International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-10, August 2020

Circular Based Node Placement in Wireless Sensor Networks

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Abstract - Wireless Sensor Network (WSN) is one of the promising technologies in today's world. Applications can be from home, science, industry, medical and so on. In every field it is proving to be one of the best methods adopted like for example patient monitoring from home to hospitals using sensors and internet at a low cost is possible. In this paper study on node placement is considered as most of the sensor network has random based deployment of nodes during simulation. Random node placements have densely placed nodes in a certain area and sometimes only few nodes are deployed in a same area. This is purely because of random distribution of nodes and thus has impact on overall performance of WSN. Proposed method considers circular based deployment for routing in WSN with its own algorithm. Circular based node deployment is a combination of random and grid based approach and proves to be effective way of routing packets to destination. Simulation results show that performance of network in terms of computation is better than the existing methods.

Keywords: Wireless Sensor Network, simulation, Random.

I. INTRODUCTION

The design of the proposed technique is carried out using analytical research methodology where the prime importance is offered to investigate the impact of various patterns of node placement in WSN. The process of node placement deals with positioning the sensor nodes over the simulation area in such a manner that it creates a better balance between energy conservation as well as communication performance. Architecture of WSN shown in figure 1, that has been adopted for the purpose of implementing the concept of energy efficiency in proposed system related to node placement. The architecture shows that proposed system takes node parameters as input which after processing results in precise node placement in WSN.

The proposed system offers a hybrid mechanism of circular deployment strategy which uses both randomized and grid-based approach for node placement. After all the nodes are positioned based on the proposed circular topology, the proposed system incorporates the concept of unidirectional and bi-directional communication strategy that assists the nodes to be communicating with other nodes finally leading to the base station. The entire concept is all about effective node placement and establishing energy efficient communication process that assists in faster response time.

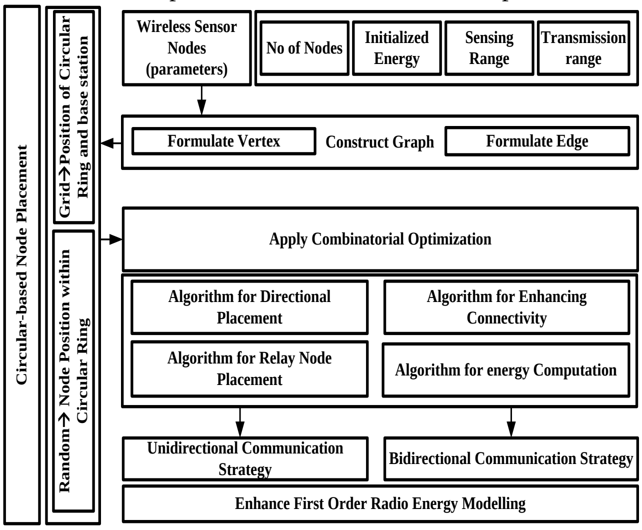

Figure 1: Proposed Architecture

II. LITERATURE REVIEW

Effectively the performance of WSN is highly impacted by the position of the node. The existing schemes of node placement are carried out before the start-up phase of the network by using certain attributes that are quite independent of states of the network. Sometimes, these strategies also consider a uniform pattern of operation associated with the network that is maintained until the end of the data aggregation. In such scheme, predefined routes are considered for transmission of an aggregated data over a period. The deployment methodologies of the existing system are of two types e.g. controlled deployment and random deployment. Controlled deployment of the sensor node is carried out exclusively for the indoor applications of WSN. Some of the standard initiative towards this research work is carried out by Accenture Technology Lab [1], Intel [2], Sydney University [3], etc. Random deployment is one of the frequently used node deployment strategy in WSN [4]. The concept of random deployment is based on the facts that sensors are dropped from certain air borne vehicle that disperse the nodes randomly into the area to be monitored. However, a study towards static node placement strategy uses both grid-based and random based node positioning system.

At present, adoption of grid-based node placement strategies is much to be seen.

Revised Manuscript Received on August 30, 2020.
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Rahman et al. [5] have addressed the problem of cost involvement in underwater sensor network by introducing two sink nodes in static position. The study outcome was found to offer higher transmission of data packet with good energy consumption.

