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TSDDR: Threshold Sensitive Density Controlled Divide and Rule Routing Protocol for Wireless Sensor Networks

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***Abstract*—In Wireless Sensor Networks, efficient energy management is of great importance. In this paper, we propose a novel routing protocol; Threshold Sensitive Density Controlled Divide and Rule (TSDDR) to prolong network lifetime and stability period. To achieve these targets, we utilize static clustering with threshold aware transmissions. Simulations are done in MATLAB and the results show that our protocol has 60% longer stability period than LEACH [1] and 36% longer stability period than DDR [2]. We also implemented the Uniform Random Model (URM) to find Packet Drop to make our scheme more practical.**

Keywords*—Cluster Heads, Coverage Hole, Energy Hole, Packet Drop, Routing Protocol, Wireless Sensor Networks (WSNs)

I. INTRODUCTION

Wireless Sensor Networks (WSNs) consist of tiny nodes that are capable of sensing different physical and environmental attributes in real time, such as, temperature, humidity, light, pressure and have the ability to provide efficient and reliable communication using a microwave link. Sensor nodes sense the data and forward it to the Base Station (BS) using direct and/or multi-hop communication. Once the BS node receives the sensed information, it processes and forwards it to the end users.

Initialization and distribution of nodes is the first phase in developing a wireless sensor network. Usually, the deployed nodes are portably battery powered and has a limited power supply. These sensor nodes are normally deployed in potential working environments, such as, observing precarious applications over battlefield or in any remote or hostile environments. Once dispersed in the network field, they are left unattended. Consequently, it becomes impossible to recharge or renew their batteries. However, the data collected by these nodes is highly critical and may be of scientific and strategic importance. Hence, efficient consumption of energy in the sensor networks is a critical measure to form a vigorousness network.

Optimization of energy consumption to elongate network lifetime has been one of the hot research topics in WSNs. To address this problem, much of the work has been done during the recent years where efficient utilization of energy, by proposing robust protocols, is taken advantage of. Clustering, in which network is divided into logical regions, is used to avoid inefficient use of energy. Clustering may be dynamic or static. In dynamic clustering, cluster and number of nodes associated with cluster change. In static clustering, cluster and number of nodes associated with cluster remain fixed throughout the network lifespan.

WSN may be either reactive or proactive. In the former case, the nodes react immediately to sudden or drastic changes in a specific attribute and keep their transmitters off otherwise; hence, these are well suited for time critical applications. In the latter case, nodes periodically switch on their sensors and transmitters, sense the environment and transmit the data of interest. Thus, these are well suited for periodic data monitoring applications.

Rest of the paper is organized as follows: section II presents the related work, while Section III presents the motivation. Proposed protocol design is described in section IV. Section V presents the simulations and results, and finally, section VI concludes the paper.

II. RELATED WORK

Cluster based routing protocol, LEACH [1], is proposed by W. Heinzelman. The communication scheme in this protocol is multi-hop. Selection of CHs is probabilistic, therefore, distribution of CHs is not uniform. This may result in unbalanced distribution of CHs in the network.

In REECH-ME [5] and DREEM-ME [6], static clustering technique is implemented. Authors in [5] proposed a Regional Energy Efficient Cluster Heads based on Maximum Energy (REECH-ME) by using static clustering technique. Selection of CHs is on the basis of residual energy of nodes. The protocol achieves longer network lifetime than LEACH. However, energy holes may be created due to unequal areas of static clusters. Static clustering [6] is proposed to prolong network lifespan by dividing the circular network into different regions. However, both REECH-ME and DREEM-ME fail to uniformly distribute the nodes in divided regions.

A reactive protocol, TEEN [4], has been implemented which is proposed for temperature specific applications. The

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protocol outperforms LEACH [1] in terms of lifetime. However, this protocol is limited for temperature specific applications.

A.Ahmad, *et al.*, [2] introduced a new routing technique; Density Controlled Divide-and-Rule (DDR) for WSNs. Protocol solve the problem of unbalanced energy utilization that causes energy and coverage holes in WSNs. A hybrid approach of uniform-random deployment of nodes is used in this work. The protocol beats LEACH [1] and REECH-ME [5] in terms of energy consumption, lifetime and stability period of the network.

