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A Location Based Technique for Critical Node Deduction and Redeployment in Sparsely Populated WSN

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Abstract

The localization and redeployment of sensors has become an important part of most of wireless sensor network applications. The haphazard and diverse nature of sensor network precluded the manual deployment of nodes in a sensor field. In this paper, we proposed a localization scheme known as LoMoB (Localization with Mobile Beacon) in which a single mobile beacon or group of mobile beacons engaged the sparsely populated network to localize sensor nodes. The scheme also helps to find the regions for the deployment of additional nodes or replaces the damage nodes in order to prolong the life time of the existing network. The scheme uses the triangulation method and does not require any extra hardware to be mounted. Four different scenarios of LoMoB operations are evaluated and discussed for error, performance, dead or weak node discovery and node redeployment.

Keywords: Mobile Beacon, Sensor Network, Localization, Redeployment

1. Introduction

A Wireless sensor network (WSN) is composed of large number of sensor nodes that are deployed to monitor an area of interest or hostile environment [1]. Usually the wireless sensor nodes are used to measure acoustic, visual, thermal, seismic like parameters [2][3]. In most of the cases, the deployment of sensor nodes is carried out in random manner and hence the position of a sensor node plays a vital role in order to ensure the coverage of sensing field and redeployment. Figure 1 represents the general application of sensor network. Recently, the redeployment of sensor nodes with the help of localization has become a hot topic and many researchers have proposed different localization and redeployment schemes over the years [4-7].

A secure Localization and redeployment of sensor nodes can meet many challenges of network operations like routing of data, topology control, network life time [8-10]. Also the power management, accuracy and reliability are the most key component that play a vital role in the overall efficiency of WSN [11-13].There are various sources that are used in localization of sensor nodes. Selection of a source for a particular localization technique depends upon the nature of the sensor network and the situation in which a network is deployed. Some of the commonly used sources are:

- Radio Signal Strength Indicator (RSSI)
- Angle of Arrival (ToA)
- Time of Arrival (AoA)

Almost all the research done for the localization of sensor nodes in Wireless Sensor Network depends upon one or more of the above discussed techniques. The authors in [14] proposed a direction estimation method for localization of sensor nodes by using angle of arrival (AoA) estimation in which the angular direction and the known position of the beacons are used for determining the position of node by triangulation technique. In [15], the authors proposed localization of sensor nodes in WSN on the basis of Angle-of-Arrival (AoA) and Time-of-Arrival (ToA) techniques. The author in [9] focused

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in the reliability of sensor networks deployed over a square area. To major parameters are highlighted connectivity and failure.

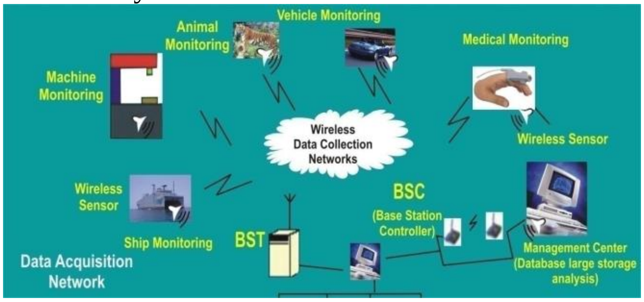

Figure 1 A general application of wireless sensor networks

The authors in [16] used spotlights to localize the sensor node in the network. The spotlight localization is an example of event based localization system in WSN. In [1], the authors proposed a protocol that uses only two beacons instead of traditional three reference nodes. The two beacons with known position starts recursion by sending their positions to the network. Signals transmitted from two beacons must be sensed by each sensor node. In [17], a localization scheme is proposed that uses only one mobile beacon to locate a sensor node in the sensor field. This beacon is assumed to be a powerful entity operated by GPS or AGPS, an aero-plane or even a human being can carry the beacon which has no limitations of power, transmission range, processing or storage overhead. In [3], a rotary-antenna based localization scheme is proposed, in which less power consumption is claimed. The anchor node is equipped with two rotary antennas emitting the signal on same frequency to generate Doppler shift and radio interference.

