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Energy and Movement Assisted Sensor Deployment Method for Hole Detection and Healing

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Abstract— A wireless sensor network is a recently emerged prominenet network technology. It found many applications in disaster management, military applications, agriculture etc. WSN are commonly used to monitoring and recording special events in a geographical area called region of interest (RoI). The WSN are made up small sensors called sensor nodes. These nodes are very sensitive to various types of failures. Also these sensors are operated with the help of a limited battery power. This limited energy becomes another bottleneck to the performance of WSN. The failures of nodes in the WSN cause formation of holes in the network. This holes causes performance degradation of the network. So we have to find and heal the hole to improve the networ performance. The four key elements that ensure coverage for WSNs are determining the boundary of RoI, detecting coverage holes and estimating their characteristics, determining the best target locations to relocate nodes to repair holes, and dispatching of mobile nodes to the target location while minimizing the moving and messaging cost. The coverage enhancement and hole healing is a big task in the field of wireless sensor networks. Here we present a localized and distributed approach called energy and movement assisted sensor deployment method for hole detection and healing. It considers the energy of relocating nodes and best target location to relocate the nodes with minimum effort.

Keywords— Holes, Hole Detection, Hole Healing, RoI

I. INTRODUCTION

Wireless sensor networks are a group of specialized sensor nodes for monitoring special events in a location. These nodes have small sensing, computational and communicational power for recording special conditions in a geographical area and communicated to common destination called sink [1]. In recent years, the wireless sensor networks have more importance. There are number of applications present for WSN such as environment monitoring and data collection for various purposes. The sensor nodes are deployed in the area to be monitored, this region is called region of interest (RoI). The performance of the network is based on the effectiveness of the sensor nodes in the RoI.

A wireless sensor net work contain one or more sink or base stations and tens or thousands of sensor nodes. The tiny sensor nodes deployed in the RoI in large numbers and they collaborate to work together to form a network and gather data.[2]. The sensor nodes very vulnerable to various types of failure such as their energy source depletion, sudden shocks caused by their deployment etc. These failures form different types of holes in the network. Coverage holes, routing holes, jamming holes and worm holes are some of the examples of holes. These holes reduce the performance or even break down the entire network. However the emergence of hole in the RoI unavoidable because of the inner nature of WSN, sudden deployment, environmental factors, and external attacks. So the area covered by holes or the area devoid of any nodes are not monitored. So the event occurred in this area not reported, therefore the main task of the sensor network is not meet.

So there is a strong need for an effective and efficient method for this hole detection and recovering the hole. This paper proposes a solution for this problem. There are different methods are available for this purpose. But most of them have a centralized approach and high message complexity. The global computations of the existing methods create some computational overhead. In this method at the time of node relocation the nodes are relocated on the basis of their energy level. The remaining energy level of sensor node decide the distance to be covered for hole healing. The proposed method operated mainly in three phase. In first phase we find out the presence of hole in the RoI. In second step calculate the remaining energy level of the sensor nodes and in final steps the nodes with sufficient energy and distance relocated to heal the hole. The overlapped sensing area of sensor nodes are make use for healing purpose. This overlapped area is reduced using a repulsive force between nodes and nodes are moved to the centre of hole using a attractive force.This proposed method is a distributed and localized approach so it reduces the message passing overhead and complexity. Also it can detect and heal various form and shapes.

The first phase consist of three sub task; hole identification, hole discovery and border detection. For hole identification we use TENT rule. By using TENT rule trace the stuck nodes that cause the formation of holes in the WSN. After discovered the stuck node the hole discovery step executed. Using this step the identified hole's characteristics are found out. The hole's maximum distance, hole radius etc are traced by using this phase. Before going

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to the further phase we have to find out the border nodes. Because there is a chance for misinterpreting this border nodes as stuck nodes. So we have to differentiate the border nodes from interior nodes. This task is handled with border detection phase. After detecting the hole and border nodes we have to find out the remaining energy levels of the sensor nodes. So in the second phase of this method we calculate the remaining energy level of the sensor nodes. The nodes have an initial energy level and this power reduced in time to time based on some factors like sensing area, distance moved, antenna length etc.

The final step of the proposed method is called hole healing and this phase consist of two sub task called hole healing area determination and node relocation. In the hole healing area determination, find out the area around the hole with sufficient number of sensor nodes for healing the discovered hole. The deployed nodes in the sensor field have overlapped sensing area. Here we make use of this overlapped area to heal the hole. For this purpose we make use virtual force based local healing method for hole healing.