A distributed coverage hole repair algorithm (HORA) for WSNs is proposed in [8]. Authors address the energy hole problem due to frequent sensing and non-uniform nodes distribution. They proposed a pixel-based transmission scheme to mitigate inefficient use of energy. Energy hole is created due to non-uniform distribution of the nodes. In hot-spots regions, energy is consumed at very fast rate, due to which nodes behind the energy hole cannot transmit to BS. In order to get rid of coverage holes of network, nodes with high degree of density are moved meanwhile keeping the coverage area of neighbors of that moving node same. It is observed that substantial amount of coverage overlapping may be minimized and percentage of coverage of the holes can be maximized by using this approach.

Deployment guidelines for sensors to achieve maximum lifetime and to avoid energy holes in WSNs is presented in [7]. The authors design an algorithm to identify an optimal transmission radius and the corresponding achievable maximum network lifetime. However, the factors like network coverage, network redeployment, data packet loss, network delay are not considered in this work.

III. MOTIVATION

Energy is a very scarce resource and must be used very efficiently, especially when its the case of portable and non-chargeable power supply. During the recent years, much research has been done in the area of WSNs. However, lack of significant attention has been noted that is being given to the time critically of applications. Most of the protocols give attention to reduce coverage holes and energy holes to maximize network life time but they assume a sensor node to collect and transmit a sensed attribute periodically from its environment.

LEACH [1] uses dynamic clustering that results in a variable number of clusters. Also, the selection of CHs is probabilistic. These factors lead to quick death of the nodes in LEACH. In DDR [2], the nodes uses static clustering but the use of periodic transmissions make the nodes die quickly. As a result, the network in DDR has a smaller lifetime. We believe that there exists a need for the sensor networks to be reactive, i.e., to respond only to drastic changes or a sudden event. We also believe that the dynamic clustering technique in the existing reactive protocol (TEEN) [4] leads to quick death of the network. So, in our research, we have focused to develop a protocol which can fulfill these requirements and can prolong the network lifespan.

IV. PROPOSED PROTOCOL DESIGN

In this section, we firstly describe the radio model and network field division into clusters. Then we present the communication architecture and cluster head selection. Energy consumption in clusters and protocol operation is then explained in the end of this section.

A. Radio Model

We assume a simple first order radio model. The radio parameters for our model are shown in table 1. We also take into account d^2 energy losses due to channel transmission. Thus to transmit a k-bit message at distance d, the mathematical expressions are:

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \tag{1}$$

$$if d < d_o \qquad E_{Tx}(k,d) = E_{elec} \times k + \epsilon_{fs} \times k \times d^2 \tag{2}$$

$$if d \geq d_o \qquad E_{Tx}(k,d) = E_{elec} \times k + \epsilon_{mp} \times k \times d^4 \tag{3}$$

$$ReceptionEnergy: \qquad E_{Rx}(k) = E_{elec} \times k \tag{4}$$

B. Network Model

We have taken $100m \times 100m$ area for the network field with BS at the central reference point i.e. $C_p(x_1, y_1)$. The field is divided it into three concentric squares with center as coordinates of BS. A total of 100 nodes are deployed uniformly in the field. In our protocol, number of clusters and CHs is fixed.

1) Cluster Formation: The entire network field is divided into nine regions. Nodes are deployed randomly and distributed uniformly in each region. Firstly, network has been divided into n equidistant concentric squares. The value of n depends upon network field area and number of deployed nodes. Hence, value of n is set to 3 in our work. These concentric squares are named as: Internal Square (I_s), Middle Square (M_s) and Outer square (O_s).

Following equations divide network field into concentric squares:

$$T_r^{I_s}(x_2, y_2) = (x_1 + \beta, y_1 + \beta), \tag{5}$$

$$B_r^{I_s}(x_2, y_2) = (x_1 + \beta, y_1 - \beta), \tag{6}$$

$$T_l^{I_s}(x_2, y_2) = (x_1 - \beta, y_1 + \beta), \tag{7}$$

$$B_l^{I_s}(x_2, y_2) = (x_1 - \beta, y_1 - \beta), \tag{8}$$

where $\beta = x_1/N$ is the distance from the center of network field to the boundary of I_s. $T_r^{I_s}$,$T_l^{I_s}$,$B_r^{I_s}$ and $B_l^{I_s}$ are the top right, top left, bottom right and bottom left corners of square I_s, respectively. Using equations (5)-(8), square regions can be formed for any concentric square. β is multiple of 2 for M_s, multiple of 3 for O_s and multiple of n for n^{th} region.