2. Node Disconnection from the Network: A Key Problem

As we know that the nodes of a sensor network are meant for sensing, processing, transmitting and receiving of the data. Some of the sensor nodes in the network may get disconnected due to low power in the battery or due to some other barriers in the sensing field. This disconnection becomes very critical if the lost node is either cluster head or a joint node (joining two parts of the network).This disconnected part of the network becomes unable to transmit the data, and the entire nodes in the network remains unattended and the server would have no idea about their position. Not having known, the position of the nodes in the disconnected part of the sensor networks, explicit nodes (whether beacons or sensing relay nodes) cannot be deployed specially in case of aerial deployment of the nodes. The exact number of nodes to be deployed is not predictable which also affect the decision deployment.

3. Proposed Methodology

The author in [17] proposed a localization scheme by using a single mobile beacon. The beacon sends its position information in a beacon signal from three different non linear positions to a single node. The sensor node calculates the distance by using RSSI and computes its position by applying the triangulation method. Keeping the immediacy of localization processing of many industrial and military applications in to account, the scheme proposed is not very feasible. The author also did not propose any specific trajectory for the mobile beacon. Also, there are certain situations where more than one mobile beacon is required according to the need and requirement of the network. Moreover, the localization of sensor network does not solve the problem of network disconnection which is affects the overall performance of the network. We thus proposed a localization scheme that is not only localize the nodes but also discover the disconnected parts of the network for onward redeployment of their neighbors and expedites the localization processing. The proposed scheme which we termed as Localization with Mobile Beacon(s) (LoMoB) works in four different Scenarios. The proposed scheme uses mobile beacons that move across the network to carry out localization as a pre-process for redeployment without engaging a settled or localized node all the time.This movement can be carried out periodically in order to get the latest info about the node positions and the network connectivity status. The mobile beacons can be a vehicle, a robot or even a human being deciding the path to be followed predetermined or randomly. Four Scenarios become bases for the proposed methodology are as under:

1. Localization by using Single Mobile Beacon
2. Localization by using Two Mobile Beacons
3. Localization by using Three Mobile Beacons
4. Localization by using one mobile node and a settled node

The scenario-1 is also proposed in [17], we expanded the idea of paper by proposing the trajectory for the beacon. Also results are compared with scenario-1 to prove the efficiency of LoMoB. The selection of a Scenario depends upon immediacy and computing overhead of the application or of the sensor field.

4. System and Working of LoMoB

4.1. Scenario-1: Localization with Single Mobile Beacon.

In this Scenario, a single mobile beacon node locates the sensor nodes from three nonlinear positions. The starting point for mobile beacon is taken at (0, 0). The practical process of localization is shown in Figure 2 where a sensor node receives beacon message from mobile beacon at its three different positions. Upon the receiving of beacon signal, the target node sets a timer and a counter to count the number of beacon massages with timing

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information.

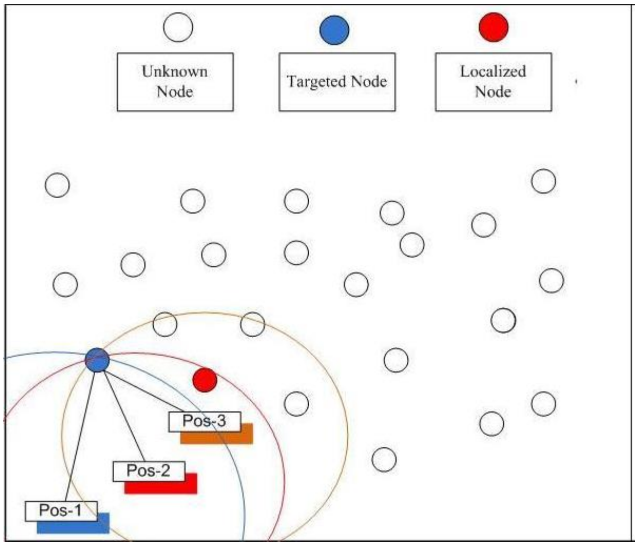

Figure 2 Scenario 1 (localization with single mobile beacon)

The message contains a beacon header, beacon ID and the position of mobile beacon. The beacon broadcast messages from three different positions with constant signal strength (1 watt in our case). A minimum of three messages are required at the sensor node end to start the localization process. The triangulation technique is used and the intersection point of all the three circles developed on the basis of distances calculated from the three versions of the RSSI will be the node position. If number of received beacons is less than three till end of the timer, the target node discards and waits for new set of beacon messages.