II. RELATED WORK

Various existing methods are used for detecting holes in WSN and border detection. All of them have its on advantages and shortcomings. In real wireless sensor network the node deployment is not uniform. So these networks contain some regions that are not covered by any sensor nodes, called holes. The TENT rule and BOUNDHOLE [11] are one of the method that used for identifying and build routes around holes. The Homology is another method of finding holes and coverage detection in wireless sensor networks. It is a powerful solution to the coverage problem in WSN. In this method two type of communication graphs are used, called rips complex and nerve complex. The nerve communication graph give the details about the coverage intersection about the individual sensor nodes. The rips complex calculate the connectivity information based on the inter node communication. Topological hole and border detection methods are simple distributed approach to locate nodes near the boundary of the sensor field and the hole boundaries. This method purely relay on the topology of the communication graph. Hare the only information available is, whether the nodes can communicate with each other or not. The topological methods never use the any location information about the sensor nodes. The communication graph has node and edges if corresponding wireless station can communicate with each other. If two nodes can communicate with each other then they come under a common communication radius. For proper working of this topological hole and border detection methods a dense communication graph is need.[6,8,10].

In "Coverage and Hole-Detection in Sensor Networks via Homology"[4] the author proposes a hole detection procedure based on homology theory. It makes use of two type of communication graph called nerve complex and rip complex. The nerve complex communication graph gives the information about coverage intersection of individual sensor nodes. Its computation is very difficult because the exact location of sensor nodes is needed. The rips complex calculate the connectivity information based on the inter node communication.

The "Blind Swarm for Coverage in 2-D"[5] discuss the coverage problem in robot sensor network. It is a new set of tools for coverage problems in robotic network with minimum knowledge about location and orientation information. This method makes use of the homology theory. It only needs some minimum amount of environmental knowledge to estimate the coverage. It does not mention any node placement strategy in order to maximize coverage as well as relocation of nodes to fill coverage holes. Also this method depends on some centralized computation with some additional complexities. F Stefan in [6] "Topological Hole Detection in Wireless Sensor Networks and its Applications" propose a basic method to detect the inner and outer boundary of holes in wireless sensor networks. It is simple distributed procedure to locate the nodes that come near the boundary of the sensor field as well as near the hole boundaries. This method is purely based on topology of communication graph. The only information available is which node can communicate with each other. This method does not make use of any location information of the sensor nodes.

"Hole Detection or: How Much Geometry How Much Geometry Hides in Connectivity" [7] present an algorithm for detecting hole boundaries in wireless sensor networks that is purely represented by communication graph. If we want to detect the (boundaries of) holes in the monitored space created by fire or other phenomena via examination of the communication graph of the wireless nodes. The communication graph of a wireless network has a node for each wireless station and an edge between two nodes if the respective stations can communicate with each other. Neighborhood-Based Topology Recognition in Sensor Networks [8] describes the method for determining the structure of boundary nodes of a region. In this work, without use of any location hardware detect boundary, making sensors close to the boundary of the region aware of its position. It also differentiates between exterior boundary and interior boundary, also compute both boundary distance between all nodes and overall region thickness. The main drawback of this approach is, the requirement of high density of nodes. In "A New Approach for Boundary Recognition in Geometric Sensor Networks"[9] describe a new approach with following problem in the wireless sensor networks. A large, dense number of sensor nodes are scattered along a polygonal region R. There is no central control unit, the nodes can locally to neighbor nodes within in the communication radius by make use of wireless radio. There is no information about their coordinate or distance to other nodes. Y.Wang in [10] proposes another boundary and hole detection method that is based on the topology. Its goal is to find the boundary nodes by make use of only connectivity information. It does not relay on the node location information or inter node distance. Its a practical distributed algorithm for boundary detection by using only the communication graph and do not make any unrealistic assumptions. It does not use any location information, angular information or distance information. It takes only 3 network flooding procedure and well suited for non uniform distribution. The main drawback of this procedure is that. It follow on a centralized approach, so a centralized approach of collecting all of the node information to a central sensor is not feasible for large networks.