Gomathi et al. [6] introduced unique routing strategy where a three-dimensional mobs cast routing concept has been introduced for facilitating routing in underwater sensor network. Study towards communication over indoor environment was carried out by Chang et al. [7] by incorporating a technique where minimal relay nodes as well as sensor nodes are used for constructing indoor environment.

Mohapatra et al. [8] have presented a technique where the placement problem of both cluster head as well as relay node is addressed. For this purpose, the authors have presented two different techniques. The first technique uses static relay nodes placement using minimum disk cover approach while the second technique uses selection of cluster head based on highest residual energy. It also uses received signal strength indicator for further establishing communication. Selmin et al. [9] have worked towards network optimization by constructing a cost function of convex quadratic. The technique uses the concept of connectivity followed by conditions of node localization using optimization principle. Similar direction of adoption of optimization is also carried out by Abidin and Radzi [10] where a node placement algorithm is implemented from the biological behavior. The technique uses marking mechanism of terrestrial predators for accomplishing maximum energy optimization with maximized coverage by using static node placement. One of the significant problem of traffic called as congestion was addressed in the work of Cha et al. [11] where it was solved using static node placement approach. The technique basically performs identification of any forms of congestion origination points and then configures the routing based on static sensor node itself. Another problem of WSN application taken in literature was related to usage of wind farm monitoring. The major problem in such application is to evolve up with placement of relay nodes for an effective load balancing in WSN. The solution to such problem was offered by Chen et al. [12] where a heuristic-based technique has been introduced using Euclidean space-based approach for selecting a candidate relay node in WSN. Apart from static node placement, random node placements are also found to be implemented towards WSN. The study carried out by Li et al. [13] have used random node placement of the sensor for the purpose of increasing the capability of monitoring a large area with a minimal number of sensors. Lu et al. [14] have presented a heuristic algorithm for optimizing the cost of processing using random node placement strategy. Ma et al. [15] have addressed the problem of node placement of relay node considering the constraint of delay. An approximation based technique is used where random relay nodes are used by levels to solve such problems. The technique also offers compliance with the reduced time complexity. Similar problems have also been addressed by Misra et al. [16] by using an approximation based on polynomial time approach. Study towards optimization of node placement has been carried out by Wang et al. [17] by deploying Particle Swarm Optimization (PSO). Wang and Wei [18] have also addressed the problem of relay node placement in WSN by introducing a hybrid technique considering minimal distance. Study towards approximation technique for relay node placement is also carried out by Willig [19] where importance was given to accomplish trustworthy transmission. The technique uses the iterative strategy of relay node placement and also uses scheduling based approach.

III. PROPOSED WORK

The problem of energy efficiency among the sensing nodes is addressed by presenting circular grid patterns of deploying within the simulation area. Owing to the more symmetric pattern of node deployment, the proposed system considers adopting larger simulation area of 1200 x 1500 m^2. Fig.2 shows the circular distribution of the nodes with base station positioned at the center. The figure shows that there are 8 sensors covering the first inner circumference which is topped up by 16 sensors on the 2nd outer circumference. Each of the circumferences is separated by 1 meter of spatial distance.

