Energy Efficient Wireless Sensor Network System for Localization

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***Abstract*—This paper introduces an enhanced overlapping connectivity-based localization technique. Constructed experiments showed that using the information obtained from closer anchor nodes in the communication range results in better position estimations. In this work, received signal strength indication (RSSI) measurements are used to estimate the distance of an anchor node to a mobile node. The optimal number of anchor nodes to be used in localization is determined empirically with the performed experiments. The enhanced localization technique is implemented on a wireless sensor network system consisting of GenetLab sensor nodes. Each node has MSP430 processor and TinyOS operating system deployed. In order to increase the energy efficiency of the wireless sensor network system, the anchor nodes are operated in active-state or semi-active state based on the position of the mobile nodes. It is shown that such an approach enhances the energy efficiency of the system under various movement scenarios and network topologies.**

Keywords-sensor network; localization; energy efficiency

I. INTRODUCTION

Wireless sensor networks have attracted great interest over the last decade. Low-cost, low power and multifunctional small sensor nodes have become available through the recent developments in electronics and wireless communications [1].

Accurate and low power localization of sensor nodes is crucial for many applications to work efficiently. Various localization techniques have been introduced so far. In general, localization techniques can be classified as measurement and non-measurement based techniques. Additionally, both of these classes are also divided into two sub classes as single-hop and multi-hop techniques. In measurement based techniques, localization is performed by using measured distance with the other anchor nodes using the techniques such as time of arrival (ToA), time difference of arrival (TDoA), and angle of arrival of signals (AoA) [2]. Non-measurement based localization techniques which are also called connectivity-based techniques do not use distance measurements. In the single-hop localization, only one-hop neighbors are considered for localization, whereas in the multi-hop localization, multi-hop distanced anchor nodes are participating. The connectivity-based single-hop localization techniques are easier to implement, more energy efficient than the other techniques and also less affected from the environment. Because of these advantages, in this work, we focus on one-hop distance localization techniques.

The overlapping connectivity-based localization algorithm which is defined by Bulusu et al. [3] is taken as the reference point in our work. The overlapping connectivity uses the location information obtained from anchor nodes to evaluate the location of a mobile node. The mobile nodes estimate their locations in x and y coordinates by taking average of obtained locations of the anchor nodes as shown in (1):

$$(X_{est}, Y_{est}) = \left(\frac{X_{i1} + ... + X_{ik}}{k}, \frac{Y_{i1} + ... + Y_{ik}}{k} \right) \tag{1}$$

where X_{est} and Y_{est} denotes x-coordinate and y-coordinate estimates of the mobile node, $X_{i1}......X_{ik}$ and $Y_{i1}......Y_{ik}$ denote x and y coordinates of the k anchor nodes within the coverage area of the mobile node. The coverage area spans by the anchor nodes within one-hop distance to the mobile node.

In our work, the overlapping connectivity technique is improved by using some of the anchor nodes instead of using whole anchor set within the coverage area of a mobile node. The criteria for selecting an anchor node is based on the received signal strength indication (RSSI) measurements and the direction of the mobile node. Using all of the anchor nodes in one-hop distance to calculate (1) gives rough estimates for localization as seen in simulation results. On the other hand, localization techniques based on only RSSI measurements can give erroneous results depending on environmental conditions. We have implemented overlapping connectivity localization method with a modification of using only a portion of the neighboring anchor nodes by using the RSSI measurements. Based on the results of our simulations we decide about the number of neighboring anchor nodes to be used in our calculations. Moreover, for considering energy efficiency, the anchor nodes are designed to work in two states: semi-active state and active state. In the introduced system, the anchor nodes, which have a mobile node around, broadcast their location information periodically (in the active state). Otherwise, they switch to semi-active state.

Sensor node applications are highly vulnerable to the environmental conditions due to the wireless communication medium, special harsh conditions of the deployment terrains of the sensor nodes and their limited processing capabilities. Therefore, implementation of an algorithm for WSNs with a real testbed becomes more important in order to get more realistic results likewise the testbed environment in our work.

The rest of the paper is organized as follows: Section II overviews the localization algorithms in WSNs. Section III describes the testbed employed. In Section IV, the suggested localization technique is described and the test results by using various topologies are given. In Section V, the energy efficiency of the employed WSN system is enhanced. Finally, Section VI concludes the paper.