4.2. Scenario-2: Localization with Two Mobile Beacons

In this scheme, two mobile beacon starts motion from some known positions. Both the beacons takes different trajectories however, the separation between the mobile beacons is controlled in order to maintain the received signal strength above a threshold at the sensor node. In our case we took one beacon with sinusoidal and other with saw-tooth paths. Upon the reception of first beacon message, the target node sets timer and counter and stop them when the beacon massage from the second beacon is received. Then it starts the localization and position estimation process. Here the situation is a bit different from Scenario-1.

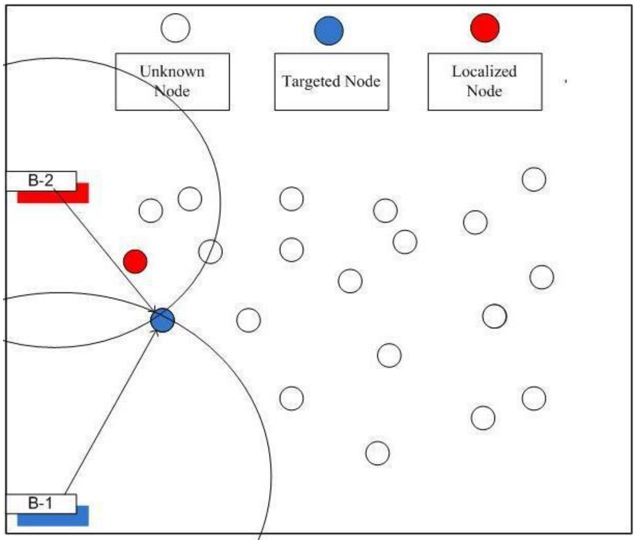

Figure 3 Scenario 2 (Localization by using two mobile beacons)

As shown in fig 3, in this case, we will have two intersection points and therefore it is difficult to point out the exact position of a sensor node. The solution to this problem is proposed in [1], we will have an originating point at (0, 0) that is known as the reference point. Distance from reference point to both the intersection points will be calculated and the more distant intersection point will be the position of node to be localized. Figure 3 shows the conceptual implimentation of proposed scenario where two mobile beacons localize a sensor node. The position of both beacons B1 and B2 must be known.

4.3. Scenario-3: Localization with Three Mobile Beacons

In this case three mobile beacons are used for localization. This Scenario is used in sparsely populated network or where the number of sensor nodes is increasing from time to time. The sensor nodes wait for three massages from three different mobile beacons. Each sensor node stores the ID of mobile beacon and if it receives duplicate signals from the same beacon it discards either the earlier or the newly arrived signal.

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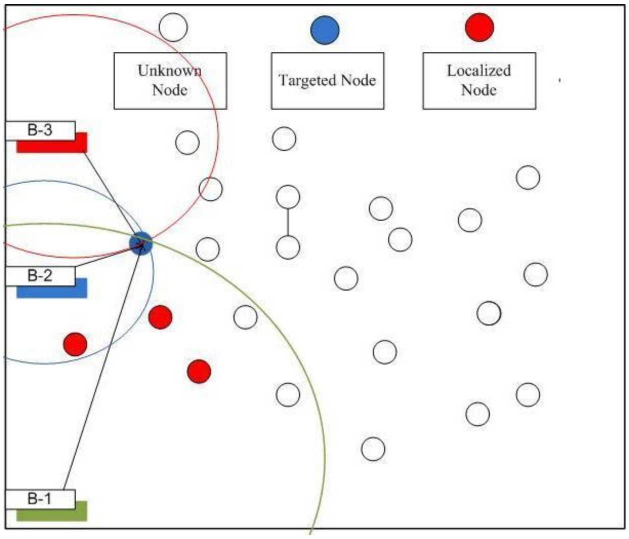

Figure 4 Scenario 3 (Localization by using three mobile beacons)

Fig 4 shows the proposed scenario with three mobile beacons.The trajectories of the mobile beacons will be different however the separation between the beacons nodes is kept within a threshold during the localization process. Figure 4 shows the third Scenario in detail where the localization process is taking place in a sensor node. This method is fast and good for sparsely populated networks.