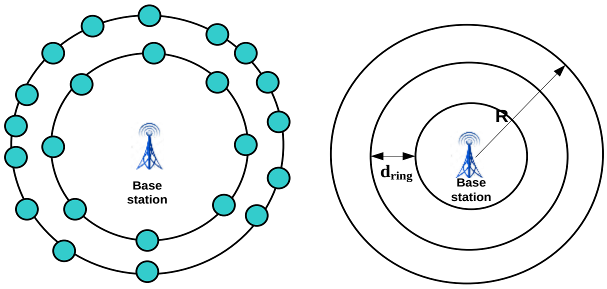

Figure 2 Proposed Node Placement by Circular Manner

The design principle of the proposed system deploys nodes in the circular plane with a specific radius. The proposed study considers a single base station located in the center of the zone under surveillance. The complete area consists of various circular rings situated at a distance d_{ring} from each other. All the sensors residing over the one circular ring has a similar density which might be different from other node residing on the different circular ring. The study thereby considers that a single circular ring has all homogeneous nodes while any other form of the node has to be positioned in the different circular ring. As the base station is positioned at the center, therefore, the direction of the incoming traffic will be from outer circular ring to inner circular ring. The traffic will mean the sensed data captured by the sensors and forward it to the sink. A single hop is always used for forwarding the fused data from the outer circular ring to the other circular ring located in its proximity, which it then forwarded to the sink. Therefore, multiple single hop based connectivity between two adjacent rings is used to forward the data from the outer circular ring to a base station located at the center of all the rings. One of the significant advantages of this process of communication is that cost of data transmission between the circular rings is always one hop. The initialized energy over the multiple circular rings is highly distinct. The study assumes that initial level of energy consumption is due to i) sensing the self-monitored area and yielding the data, ii) forwarding the data, and iii) receiving the data. Although the majority of the existing studies towards energy computation emphasizes on considering forwarding and receiving data, in reality, it misses out considering the node that is located quite at the far end (in grid / random process).

Such forms of the sensors that keep a higher spatial distance from the base station have the tendency to opt for reduced jobs for data forwarding to sink leading to more area of perceiving. However, when the system also offers a speed factor in all the three cases, the amount of the energy being consumed in case of (i), (ii), and (iii) is directly proportional to the original perceived size of the area, the size of the data being forwarded and size of the data being received respectively. The study also assumes that amount of the data packet that is forwarded by the sensor is equivalent to that what is being originally transmitted by the source sensor node. The system considers network lifetime as the duration between initial operations of the node till when the sensor experience its first node death. The proposed system uses graph theory for constructing the network topology where significance is given to the placement of the relay node within the circular topology. The proposed study considers filling up the positions of the nodes in the circular ring topology in a random fashion. The sensors do not show any form of randomness in the node placement other than in the circular ring. At the same time, it is not necessary that any two nodes even in the same ring should be equidistance from each other. The amount of the energy being consumed is increasingly dependent on the spatial distance on which the data packets are forwarded to the base station. Hence, it can also be said that proposed circular topology is a hybridized form of both random and grid approach. The randomness approach is meant for the positions of the sensors in a circular ring, whereas the position of the base station and position of the circular rings are formed using the grid-based approach in WSN. The simulation is carried out considering a different number of nodes residing over the circular ring with different variations of their positions over the circular ring. The neighbor nodes for any particular sensor could be residing on a same circular ring or different node residing on the adjacent circular ring. Therefore, single hop connectivity is formed during the process of data aggregation in WSN.

Consider that there are x-number of sensors in the simulation area dispersed for its circular pattern of deployment. The proposed system represents a variable η for cumulative number of grid and can be empirically represented as follows,

$$\eta = \sqrt{x-1} \tag{1}$$

The proposed system computes sensing range S that is dependent on radius R and distance d existing between two sensors that can be empirically represented as follows,

$$S = \sqrt{\frac{\pi R^2}{d}} \tag{2}$$

The proposed system considers predefined features of the nodes where the placement of the node is highly emphasized. It will mean that if there is any single sensor that is depleting its residual energy than it is possible to find out the exact position of the node at that instance of time. The placement of the sensor node for a given circular ring is empirically represented as,

$$P_{node} = (S, \theta) \tag{3}$$

In the above expression, the variable S will represent sensing range while θ represents the specific angle for every node [0°-360°]. Interestingly, all the nodes are positioned in the above-mentioned process in WSN in the grid manner. The proposed system represents the above placement of the nodes as an optimized position that potentially assists in communication with each other over the circular topology in WSN. Another fact to understand that any node lying at any point of the circular ring can sense the event and perform data fusion process. Once the event is being sensed, the node captures the data and checks with its respective distance with the destination node (i.e. base station). Now the challenge in this phase is whether the receiving node (or an intermediate node) should forward to the node in the same circular ring or different circular ring. The study incorporates a principle of thresholding of residual energy for this purpose to make a decision whether the forwarding of the received packet should be done on the neighbor node on same or different circular ring.

