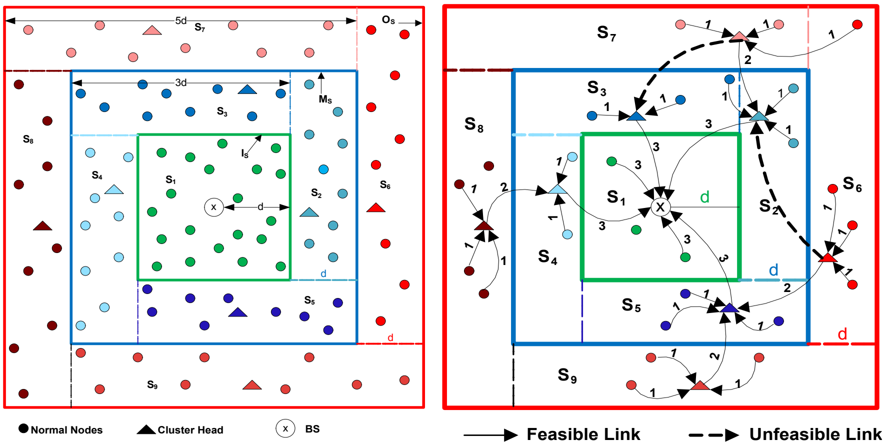


Fig. 1. (a) Deployment of nodes; (b) Communication Architecture.

Hence we can establish a relation from equation (6) to find α for n^{th} square as:

$$\alpha_n = nd \tag{7}$$

Following equations are used to find the dimensions of n^{th} square:

$$T_R^{S_n}(x_n, y_n) = (x_1 + \alpha_n, y_1 + \alpha_n), \tag{8}$$

$$B_R^{S_n}(x_n, y_n) = (x_1 + \alpha_n, y_1 - \alpha_n), \tag{9}$$

$$T_L^{S_n}(x_n, y_n) = (x_1 - \alpha_n, y_1 + \alpha_n), \tag{10}$$

$$B_L^{S_n}(x_n, y_n) = (x_1 - \alpha_n, y_1 - \alpha_n). \tag{11}$$

In next step, the area between two concentric squares is further divided into rectangles. For division of area between I_s and M_s, we consider the top right and bottom right corners of I_s as the reference points. To make a rectangle we add α in $B_R^{I_s}$ and $T_R^{I_s}$ to get points A and B, respectively. After connecting A with top right and B with bottom right corner of I_s , we get the segment S_2. Similarly, we can get segments S_3, S_4 and S_5. Following the same way, area between M_s and O_s is divided into segments S_6 , S_7, S_8 and S_9.

4.1.2. Deployment of Nodes

Nodes are uniformly distributed in the network. Each region has equal number of randomly deployed nodes as shown in fig. 1(a). This strategy helps in overcoming the formation of coverage hole.

4.2. Communication Architecture

IDDR uses 3-tier communication architecture. In tier-1, nodes of each segment forward data to the nearest CH. In tier-2, CHs of O_S segments will select nearest CH from M_S and will forward their data to respective CHs. At the end the CHs of M_S and nodes of S_1 forward their data to BS. Fig. 1(b) illustrates 3-tier communication architecture of our scheme.

4.3. CH Selection

CH selection is an essential phase in any clustering protocol. In IDDR, each segment has its own CH except segment S_1 in which nodes directly communicate with BS. Number of CHs remains constant throughout the network lifetime. Nodes are free to join the nearest CH and also CHs of O_S may select the nearest CH from M_S to forward the aggregated data of their segment. In this manner the communication distance is minimized. Algorithm 1 and 2 show steps for selection of CH and next hop CH respectively.