2) Square's Division and Node's Deployment: Each square region is divided into four rectangular regions as shown in fig. 1. By this division process, we get regions M_2, M_3, M_4 and M_5 of middle square, M_s, whereas regions M_6, M_7, M_8 and M_9 of outer square O_s. Square I_s is closest to the BS and is not divided into any further regions. After division of square regions, nodes are deployed uniformly over the entire network

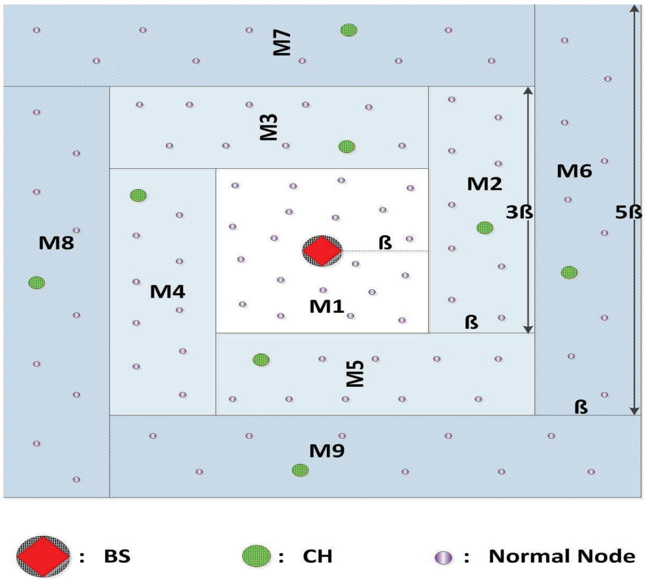

Fig. 1. Deployment of Nodes

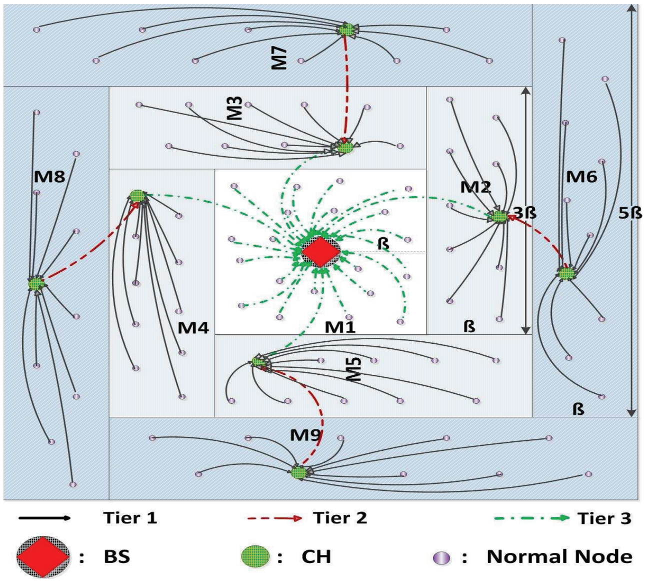

Fig. 2. Communication Architecture

field. 20 nodes are deployed in region M_1 while 10 nodes are deployed in all the other regions i.e., M_2, M_3, ... , M_9.

C. Communication Architecture

In our proposed model, data from the sensors reach BS by using multi-hop scheme. It consists of 3-Tier communication architecture. In Tier-1, all the non-CH nodes forward their sensed data to their respective CHs. In Tier-2, CHs of the outer regions O_s send their data to the nearest CHs of the middle region M_s. To achieve energy efficiency, CHs of O_s find their distance to the next level CHs and send the data to the nearest CHs. For instance, CH of region M_6 finds its distance with the CHs of region M_2, M_5 and M_7, and forwards its data to the minimum distant CH. In Tier-3, nodes of inner region I_s and CHs of middle region M_s communicate with BS. Fig. 2 depicts this 3-Tier architecture of our implemented work.