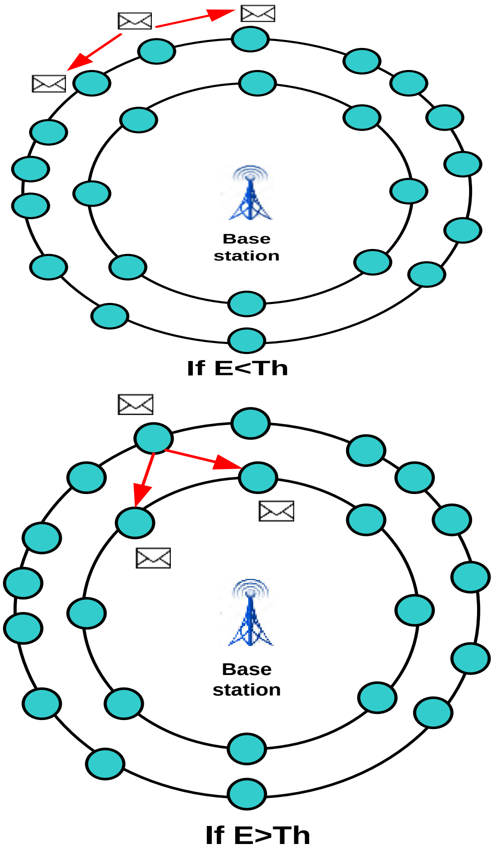

Figure 3 Process of forwarding fused data

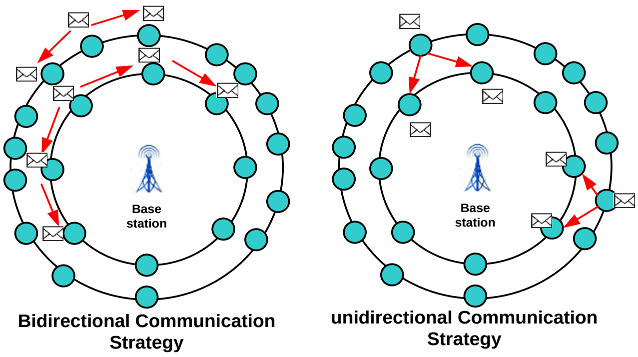

Figure 4 Modes of Directionality of Data flow

Figure 3 highlights the process of fused data where the threshold factor is the decision-based factor based on which the decision is taken for forwarding the data packet.

If the residual energy of the nodes lying in one circular ring is found less than the threshold of residual energy that it is considered that this node doesn't offer complete reliability to forward the received data packets to the inner circular ring. It is because transmittance energy required for a sensor node is less if it has to forward it to other nodes in the same circular ring. However, when it has to forward to inner circular ring, it has to opt for single hop network which requires a little bit more transmittance energy. Therefore, if the residual energy of the sensor node is found more than the threshold, it is preferred to opt for forwarding the data to the node residing in the inner circular ring. Therefore, the proposed system offers a dual directional mechanism to forward the data as shown in Fig.4.

The first mode of data flow directionality is a unidirectional and second one is bidirectional mechanism of data flow. A trajectory path can be utilized for forwarding the data (Unidirectional), or it can also be taken in the form of circular path (i.e. bidirectional). The distance between the circular rings d_{ring} can be expressed in the form of,

$$d_{ring} = \left(\frac{1}{2} \times A \times \left(\frac{\pi}{180^\circ} \right) \times R^2 \right) \tag{4}$$

In the above expression, the variable R is considered as radius of the circular ring and A is considered as the difference between the angles by two nodes. As the circular rings are positioned in the form of uniform grids, therefore, the positions of the sensors are highly pre-determined that potentially assists in routing. Therefore, the location of the nodes can be expressed as,

$$NL_o = F(\theta_1)R \tag{5}$$

$$F(\theta_1) = \frac{\frac{2}{3}\sin\frac{\theta}{2}}{\theta} \tag{6}$$

In the above expression, the value of the angle θ is 0^o to 360^o while the placement of the sensor is denoted as F (θ_1). The process of routing is followed instantly by the deployment of the nodes are accomplished for a given simulation area. The process of routing could be possibly done either by trajectory or by circular routes. A matrix that stores these two information is called as a master route which is used in algorithm formation. Once the diversity of the deployment is set than all the sensors are assigned with the density of traffic, energy, adjacent node information, energy-related information, etc. Using the concept of first order radio-energy model [20], all the nodes are initialized with 50 joule of energy.