II. LITERATURE SURVEY

Sensing an environmental stimuli is the main functionality of a WSN. The coupling location information is important for many WSN applications to process the sensed data. Therefore, the location accuracy is fundamental in many WSN applications. Energy and cost efficient localization techniques are important in WSN because of the sensor nodes' limited processing capabilities. The location of a sensor node can be obtained from the global positioning system (GPS) or can be embedded to the sensor node at the deployment phase. GPS is not an efficient choice for determining the location because of the cost and energy restrictions. Furthermore, GPS is not compatible with indoor environments. Instead of using GPS, sensor nodes can find their locations with the help of some other nodes which know about their location.

Measurement based localization techniques are based on ToA, TDoA, AoA and RSSI. ToA, TDoA and AoA have constraints imposed by hardware requirements. AoA needs directional antenna. ToA and TDoA require a slow signal transmission which can be estimated. Since RSSI does not need any additional hardware, it is widely used.

An RSSI-based localization algorithm using a single mobile anchor node is proposed in [4], in which authors employ un-located sensor nodes whose locations are determined by calculating beacon points according to beacon information taken from the mobile anchor node. Beacon points are chosen according to maximum RSSI points. It is claimed that the mobile node that is equipped with GPS, does not violate energy-constraint.

Non-measurement based localization techniques are centroid algorithm, DV-hop algorithm, amorphous algorithm, APIT algorithm, etc. The most known non-measurement based localization techniques are centroid algorithm and DV-hop algorithm. In centroid localization algorithm, the localization error is increased when number of anchor nodes are not sufficiently high or the deployment of the anchor nodes is irregular. Different centroid algorithms are proposed to improve location estimations. In [5], mobile nodes use the information of its cluster whose nodes are weighted according to received RSSI and weighted centroid localization (WCL) is executed. In [6], weighted centroid algorithm and RSSI value taken from unknown nodes for determining distances are combined and tested on 2D and 3D simulation environments. Location of unknown nodes are determined by anchor nodes which are located in the range of circle whose center is an unknown node. They weighted anchor nodes which are in the defined circle by 1, rest of the anchor nodes are weighted by 0. Then, the relationship between localization error and the number of anchor nodes used in localization process is experimented and also it is observed that localization error is highly affected by the distribution of anchor nodes.

Non-measurement localization techniques are cost and energy efficient but location error is much more than measurement localization techniques [5]. These algorithms usually do not try to optimize or minimize the location estimation errors while producing a reasonable estimation with a very low algorithm complexity. Therefore, the localization error is higher in these techniques compared to localization techniques using distance measurements. We propose combining measurement and non-measurement based localization techniques to get lower localization error. Additionally, dependency of localization error with respect to the number of anchor nodes and the deployment of anchor nodes are investigated. Localization error, as in [6], is tried to be decreased by using a determined percentage of anchor nodes in localization process.

III. TESTBED EMPLOYED

In this work, we implement a WSN environment at the Computer Network Research Laboratory of Istanbul Technical University. Sensor nodes, which are used in our work, consist of two modules: sensor-L and node-RF. Sensor-L module contains sensors and node-RF module has processor and RF communication units [7]. RF antennas, LEDs, EEPROM, power inputs for battery, 41 pin socket which is helpful for parallel and serial port connections are placed on the node-RF module of the sensor node. Accelerometer, temperature sensor, light sensor, magnetic field sensor are placed on the sensor-L part of the sensor node. These sensor nodes employ TinyOS operating system. Programs for these sensor nodes are written in NesC programming language which is compatible with TinyOS operating system [8, 9]. In the sensor network system, anchor nodes are deployed according to a predefined pattern. They are used to route data and also the necessary information to localize the mobile nodes in the environment.

Distance Vector Routing algorithm (DVR) is employed as the routing algorithm . Count-to-infinity problem is solved by defining a timer. If a node does not send any packet before the timer expires, it is considered as offline [10].

Figure 1. Node RF card and battery

A. Types of Sensor Nodes

Anchor nodes- They have static locations, send routing packets to the neighboring anchor nodes and mobile nodes. Furthermore, they send localization packets which contain x-y coordinates periodically. Mobile nodes use their localization packets for localization. Additionally, the anchor nodes route data packets to the sink node.