"Locating and Bypassing Holes in Sensor Networks" [11] by Qing Fang and Jie Gao propose two algorithms called TENT rule and BOUNDHOLE for identifying the holes in the sensor networks and build routes around holes. According to this method a hole can be defined as a region enclosed by a polygonal cycle which contain all the nodes where local minimum appear. The most sensor networks fail due to the local minimum phenomenon in wireless sensor's greedy forwarding structure. Geographical greedy forwarding is a simple, scalable and efficient method in sensor networks where sensor locations are available. In geographical greedy forwarding, a source node know the location of the sensor node, either by acquiring from location service, or by computing using a hash function in a data centric storage scheme. A packet is forwarded to a one hop neighbor who is closer to the destination. This procedure continues until the packet reach the sink or the packet is stuck at a node if its one hop neighbour far away from destination node. The node where the packet stuck at is called local minimum or stuck node. This method tries to focus on defining and discovering holes in the sensor networks as well as building routes around them. It first finds out the presence of stuck nodes where the packets possibly get stuck in greedy multi-hop forwarding. The presence of stuck node indicates the presence of holes in the network. To check the presence of stuck node every node in the network execute the TENT rule. To help packets get out of the stuck node the bound-hole method is used [11]. This method only requires the angle information with in one hop neighbors. It is easier than obtaining accurate location information.

If a large swarm of immobile sensor nodes that can be scattered in a geographical area such as a street, the nodes does not known any size and shape of environment or position of the nodes. Their only possibility is send or receive message to neighboring nodes with in a communication range. The "Deterministic Boundary Recognition and Topology Extraction for Large Sensor Networks"[12] develop a algorithm and protocol that allow self organization of the scattered sensor nodes. This method works in two stages, in first step it recognize the boundary and in next step topology extraction. One of the key aspect of the location awareness is boundary recognition, making sensors close to the boundary of the surveyed region aware of their position. Once the boundary of the swarm is obtained it can be used to extract other information. This approach makes few assumptions and produce correct result. But it deals with quite complex combinatorial structures. "Local Geometric Algorithm for Hole Boundary Detection in sensor networks" [13] introduce a boundary detection algorithm for sensor networks which identifies voids in the networks. It uses fuzzy logic and graph theoretic concepts for computations. This hole detection method is simple and localized. The requirement of synchronization among nodes is one of the drawback of this method. Once the holes and exact boundary of hole is found, by different methods like Robomote[14], iMouse[15] find path through these voids and communication make possible.

In Energy-Efficient Deployment of Intelligent Mobile Sensor Networks, distributed energy-efficient deployment algorithms for mobile sensors and intelligent devices that form an Ambient Intelligent network are proposed. These algorithms employ a synergistic combination of cluster structuring and a peer-to-peer deployment scheme. In a peer-to-peer mode, each node moves itself to a sparse region so that the coverage of the network may increase and/or an energy-efficient node topology may be achieved. In a clustering mode, each node follows the decision of the cluster-head so that each node spends its energy in a balanced way and performs collaborative missions if necessary.[16]

Distributed sensor networks (DSNs) are important for a number of strategic applications such as coordinated target detection, surveillance, and localization. The coverage provided by a random deployment can be improved using a force-directed algorithm. In DSN, present the virtual force algorithm (VFA) as a sensor deployment strategy to enhance the coverage after an initial random placement of sensors. Sensors do not physically move but a sequence of virtual motion paths is determined for the randomly placed sensors. Once the effective sensor positions are identified, a one-time movement is carried out to redeploy the sensors at these positions. One of the drawback of this method is, it require global computation, ie all the nodes need to run the algorithm [17]. The movement-assisted sensor deployment deals with moving sensors from an initial unbalanced state to a balanced state. A localized Scan-based Movement-Assisted sensor deployment method (SMART) develops an optimal load balance solution based on the classic Hungarian method (mesh based) that uses minimum total moving distance. Assume that sensors are deployed randomly into the monitoring area without consideration of any physical obstacles. Then partition the monitoring area into many small regions and use the number of sensors in a region as its load and enhance the coverage of the network by some movement-assisted sensor replacement. It had drawbacks that, it can cause large message overhead due to the increase of scan. Also it can have global computation and for large number of holes these methods are not sufficient.[18][19]

Self-aware actuation to allow a network to reorganize its available resources and form a new functional topology in the face of run-time dynamics. This approach is called "self aware" because the actuation is not governed by a user command or application but initiated by the network to improve its own performance. In Self Aware Actuation for Fault Repair in Sensor Networks, the performance criterion is coverage, defined as the fraction of the total intended area actually covered by sensor network. This method develop an algorithm referred to as Coverage Fidelity maintenance algorithm (Co-Fi) that uses mobility as an adaptive actuation facility for automated deployment repair of the network. This method does not consider the node failure that caused by the physical damage.[20]

III. PROBLEM STATEMENT

During the operation of a wireless sensor network there may be chance for failure of sensor nodes due to many reasons. This failure causes formation of holes in the WSN. These holes make the network into ineffective and functionless. These holes are a threat to communication infrastructure in a WSN. So there is a need for an effective and efficient method for detecting and recovering these holes problem as soon as early as possible. Our problem is to design a mechanism for detecting the holes in the WSN and heal the detected hole by considering distance and energy of nodes. This method makes use of node locomotion facilities to heal the hole.