4.3. Localization by using a mobile beacon and a settled Node

In this Scenario, we use a settled node as a supporting beacon or reference node for localization. This method is fast and good for densely populated network, where all the nodes are in communication range with each other. In this case the mobile beacon takes start from a predefined position and localizes the first node from the network and perform the method discussed Scenario-1 this step behaves as the Initialization step of this scenario. After the first node is localized it becomes a settled node. In the steady phase the settled node is converted to the support beacon node and both the mobile beacon and support beacon broadcast their location information to the rest of the network. The receiving node will again calculate the received signal strengths and then the distances between node, mobile and support beacon is calculated. The situation is again just like that is discussed in Scenario-2 but there is difference of number of mobile beacons. Both the distances are then converted to radius and the position is calculated through triangulation process in this method, two intersection points are obtained which are then measured from a common reference point at (0,0) and the more distant point is taken as the position of the target node. In this way the whole network is localized. In case there are more than one support beacon in the network then the target node receiving position information from more than one support beacons will select the nearest support beacon and discard the rest.

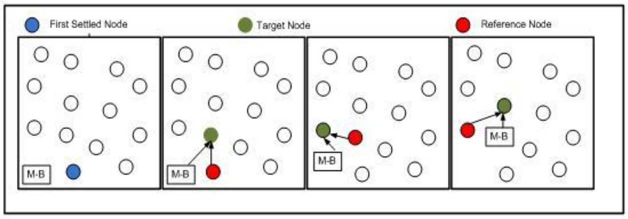

Figure 5 Scenario 4 (Localization by using a settled and single mobile beacon)

Figure 5 represents the process of localization in Scenario-4 in which, only the mobile beacon has its known position information and after the localization of first node, the actual localization process takes place.

5. Simulation and Results

In order to show the efficiency of the proposed scheme with different Scenarios, we implement our idea in Matlab(R) 8.0. We concentrate on five major performance parameters in our simulations. The first is the localization time, the second is the localization error plotted against the network density, the third is the localization error plotted against the signal to interference plus noise ratio (SINR), fourth is the probability of localization error against the SINR and fifth is the redeployment of sensor node. Initially, all the nodes are supposed to be unknown with respect to their positions. All the mobile beacons are assumed to be on their reference points and ready to carry out localization process being controlled remotely.

5.1. General Assumptions and Simulation Setup for the Proposed Scheme

Some general assumptions that are needed to be taken in to account in order to model realistic environment with a generic sense are listed as under:

1. All the nodes to be localized are randomly distributed across the sensing field.
2. Number of nodes to be deployed and localized in each Scenario is set to be 100.
3. The mobile beacon nodes may or may not be GPS enabled; however, they are connected with the central controller and their positions are known.
4. All the sensor nodes including mobile beacons can be identified by their unique IDs so that the data acquisition server can locate the sensor node with its position and ID.

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5. Communication range of each sensor node (taken as R) remains constant
6. All the nodes and mobile beacons communicate under 802.15 standards.
7. The signal power of the nodes and the beacons is set to be 1 watt which is assumed to remain constant throughout the communication.

5.2. Network Localization Delay

Network localization delay or network localization time (also known as latency) is one of the major challenges in WSNs. The latency refers to the time taken by the entire network to be localized in such a way that all the sensor nodes are aware about their positions and the sink or server has been reported about the position of each node. We simulate the proposed scheme to find out the latency of each Scenario. For Scenario-1, the total time elapsed during localization is:

$$T = T_v + T_o + T_p \quad (1)$$

Where,

T_v = time in which mobile beacon covers the distances d_1 (from point 1 to point 2) and d_2 (from point 2 to point 3)