D. Cluster Head Selection

In any clustering protocol, selection of CHs is a very important step. As already stated, our protocol uses static clustering, number of clusters and CHs remain fixed throughout the network operation. One CH is selected in each region except region 1. Hence, total of 8 CHs are selected in every round. As our protocol uses a multi-hop scheme, this significantly brings robustness in the network, and energy consumption is controlled to a greater extent. CH is selected on the basis of minimum distance from the region's midpoint. In addition, CH selection between region M_2 and M_6, M_3 and M_7, M_4 and M_8, and M_5 and M_9 is synchronized i.e., if CH in M_2 is selected on the right side of the reference point then CH in M_6 is also selected on the right side of the reference point. This results in a smaller communication distance and helps in avoiding energy and coverage holes.

E. Protocol Operation

In our proposed protocol, a reactive WSN is being implemented. The nodes send their data to BS and CHs only when the sensed attribute crosses a pre-defined threshold, and keep their transmitters off otherwise. We use the static clustering technique in which the network area is divided into 9 regions. The number of deployed nodes and clusters in these regions remain static throughout the network lifetime. Once the network is deployed, the sensors start sensing. The sensors transmit only if the threshold value is crossed. Algorithm 1 describes the stepwise operation of our proposed protocol. Following are the two types of threshold values:

1) Hard Threshold (HT): This is the first threshold value with which each normal sensor compares its sensed attribute. Its an absolute value of the attribute beyond which, the node crossing this value, turns transmitter on and reports to its CH.

2) Soft Threshold (ST): This is the second value of the threshold with which the sensor compares its value, only when the sensor has crossed hard threshold. It's a very small change in the value of the sensed attribute which triggers the node to turn its transmitter on and report to its CH. A higher value of ST may lead to lower power consumption and higher network lifetime but at the cost of lesser transmissions (which may involve critical data), and vice versa.

V. Simulations, Results and Discussions

In this section, we present and discuss the simulation results of our proposed protocol. The results are compared with the existing traditional protocols by considering following metrics: stability period, instability period, network lifetime,

TABLE I. RADIO PARAMETERS

Operation	**Energy Dissipated**
Transmitter/Receiver E_{elec}	$50nJ/bit$
Data Aggregation Energy	$5nJ/bit/signal$
Transmit Amplifier ϵ_{fs} ($d_{BS} < d_o$)	$10pJ/bit/4m^2$
Transmit Amplifier ϵ_{mp} ($d_{BS} \geq d_o$)	$0.0013pJ/bit/m^4$

Algorithm 1 **Protocol Operation**

```
Step 1$\longrightarrow$ Deploy Nodes and Initialize Network
Step 2$\longrightarrow$ Record midpoints of each region with CHs
Step 3$\longrightarrow$ Initialize $N_i$ with nodes of each region $M_i$
Step 4$\longrightarrow$ Calculate $N_i$'s regions midpoint distance
Step 5$\longrightarrow$ Select CH in descending order of distance
Step 6$\longrightarrow$ if CH.$N_i$ belongs to $O_s$ then
            if CH.$N_i$ belongs to $M_6$ then
               CH.$N_i$.nexthopCH = id.CH of $M_2$
            else CH.$N_i$ belongs to $M_7$
               CH.$N_i$.nexthopCH = id.CH of $M_3$
            else CH.$N_i$ belongs to $M_8$
               CH.$N_i$.nexthopCH = id.CH of $M_4$
            else CH.$N_i$ belongs to $M_9$
               CH.$N_i$.nexthopCH = id.CH of $M_5$
            end if
         end if
Step 7$\longrightarrow$ if the sensed value $\geq$ HT then
            if HT is crossed first time then
               Turn transmitter on and report to CH
            else
               if the sensed value $\geq$ ST then
                  Turn transmitter on and report to CH
               end if
            end if
         end if
```

number of packets sent, number of packets received and energy consumption. A total of 100 nodes are deployed randomly in the network area of $100m \times 100m$ which is divided into 9 regions. The position of the base station is at the center of the network field. Initial energy of the nodes is 0.7J. The network is simulated 5 times and average values of the parameters are plotted. Uniform Random Model [12] is also implemented in this scheme to find packet drop to make this protocol more practical. The probability of the packet drop has been set to 0.3.