The routing process of the proposed system considers neighbor-related information and incoming traffic into consideration. Applying the principle of first order radio - energy model, the proposed system considers computing total energy E_t using multiple energy related parameters. The empirical expression for energy computation is as follows,

$$E_t = \sum_{i=1}^{s} E_i \tag{7}$$

In the above expression, the variable (i) represents number of adjacent nodes while the energy required to compute it can be further represented as,

$$E_i = \sum_{j=1}^{n'} \sum_{k=1}^{i_j} e_k \tag{8}$$

In the expression shown in Equation (8), the variable e_k will represent the amount of energy being depleted during the process of data aggregation where n' represents cumulative hops lying on the route. The variable i_j represents cardinality of hops. Therefore, the variable e_k is now represented as E_t itself, and empirical can be exhibited as,

$$E_t = \sum_{i=1}^{n} \{E_1 + E_2 + E_3\} \tag{9}$$

In the above Equation (9), the variable E_1, E_2, and E_3 represents transmittance energy, receiving energy, and energy consumption for different placements types of nodes. The technique allows the sensor to utilize 50 nJ for forwarding the unit of the data packet. It is also important to understand that amount of energy being depleted depends on the amount of data bits being forwarded and therefore, the actual energy depleted for making the nodes in an active mode of communication (hearing and forwarding data) can be expressed as a product of 100 pJ/bit/m^2 with transmittance energy. Due to network condition, it is feasible that a number of packets received at the end may be less as compared to what is being forwarded. The original amount of energy being used for receiving packets is computed by subtracting energy due to the transmission with the loss of energy owing to loss of data packet. The energy consumed for forwarding message to neighbor nodes can be empirically expressed as,

$$E_{nr} = \sum_{n=0}^{m} E_{r(Actual)} + n_n \, E_I \, d_{tr}^{\ 2} \tag{10}$$

It is to be noted that above empirical expression is meant for computing energy consumption due to transmitting data to neighbor nodes. In the above expression, the variable n_n is considered as the quantity of the adjacent nodes while the other variable E_I represents the energy of single sensor node while the third variable d_{tr} represents the distance between adjacent nodes and from the source transmitting node.

The proposed system offers the neighbor node with a responsibility to forward the data packet to the next sensor node (directly leading to base station) and the energy depleted for performing this responsibility is represented as

$$E_r = E_{r(Actual)} + E_I d_{tr}^{\ 2} \tag{11}$$

Finally, the total energy of the system while the node placement is being carried out can be now expressed as,

$$E_{tot} = n_2 \,(E_r + E_{nr}) \tag{12}$$

The computation of the residual energy is computed by subtracting the total energy consumed with initialized energy.

IV. RESULTS AND DISCUSSIONS

The simulation is carried out considering 1200 x 1500 m^2 simulation area, considering 100-1000 sensor nodes with initialized energy of 50 joules and amplified energy of 100 *pJ/bit/m*^{2}. The range of communication is fixed to 20 units. The initial phase of the simulation work is carried out considering the range of transmission for the relay node to be 200 meters that slowly maximizes the quantity of the target sensors in the simulation area. The initial pilot study was witnessed with result that shows if some failures are not much then proposed system uses less number of the relay nodes as compared to the existing system of random and grid-based approach. The primary reason behind this is that proposed system utilizes the edges that have less value of weights initially. To accomplish complete fault tolerance, the existing system offers better resiliency but double the number of relay nodes. The presence of edges is more in the existing system that increases the cost of transmission especially when the number of incoming traffic increases. At the same time, proposed system is found to offer better the connectivity among the nodes. It was also explored that quantity of relay sensors initially shows increasing trend followed by minimization trend when the size of the network falls less than a certain threshold (50). It was investigated to find that if the density of the node is found less than such cut-off than the established connectivity among the network is very less. The system has the dependencies of more relay sensors with increasing size of incoming traffic to cater up to the anticipation of the coverage and connectivity by the network. The system also finds the maximization of network connectivity with the enhancement of the density if the density is found less than cut-off. It is also followed by minimization of relay sensors simultaneously. Finally, it was found that the bidirectional strategy leads to dependencies of more number of relay sensors in comparison to unidirectional communication strategy. However, the study emphasizes on energy efficiency as the complete design principle is formulated just to achieve energy efficiency, therefore, the performance parameters selected for assessing the proposed study are related to energy factors only. The explicit parameters are i) number of hops, ii) consumed energy, and iii) network lifetime mainly. The complete simulation was carried out considering 1000 simulation iteration where the priority is mainly to understand the network lifetime. The effect of proposed hybridized node placement strategy is used for assessing the effectiveness of unidirectional as well as the bidirectional communication strategy in WSN.