T_o = time taken by the beacon signal from point 3 to the target node

T_p= processing time taken by a sensor node to process computations for localization and is taken fixed as 1 sec. The time T_v can be written in terms of distances as:

$$T_v = \frac{d_1 + d_2}{v} \quad (2)$$

Where v is the velocity of the vehicle that has been taken as 60 km/h. T_o can be written in terms of the distance d_o from position 3 to the target node as

$$T_o = {d_o}/{c} \quad (3)$$

Where c is the velocity of light. In Scenario-2, 3 and 4, the latency or localization time can be calculated as

$$T = T_v + T_o + T_p \quad (4)$$

Here in this case T_o is calculated as:

$$T_o = {d_L}/{c} \quad (5)$$

Where d_L is the largest distance between the target node and mobile beacons and T_p is the processing time taken as 1 second as mentioned earlier. As plotted in Figure 6, we observe that Scenario-1 (with single mobile beacon) almost takes lesser time to localize the initial network as compared to other Scenarios. However, the overall trend of the plot is upwards which means, for exponential increase in number of nodes in the network, the localization time or latency increases exponentially.

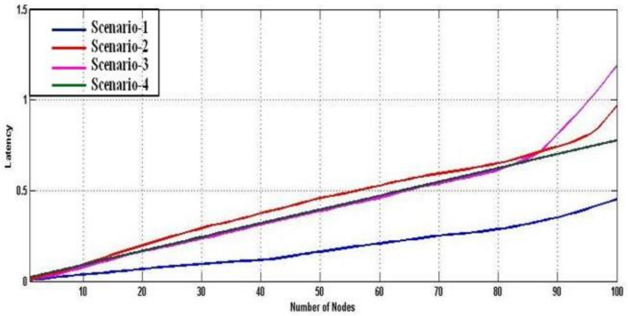

Figure 6 : Network localization delay by all scenarios

In case of Scenario-2 (with 2 mobile beacons), we can see delay in the beginning of the localization process as compared to Scenario-1. The trend of the plot is also (2) ponential increase against an increase in the number of sensor nodes. The delay in the start is due to the two mobile beacons as a node has to wait for at least two beacon signals from two different beacons. Like Scenario-1, the speed of the mobile beacons also depends upon the saturation of sensor nodes lesser the number of nodes, greater will be the speed and vies versa. Also some additional processes like removal of duplicate signal, calculation of intersection point from the reference point etc. exert significant impact on the localization time. These processes are repeated constantly on each sensor node to be localized. Similar is the case with Scenario-3 where three mobile beacons are used. Each node to be targeted has to wait for three

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different beacon signals in order to start localization process. Three mobile beacons collectively enhance the localization time. In Scenario-4, the localization time consumed is comparatively high in the start (lesser number of nodes). This is because of localization of first the node from three non linear points by the beacon. Also in less congested network, a node may or may not be in the vicinity of reference node and the mobile beacon has to select the next localized node as a reference node which may consume some time. But with the increase in number of nodes, the distances between them is also decreasing and hence every node becomes in the vicinity of other node resulting in quick and strong signal reception by the target node making the localization process more faster.

5.3. Network Density and Localization Error

A localization error is the error that is caused by the amount of interferences and uncertainty present in the received signal. These errors can lead the network in to wrong position estimation of the sensor nodes. Mean squared error is usually plotted in order to observe the effect of localization error on the system performance. Mean squared error can be written as:

$$MSE = E(|e|^2) \quad (6)$$

Where e and $E(\cdot)$ are the localization error and is the s

statistical expectation, respectively. In order to evaluate

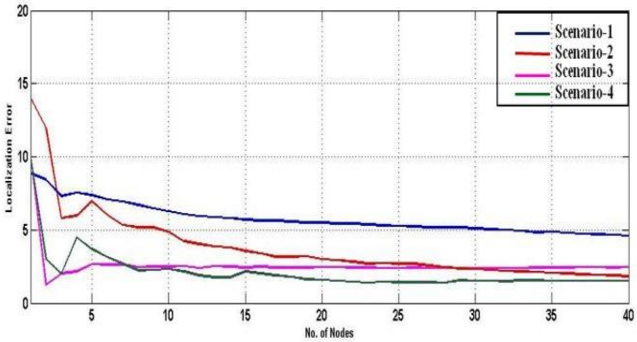

Figure 7 : Localization error produced by each scenario

the localization error over the entire density of the network, we simulated all the Scenarios of the scheme for a total number of 50 sensor nodes with the increase of 5 nodes per step.