Fig. 3 illustrates the number of packets sent to BS. It can be seen from the figure that the number of packets sent by DDR is more as compared to that sent by our protocol. The less number of packets sent in our approach is because packets are sent upon crossing the threshold value. Hence, less number of packets will result in less amount of energy consumption and will ultimately prolong the network lifetime. This is depicted in fig. 3 where packets sent by DDR end around 3500^{th} round while network in our protocol has a lifetime till 5600^{th} round.

Fig. 4 shows the packet drop rate of DDR vs. TSDDR. As can be seen from this figure, the number of packets dropped in TSDDR is smaller as compare to DDR. The reason of this smaller packet drop is the threshold sensitive nature of our proposed protocol. Implementation of Uniform Random Model (URM) and the number of packets received per round is shown in fig. 5. Results show that the number of packets received at BS is smaller in TSDDR as compared to packets received at BS in DDR.

Fig. 6 demonstrates that the network life time of our approach is 2100 rounds more than DDR and 4300 rounds more than LEACH. The first node die time (FDT) of TSDDR is 2043 whereas that of DDR and LEACH is 1396 and 800, respectively. All node die time (ADT) of TSDDR is 5600 whereas that of DDR and LEACH is 3500 and 1200, respectively. The reason behind the longer stability period is the reduced communication between the nodes and CHs, and CHs and BS. Balanced consumption of energy and uniform random distribution of nodes along with the threshold sensitive