5. Energy Model

We use first order energy model as mentioned in [6] for energy consumption calculation. This model considers the energy loss due to communication between nodes at distance d. Nodes consume energy during transmission and reception in order to process L number of bits. Energy consumption by transmitter and receiver is given below:
Transmission energy of sensor node at distance, d $>d_o$ is ,

$$E_{tx}(L,d) = E_{elec} * L + L * (e_{amp} * d^n), \tag{12}$$

Whereas, transmission energy for intermediate node is,

$$E_{tx}(L,d) = ((E_{elec} + E_{DA}) * L) + (e_{amp} * L * d^n). \tag{13}$$

For d $<d_o$ is,

$$E_{tx}(L,d) = E_{elec} * L + L * (e_{fs} * d^n), \tag{14}$$

and for intermediate node,

$$E_{tx}(L,d) = ((E_{elec} + E_{DA}) * L) + (e_{fs} * L * d^n). \tag{15}$$

. Equation for reception energy of all sensor nodes is:

$$E_{rx}(L) = E_{elec} * L. \tag{16}$$

Algorithm 1 *CH* Selection

Step 1: Initialize $[M]$ with residual energy of nodes of a segment.
Step 2: Select the maximum energy node as CH.
Step 3: Initialize $[N]$ for each node with distance from CH of its segment and all directly connected segments.
Step 4: Select min $[N]$ as CH.

Algorithm 2 Next hop *CH* Selection

```
if S(i)O_S then
  if S(i)S_6 then
    S(i).NextHop = mindist.S^2_CH, dist.S^3_CH, dist.S^5_CH
    if S(i)S_7 then
      S(i).NextHop = mindist.S^2_CH, dist.S^3_CH, dist.S^4_CH
      if S(i)S_8 then
        S(i).NextHop = mindist.S^3_CH, dist.S^4_CH, dist.S^5_CH
        if S(i)S_9 then
          S(i).NextHop = mindist.S^2_CH, dist.S^4_CH, dist.S^5_CH
        endif
      endif
    endif
  endif
endif
```

Table 2. Radio Parameters.

Symbol	Value
E_{Tx}	50 nJ/bit
E_{Rx}	50 nJ/bit
E_{fs}	10 pJ/bit/4m^2
E_{DA}	5 nJ/bit/signal
E_{init}	0.5 J

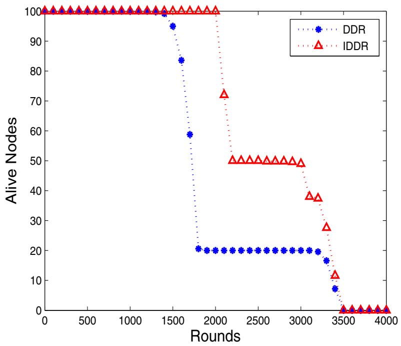


Fig. 2. Comparison of stability period

In above equations, E_{tx} and E_{rx} are the energies consumed by nodes to transmit and receive L bits over the transmission distance d, respectively. E_{elec} is the parameter that accounts for per bit energy consumed by circuitry of transmitter and receiver. n is the path loss exponent and d_o is the reference distance. e_{amp} and e_{fs} are characteristics of transmitter amplifier. E_{DA} is the data aggregation energy. Used values for these parameters are given in table 2.

6. Performance Evaluation

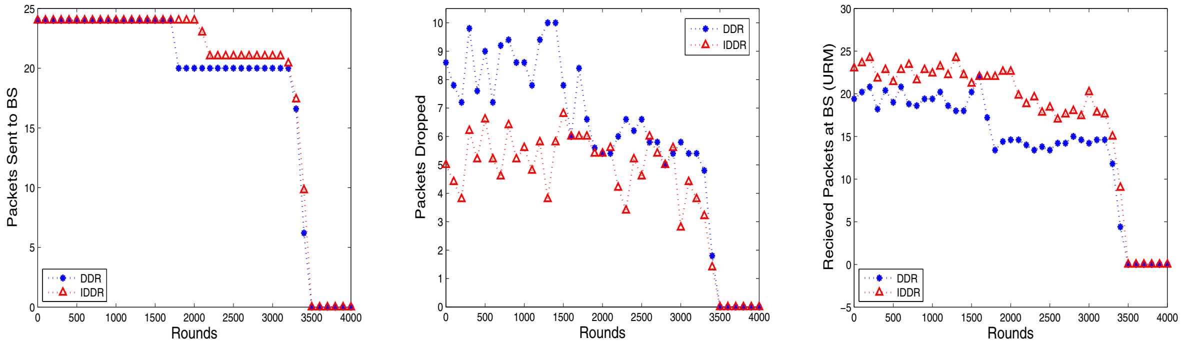
In this section we evaluate the performance of our protocol with the existing DDR protocol on basis of following metrics:

- FDT and ADT of the two protocols
- Number of packets sent per round
- Packets dropped
- Number of packets received per round
- Delay of network per round

In IDDR, packet drop rate is calculated by using Uniform Random Model (URM). The probability of the packet drop is set to 0.3. 100 nodes are deployed in the network area of 100m x 100m with the BS at (50,50). The network is homogenous i.e. all nodes have same initial energy.

6.1. Stability

Fig. 2 shows the FDT and ADT of DDR and IDDR. The first node in DDR dies in 1400^{th} round while the first node dies at almost 2100^{th} round in IDDR. It shows the FDT of IDDR is 800 rounds more than the DDR scheme. Reduced communication distances and selection of CH on the basis of maximum residual energy help in increasing



(a) Comparison of packets sent to BS; (b) Comparison of packets dropped; (c) Comparison of successfully received packets.

Fig. 3. Throughput

the stability of network. The ADT of both protocols is same but the alive nodes in unstable region of IDDR is greater than that of DDR.

6.2. *Throughput*

6.2.1. *Number of Packets Sent per round*

Fig. 3(a) shows the total number of packets sent to BS. It can be observed that more number of packets are forwarded to BS in IDDR. Twenty packets from S_1 and one packet each from S_2, S_3 and S_4, making a total of twenty four packets per round, are sent to BS till FDT. After FDT is achieved, the packets sent to BS depends on the number of alive nodes.

6.2.2. *Packets Dropped*

Fig. 3(b) shows the comparison of packet drop. The reason for less packet drop in IDDR is reduced communication distances. Both schemes have almost the same ADT. Another important factor to notice is that the packet drop is almost constant throughout the network lifetime.

6.2.3. *Packets Received at BS*

Fig. 3(c) shows that IDDR achieves higher throughput than DDR. This increased throughput is the result of reduced communication distance, balanced energy consumption and uniformity in the selection of CHs in each round.

6.3. *Delay of the Network*

We considered electromagnetic nature of the signals, through which the communication in whole network takes place. Also we assume the attenuation factors to be null. Fig. 4 depicts that the propagation delay of IDDR is less than DDR because the communication distance has been reduced. The data reaches to both, CHs and BS, efficiently. Nodes are able to communicate with the nearest CH thus reducing the communication distance resulting in lesser delay.

7. Conclusion

This research paper focuses on minimization of energy hole by using dynamic clustering. The network is divided into segments which reduces the communication distance between nodes and CH, CH and CH and CH and BS. Using

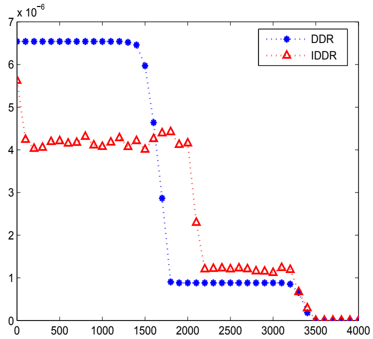


Fig. 4. Delay of the network

this technique we are able to achieve increased stability in IDDR. CH selection in the proposed protocol is done on the basis of maximal residual energy. Furthermore, the nodes in the outer region do multi-hop communication on the basis of minimum distance with the CHs in the middle region. The results prove that IDDR outperforms DDR on the basis of increased stability period, enhanced throughput and lesser propagation delay per round.

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