Figure 7 shows the simulation results of each of the above mentioned Scenarios, where mean squared error has been plotted against network density in linear and logarithmic fashions. In Figure 7 and 8, the constant behavior of the plot representing Scenario-3 shows that this scheme works ideally in less dense sensor field with least amount of error. However, it exhibits a constant behavior beyond the point where the nodes are distributed randomly in the whole field. The behavior remains constant till the same field is packed with the sensor nodes. Observing the plot of Scenario-2 in the figure, we can see that in the less dense environment, the localization error is high. This may be due to the larger distances between the nodes and the mobile beacons that affect the RSSI with more interference.

However, the localization error decreases dramatically and the result indicates a sharp decrease for a higher density. The Scenario-1 has relatively higher localization error. This is due to the fact that in this case, there is only a single mobile node (means a single beacon Signal) that covers the entire network. Therefore, there is a chance of greater amount of noise and uncertainty as compared to other Scenarios discussed before. The Scenario-4 gives relatively good result in this performance evaluation procedure. The mean squared error or localization error decreases and reaches to a constant mode after localizing of 20 nodes. The initial behavior of plot that starts from 9 points in the plot is due to the localization of the very first node in the network with the help of technique explained in Scenario-1. he increase in number of nodes and increase in powerful signaling among them, the localization error is relatively lower than that in other Scenarios.

5.4. Signal to Interference plus Noise Ratio (SINR)

Figure 8 represent the mean squared error against different SINR (Signal to Interference plus Noise Ratio) for each Scenario. SINR shows the strength of the signal received against interference and noise present in

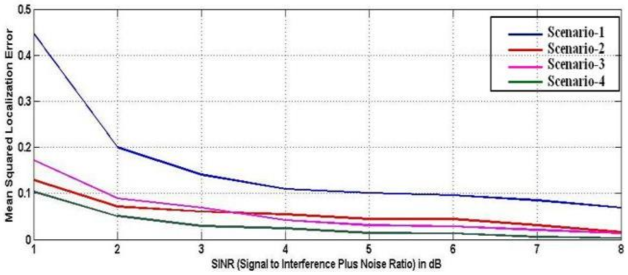

Figure 7 Mean Squared Localization Error Calculated by Each Scenario

atmosphere. The mean squared error is actually the squared of the localization error caused by the presence

of interference and noise. Scenario-1 has a greater value of error in the start but the error decreases more rapidly with the increasing values of SINR as compared to other Scenarios. The performance of the rest of the Scenarios (i.e. 2, 3 and 4) is satisfactory. The initial mean squared error of these

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Scenarios is between 0.1 and 0.2 is already low as compared to the one in Scenario-1.The simulation results show that the mean squared error decreases with an increase in SINR initially however, it become almost constant for higher values of SINR. This result concludes that the mean squared error of each Scenario is low for higher SINR values.

5.5. Total Nodes Localized by Each Scenario

The performance evaluation of LoMoB with respect to no. of nodes localized by each scenario is compared with the work done in [1] and we called it scenario-5. Figure 9 represents the number of nodes localized by each scenario. The plot represents 3 occurrences from which the behavior of each scenario can be observed. We observed that scenario-5 localized the minimum nodes among all the scenarios. As scenario-1 uses a single mobile beacon therefore it cannot cover the maximum sensing field as compared to other scenarios. During the simulation process, it was observed that most of the sensor nodes at the edge of sensor field are remained un-localized as they are unable to receive the signal from three different and nonlinear positions transmitted by the single mobile beacon. This scenario can perform well in small sized sensor fields. Similarly scenarios-2 and 3 gives quite satisfactory results because the maximum area is covered by the both the mobile beacons resulting the reception of signal by maximum sensor node from the beacons in both scenarios. The results shows both the scenarios can work ideally where maximum resources of beacons are available and maximum node localization is required. The performance of scenario-4 is somewhere between scenario-1 and 5. Since the scenario-4 uses a settled node as a reference node in the localization process therefore this localization scheme also depends upon the energy power and signal strength of the reference node and may not work ideal for periodic localization process. Scenario-5 carries out the localization process without using any mobile beacon. This scenario is proposed in [1] which uses the deployed sensor nodes as beacon known as reference nodes. This is a recursive process where the localization process is repeatedly carried out at the settled node end to locate the sensor nodes at its neighbors. The simulation results show that this scenario can work very ideally with a saturated sensor field because the sensor node can communicate easily with each other due to a strong signal power. Where as in periodic localization process where the sensor nodes are localized after a specific interval or an event, this scenario may not work ideally because the energy is constantly consumed by the sensor nodes and it may limit the communication range. Also some nodes may die due to complete power consumption due to which a settled node cannot reach its signal to the next neighbor and it can also affect the performance the localization process