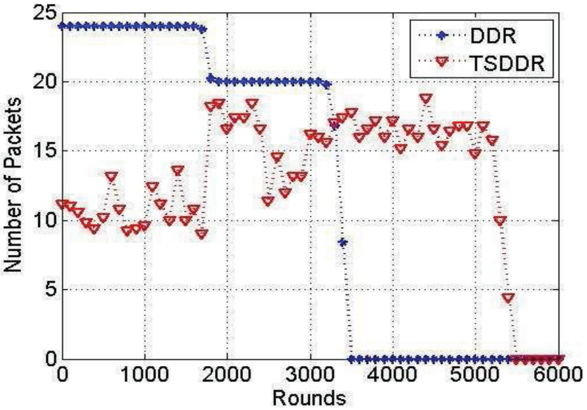

Fig. 3. Packets Sent to BS

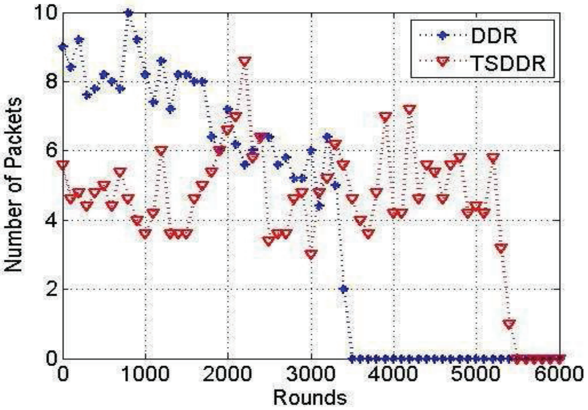

Fig. 4. Packets Dropped Comparison

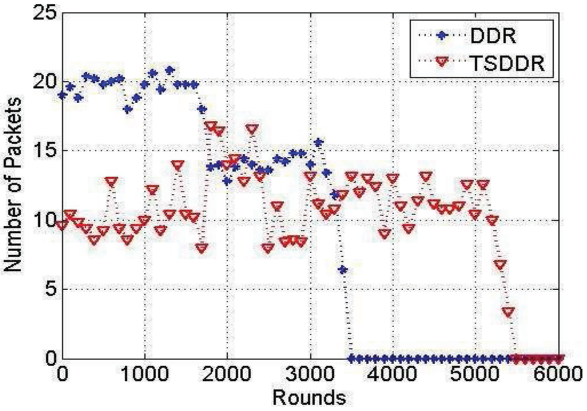

Fig. 5. Packets Received on BS

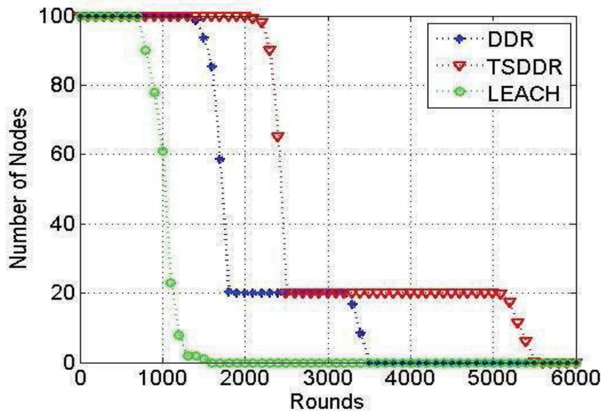

Fig. 6. Alive Nodes

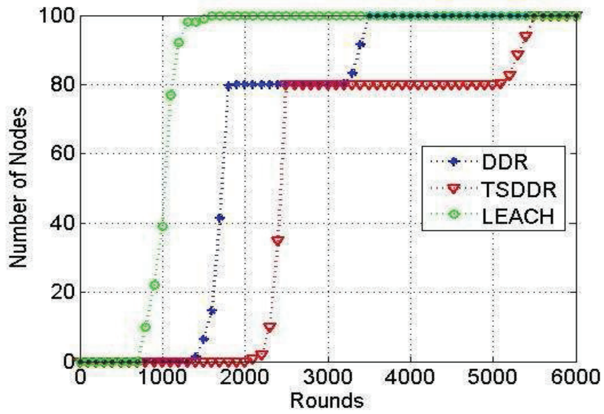

Fig. 7. Stability Period and Network Lifetime

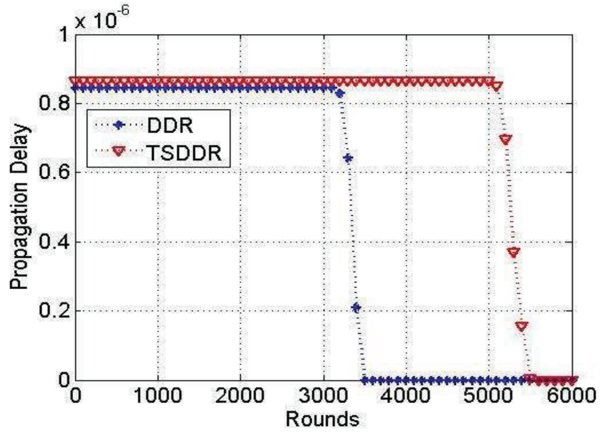

Fig. 8. Propagation Delay

nature not only increases network lifetime but it also helps to mitigate the problem of energy hole and coverage hole.

Similarly, in fig. 7, the number of dead nodes per round is shown. This figure illustrates that the first node in our work dies after 2000^{th} round, whereas, in DDR and LEACH, after 1300^{th} and 800^{th} round, respectively, which confirms that our protocol is much more efficient than DDR and LEACH in terms of network life time and energy consumption.

Fig. 8 shows the propagation delay that each packet experience due to factors like interference, dispersion, refraction, reflection, etc., in non-ideal wireless communication. The delay has been calculated by considering the electromagnetic wavy nature of the signals through which the communication between nodes, CHs and BS take place. Figure shows that delay for each packet is same because all the packets are communicating through the electromagnetic signals which move at the speed of light when assuming all attenuation factors to be null.

VI. CONCLUSION AND FUTURE WORK

In this paper, we focus on efficient utilization of energy to mitigate energy and coverage holes in WSNs. A novel protocol is proposed to avoid frequent communication by using reactive and threshold dependent transmission scheme. Sensors in our protocol transmit only if they sense a drastic change or a sudden event. Static clustering technique along with uniform distribution of nodes has been used to prolong the network lifetime. CHs are selected on the basis of minimum distance from reference point of their respective regions. 3-Tier communication architecture is introduced to minimize the communication distance.

The performance evaluation of our proposed protocol is compared with LEACH [1] and DDR [2]. Results validate that TSDDR outperform the existing routing protocols in terms of stability period and network lifetime. Our approach is 36% and 60% better than LEACH and DDR, respectively, in terms of the network lifetime. In future, we are interested in introducing heterogeneity in the deployed nodes so as to achieve longer stability period.

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