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IV. PROPOSED MECHANISMS

In this method find the best answer to the questions like how to detect a hole?, how to estimate its size?, how to heal the hole without effecting the performance of the WSN?. This distributed and localized hole detection and healing algorithm deals with holes of various forms and sizes despite the nodes distribution and density This hole detection and healing are based on hole detection, calculation of energy of sensor nodes and hole healing. Our detection mechanism detects holes with different size and shape. Also this method ensures that only the nodes with appropriate distance and energy are participated in the healing process. This method find the presence of hole in the network and estimate its characteristics. Finally it find the best target location to relocate the mobile node to heal the hole and move the mobile nodes into the target location.

A. Hole Detection

The first phase of the proposed method is hole detection. In this step the stuck nodes are find out from the deployed sensor nodes. The stuck nodes are those nodes where packets can possibly get stuck in packet forwarding. The stuck nodes are traced by using TENT rule. The TENT rule specifies that a node is not a stuck node when there is no angle spanned by a pair of its angularly adjacent neighbors greater than $2\pi/3$. We adapt this technique to find the stuck nodes. The hole detection phase sub divided into three sub task; hole identification, hole discovery and border detection.

The first task is to identify the existence of the hole. Each node p in the network executes the TENT rule to check if it is a stuck node as follow. First, it orders all its 1-hop neighbours counter clockwise. Let u and v be a pair of angularly adjacent nodes. Second it draws the perpendicular bisector of up and vp,l_1, l_2. l_1 and l_2 intersect at point o and divide the plane into four quadrants (see Fig.1). Only the points in the quadrant containing p are closer to p than u and v. Finally, if o is outside the communication range of p, the angle vpu is a stuck angle and p considers itself stuck node.

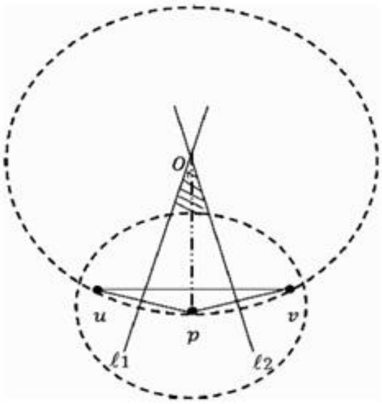

Fig. 1 p is a strongly stuck node

Next, using the discovery step find the hole and its characteristics. All nodes that are identified as stuck node execute the hole discovery process. This step find the hole boundary and hole characteristics like centre of hole, radius etc. One of the stuck node generate a hole discovery(HD) packet and sent to the neighboring stuck node. This node add its location information to the HD packet and forward to next stuck node. This process continue until the HD packet received by the initiator node. The HD packet initiated node bi extract the node location of the all other boundary node b_1,b_2, : : : , $_{bN}$ from the HD packet. From this location information it select two nodes b_m and b_n so that the distance between them is maximum.

$$Distance(b_m, b_n) = Max\{Distance(b_j, b_k)/b_j, b_k \in \{b_0, b_1, \ldots, b_N\}\}.$$

Then it calculates the centre of the hole by following equation.

$$\begin{cases} x_v = (x_{b_m} + x_{b_n})/2 \\ y_v = (y_{b_m} + y_{b_n})/2. \end{cases}$$

Each stuck node sends a HD packet without any coordination among stuck nodes. Thus, there will be redundancy in the discovery process. This will generate unnecessary traffic and more packet collisions; the situation may become worse especially for large holes. To avoid this problem, use a mechanism to prevent redundancy in the discovery process. The basic idea is to remove redundant HD packets as soon as possible. The method for deciding whether a HD packet is redundant is as follows: at each node, if a HD packet arrives and discovers that the packet has a Hole-ID greater than a Hole-ID carried by a packet already passed, the packet will be considered redundant and it will be deleted. At the end of this step the node that has the smallest Hole-ID removes the HD packet and names itself as Hole Manager (HM): it will be responsible for the hole-healing announcement.