5.6. Died / Disconnected Node Discovery

Figure 10 represents the no. of disconnected node discovered by each scenario in sensor network. The disconnected nodes are those which have been either died due to powerless batteries or they are externally damaged or they have not enough power to communicate efficiently.

In order to locate the disconnected nodes, each beacon will transmit the beacon message to the sensor nodes and will wait for the acknowledgment from the sensor node (each beacon has the complete information about the position of each sensor node). The node that fails to respond the beacon message will be considered as dead or disconnected node. This failure can be either due to powerless batteries or power remains below a threshold in the battery. In the simulation results, the scenario-3 gives better results in the localization of disconnected nodes. This is because the ratio of signal propagation is much more spreader as compared to other scenario. Each beacon is capable of locating the disconnected node therefore this scenario can cover maximum area of the network.

Similar is the case with scenario-2. The two mobile beacons move across the network in order to locate the position of disconnected nodes or part of a network. The technique of localization is similar as discussed for scenario-3. Scenario-1 and Scenario-4 gives almost same result. This is because both the scenarios uses a single mobile beacon and it is difficult for a single mobile beacon to cover the entire network and receive the acknowledgments. In Scenario-5, since there is no mobile beacon and localization process is carried out through settled nodes therefore it is difficult to detect and locate the disconnected nodes. A reference node cannot hold the location position of all the sensor nodes and also, if there is a died node in the neighbor of a sensor node it is difficult for it to communicate with the rest of node present across the died node (one hop communication). The result shows that Scenaro-5 discovered minimum no. of died nodes (less than 20)

6. Throughput

Figure 11 shows the initial throughput of the network with full load of the nodes. This simulation result of data transfer is taken soon after the deployment of sensor nodes and their localization. The x-axis in the figure represents different

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scenarios at diffrent iterations whereas y-axis shows the throughput of the network. We assumed that the server at the data receiving end accept the data from the localized nodes only. Figure 12 shows a remarkable decrease in the throughput of the data.

This decrease is mainly due to less power remained in the battery or external damage. There might be some other factors which can cause decrease in throughput like multipath, absence of events, heavy processing etc. In order to locate the disconnected or damaged nodes in the network, the localization process will be executed once again but this time every individual mobile beacon will locate the disconnected node. The result of throughput after the redeployment of the sensor node is shown in Figure 13, where we can see the increase in the throughput in the sensor network.

However there are some other factors that decreases the throughput as discussed in above paragraphs and which are beyond our scope of research. The result in increase of through put is directly proportional to the number of disconnected nodes localized by each scenario.

7. Conclusion

In this paper, we introduce a new mobile beacon based localization and redeployment process known as LoMoB (Localization with Mobile Beacon) in which the additional nodes can be redeployed or the disconnected regions can be identified by a single mobile beacon or group of mobile beacons in sparsely populated Wireless Sensor Networks. The scheme also helps to prolong the life time of the existing network. Four different scenarios of LoMoB operations are evaluated and discussed for error, performance, dead or weak node discovery and node redeployment. Four of the Scenarios of the proposed scheme were evaluated for latency or localization time and it was observed that Scenario-1 and 4 gave relatively minimum latency during localization of the nodes of a sensor network. Overall trend of the latency for linearly increasing population of the nodes was exponential rather than linear. Similarly, localization error observed for different number of nodes and several of received SINR (Signal to Interference plus Noise Ratio). It was observed that in each Scenario, the mean squared value of localization error decreased with the increasing number of nodes. However, Scenario-4 was observed to exhibit a rapid decrease in localization error as compared to other