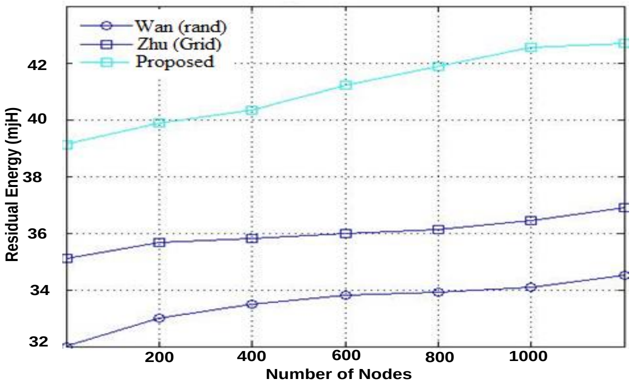

Figure 5 Analysis of Residual Energy

Fig.5 showcase that for one iteration proposed system offers significantly higher retention of residual energy as compared to the scheme presented by Wan et al. [21] and Zhu et al. [22]. Residual energy of nodes involed in routing for one iteration. The existing technique presented by Wan et al. [21] and Zhu et al. [22] mainly uses the recursive principle of minimizing power without considering the sudden increase in the traffic size. This phenomenon suddenly causes unsymmetrical nodal density formation in the simulation area that causes un-parallel capacity to process the incoming traffic. This causes the nodes to deplete more amount of transmittance energy by the existing system. On the other side, the proposed system offers a comprehensive and dynamic mechanism of node placement strategy which emphasizes on the rejection of routes with more possibilities of failures. This causes the proposed system to offer better sustenance towards processing larger incoming traffic. Another reason behind this is that proposed system offers better dynamic decision making capability of routing without affecting the existing communication scheme. The integrated mechanism of deploying dual strategies using combinatorial optimization assists the node to completely process its queries along with successful placement of the relay node to further speeding up the process of the data aggregation. Hence, the maximum amount of the residual energy is conserved in this process.

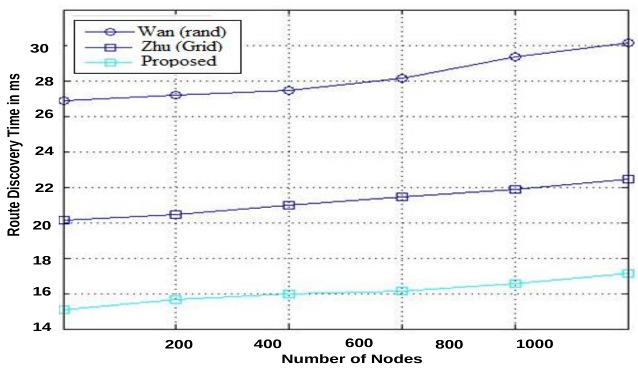

Figure 6 Analysis fo Route discovery time

Fig.6 highlights the outcome for analysis of the route discovery time for both the proposed and existing system. Although all the system shows a very low trend of enhancement towards route discovery time with increasing number of nodes, proposed system offers much better outcome.

The curve of grid deployment is quite linear in nature owing to the predetermined nature of the node position; therefore, the route discovery time has only lower growth with increasing time. However, the pattern of growth in time for route discovery for random deployment is more as compared to the grid-based deployment. On the other hand, proposed system offers faster discovery of routes. This trend of outcome proves that proposed system can be used for traffic that is characterized by uncertainty behavior or even it can be used for managing increasing traffic condition in WSN. This property is highly supportive of time critical application in WSN.