The next step is called the border detection, found out the network boundary node. There by avoid the initiation of hole discovery process by those nodes. This can be done by using Boolean variable in hole discovery packet and each stuck node compare this values with nodes coordinate values with receiving packet and set the variable. Thus identify the network boundary nodes. To discover the network boundary in a distributed way, will follow the following steps:

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- Each node of the network executes the TENT rule
- Each stuck node launches DHD to identify the nodes that surround the hole
- In the HD packet, define four Boolean variables to identify the network boundary X_{max},Y_{max},X_{min},Y_{min}. Each stuck node, which receives a HD packet, compares the coordinates X_{max},Y_{max},X_{min},Y_{min} defined in the packet with its coordinates, and if it finds that it has a higher or a lower value than one of these values compared to all its neighbors, it sets the corresponding Boolean variable to 1
- At the end of this procedure, the largest hole that defines the network boundary will be defined by the coordinates X_{max},Y_{max},X_{min},Y_{min}
- cancel the healing process that will be launched by the HM node

Thus the boundary of the network is traced and avoid executing the healing process by this boundary nodes.

B. Energy Calculation

The nodes are deployed in the sensor field with a specified energy level. The main source of energy is from a battery. The energy of the sensor nodes decreased from time to time from the initial deployment. The main factors effecting this degradation are communication range, sensing range, antenna length etc. So at the time of relocation, we have to consider the remaining energy level of the sensor nodes in the hole healing area. Otherwise the nodes with lower level of energy participated in the healing process. After healing process the energy will depleted soon and the nodes become useless. So it causes formation of additional holes in the network. To avoid this worst case, before the nodes are relocated for healing the remaining energy of nodes are calculated and node with highest energy move more distance than node with lower energy.

C. Hole Healing

The second phase of the HEAL consist of two sub phases including Hole Healing Area (HHA) determination and node relocation. Here use the node locomotion facilities to heal detected holes. This is completely distributed and uses the virtual force concept. In this phase define the HHA (Hole Healing Area) in which the forces will be effective. This allows a local healing where only the nodes located at an appropriate distance from the hole will be involved in the healing process.

HM node calculates the centre and radius of the hole. To find out the HHA first find out the radius of the hole. For this an iterative approach is used based on the formula R= r *(1+ B) where r is the radius of hole, B is constant depend on node density and sensing range. Start with a value 0 to B and increase up to finding sufficient number of nodes to recover the hole.

In the node relocation stage heal the hole by the help of nodes with sufficient energy in the HHA. For this purpose two type of virtual forces used. An attractive force that attract the node to the hole centre and a repulsive force that reduce the overlapped area between nodes to heal the hole. The nodes that receive forces from the hole centre, move towards it. The attractive and repulsive forces are balanced to minimize the overlapping area between cells. Thus the holes are healed using this method.

V. EXPERIMENTS

The energy based localized sensor deployment method for hole detection and healing in WSN implemented in the NS-2 simulator. The deployment of sensor nodes in the region of interest is carried out using NS-2. The sensor nodes are deployed statically and the holes are found out from the sensing area. The current sensing are consist of 200 mobile sensor nodes with one hole present in it. After the initial sensor deployment the nodes are communicated to each other and find the stuck nodes. From the stuck node information find the hole and finally heal the hole based on our method. The current method tested on the basis of nodes and hole characteristic as well as the previous work in the field.

To check the performance of the healing process, the nodes are deterministically deployed into the sensor field in different times with varying hole radii. The same way the test was conducted on the basis of changing the number of holes in the current sensor field. The total distance travelled by the sensor nodes to cover the holes, attractive and repulsive force to heal the hole are directly depend on the radius of the circle. The distance covered by the nodes in the HHA is not uniform. The movement is decided by their position and energy. The holes near the hole boundary as well as the nodes with higher energy levels travel more distance than other nodes. The size of the hole determines the number of movements performed by the nodes to heal the hole. Up on the experimental results, the presence of both large and small holes did not affect the correctness of the method.