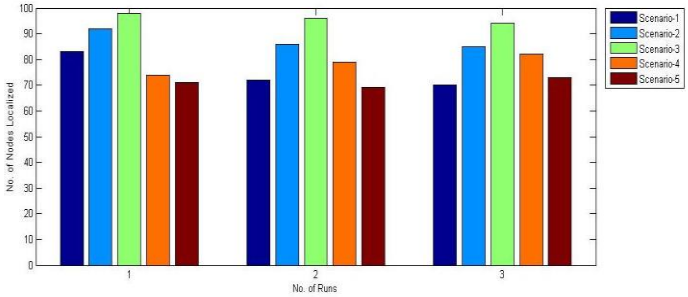

Figure 9: Number of nodes localized by each scenario soon after deployment

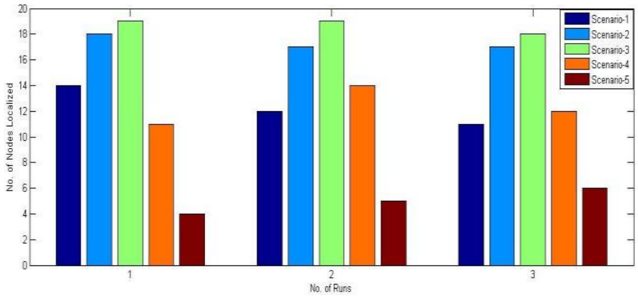

Figure 10: Died node discovery by each scenario

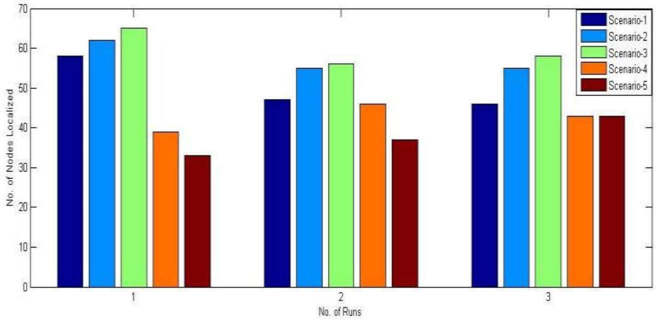

Figure 11: Maximum throughput achieved by each scenario after death of critical nodes

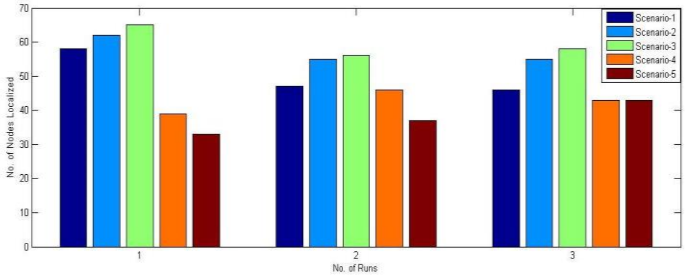

Figure 12: Throughput achieved by each scenario after redeployment

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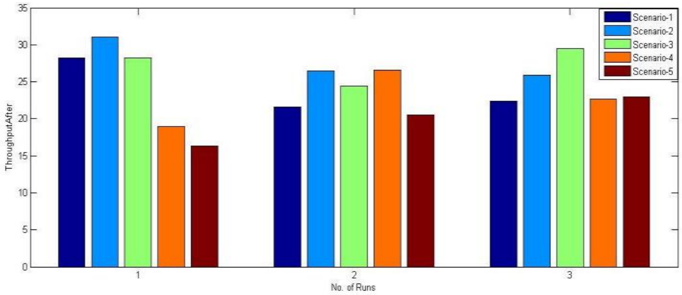

Figure 13: Effect on throughput after redeployment of sensor nodes

Scenarios which means that this Scenario of the LoMoB can work ideally in denser network. Four of the LoMoBs Scenarios showed almost the same performance with increasing SINR and localization error stays at its minimum value for higher SINR values.

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