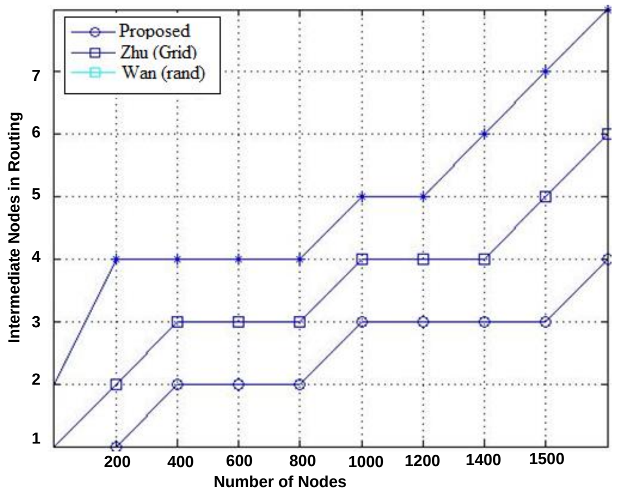

Figure 7 Analysis of Number of Intermediate Nodes

Fig.7 highlights the analysis of the number of the nodes assisting in performing data aggregation process in WSN. It should be noted that such forms of nodes i.e. intermediate nodes can reside on any circular ring. This will only mean the inclusion of some hops that is accounted as cost included in the communication process while including some intermediate nodes. The outcome directly shows that proposed system offers considerably lower inclusion of intermediate nodes while performing the relay node placement. A closer look will show that circular and grid based deployment has increasing dependencies on some intermediate nodes for assisting in the communication process. This shows the cost effectiveness of the proposed system will lower resource consumption which indirectly contributes to the increase in network lifetime. This outcome is in agreement with the supportability of time and mission critical application in WSN with better cost effectiveness.

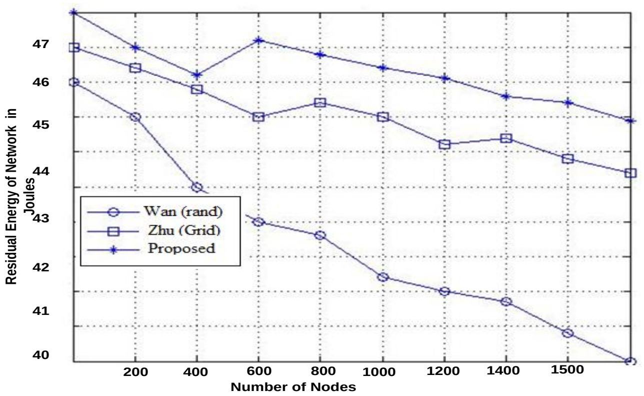

Figure 8 Analysis of Residual energy

Fig.8 showcases the amount of the residual energy for 1000 iterations with increasing number of sensor nodes. The outcome highlights that proposed system offer better retention of the residual energy as compared to the existing deployment strategies of random and grid. The decreasing trend of residual energy is quite normal, but even the decreasing trend of random-based deployment strategy is too much declining which leads the node to deplete its residual energy at a faster rate. The random deployment has unsymmetrical distribution pattern causing non-linear load balancing capabilities for the sensors. Therefore, some nodes will be able to retain more energy at the cost of residual energy of other nodes, and soon the network progressively degrades causing faster node death. On the other hand, grid-based deployment exhibits quite predictive behavior on residual energy. However, all the nodes start decreasing in almost a similar rate in grid based node placement. This outcome proves that proposed system has enough capability to sustain for a longer duration even with increasing traffic condition. Therefore, proposed hybridized technique can be used for applications which require long-term monitoring in adverse conditions.

V. CONCLUSION

Work is carried out for improving performance of WSN. Even though lot of research is been carried out in this area but the basic factor of node placement in network for simulation is always missed out. Proposed work considers circular way of distribution of nodes which is combination of random and grid node deployment. Using proposed methodology randomness is completely avoided and all the nodes have equal chance of participating in the simulation. Computation is measured in terms of energy and routing is carried out for proposed, Wan (Random), Zhu (grid). Simulation shows that proposed approach has more energy saving for nodes compared to existing methodology.

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