The performance of the implemented energy based localized sensor deployment method for hole detection and healing was compared with that of DSSA, SMART [20]. also this method is compared againt the method in[1]. DSSA is a centralized movement assisted virtual force based algorithm. SMART is a grid quorum based movement assisted localized algorithm. With these two methods compare the performance of the current method. The comparison is mainly carried on the basis of number of movements of sensor nodes, rate of improvement in the network coverage and the total distance travelled by the sensor nodes to heal the hole. The result of comparison is given in the following figures. This proposed method take less number of movements of sensor node to heal the hole after a better node density. The graph in the fig2 shows the result.

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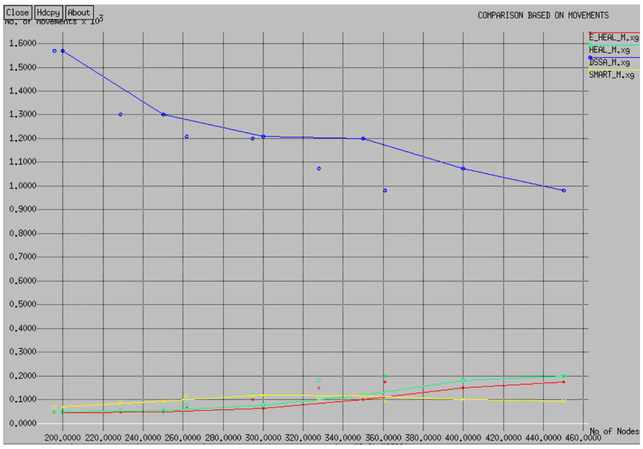

Fig. 2 comparison based on movements

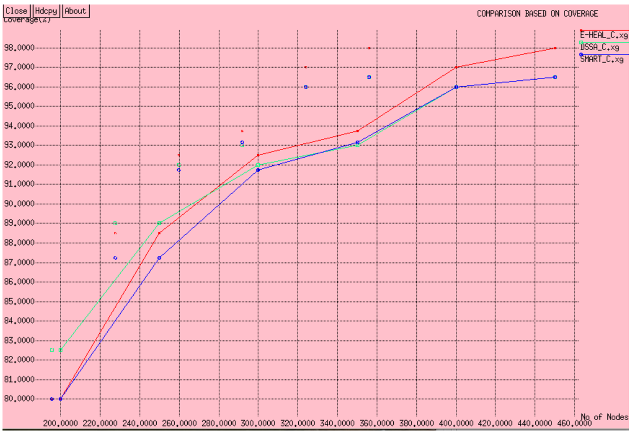

Fig. 3 comparison based on coverage

The fig3 shows the performance comparison based on number of movements. With the low node density the proposed method shows some worst result compared to other. When the node density incresaes the performance of the proposed method increases. The same result shown (fig4) in the comparison based on total distance traveled. It shoe better performance than DSSA.

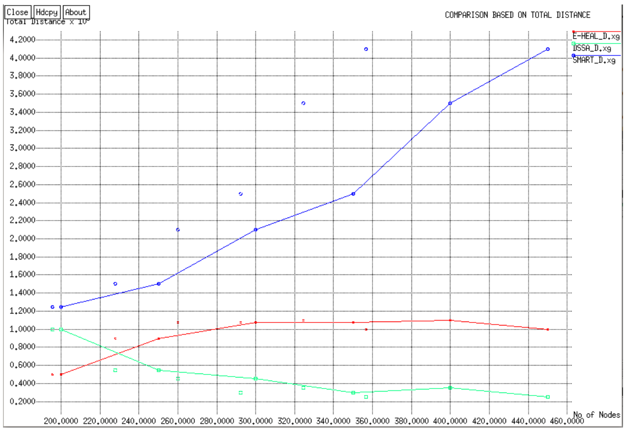

Fig. 4 comparison based on distance

VI. CONCLUSION

The problem of effective hole detection and healing in Wireless Sensor Networks is a difficult task. With these proposed method we can effectively and efficiently discover and heal the hole in a WSN. This proposed and implemented method became a lightweight and comprehensive two phase protocol for ensuring coverage enhancement in Wireless Sensor Networks. It can heal holes of various shape and forms with low complexity. It shows performance improvements by considering the energy of nodes for relocation. The current method is worked in two phase. In first phase it detect the existence of the holes in the WSN and find the characteristics of the hole such as centre, radius etc. then using the second phase of the method the detected hole healed with minimum effort. The nodes are relocated for healing is on the basis of distance and energy. So the coverage and performance of the network will be maintained. The wireless sensor network found large applications in civil and military field, so this method have its own importance in these fields. Also it shows some performance improvements than the current methods.

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