Mobile nodes- They move in the WSN. They determine their location using the packets sent by the neighboring anchor nodes. These nodes send their localization calculations to sink node periodically.

Sink node- It is connected to computer with a serial port. It sends the obtained data packets to the computer.

B. Types of Packets

In order to manage the system and transmit data, the following packet types are employed.

Routing Packets- Routing packets are sent by all of the nodes except the sink node. They are used to form the routing tables according to DVR. This routing packets include node id, next hops and hop counts to other nodes.

Localization Packets- Localization packets are sent by anchor nodes periodically. They include node id, X and Y coordinates.

Mobile-to-sink Packets- Mobile-to-sink packets are sent by mobile nodes to report their location to sink node. These packets are routed to the sink by using DVR routing tables. These packets contain node id, source node id, destination node id (sink node id), X and Y coordinates.

Data Packets- These packets are formed by the nodes in order to transmit the information related to the application to the sink node.

The wireless sensor network environment employed is given in Fig. 2.

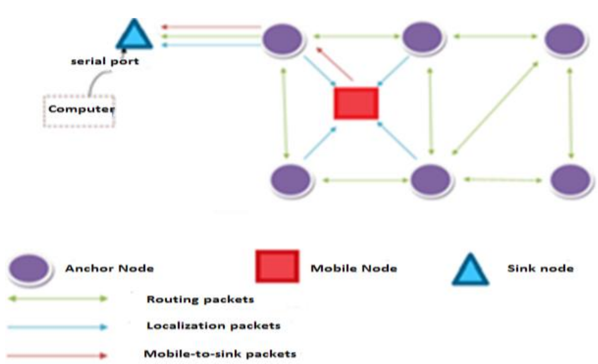

Figure 2. Wireless Sensor Network Structure

IV. LOCALIZATION TECHNIQUE INTRODUCED

Simulation results and testbed results are obtained.

A. Enhancing The Precision Of Localization Estimates

In this work, initially we study the effect of the number of neighboring anchor nodes used in the precision of the location estimates by simulation. Simulations are done using various topologies to find the necessary number of anchor nodes. One-hop distance is taken as 55 meters in the simulations. The distance between anchor nodes are changed between 20-50 meters. The anchor nodes are regularly placed as shown in Fig. 3.

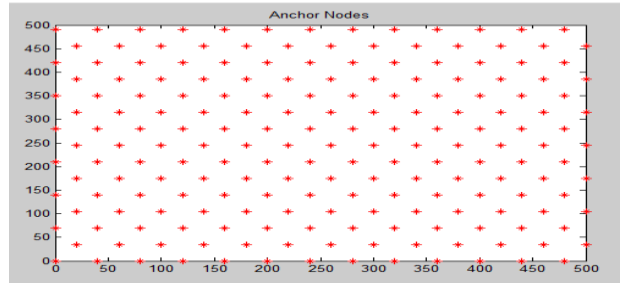

Figure 3. Anchor Nodes Placement in a $500*500m^2$ region

Mobile nodes move randomly. Simulations are based on three random paths with 100 discrete movements of the mobile node. Mobile nodes move in one of four directions (+x, -x, +y, -y) in time unit by random distances (between 15m and 45m). A random 100-step movement scenario is given in Fig. 4.

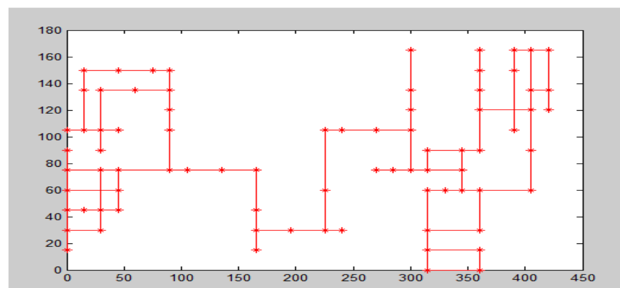

Figure 4. Random movement of mobile node

Simulations are repeated by changing the distance between anchor nodes. Average number of the anchor nodes, which are one-hop distance to mobile node, is given for different cases in Table 1.

TABLE I. CASES

Case No	Distance Between Anchors	Average number of neighboring anchor node
1	20m	≈23
2	30m	≈10
3	40m	≈5
4	50m	≈4

Above mentioned simulation scenarios are employed for location estimations by using the connectivity-based localization [3] first.

Then we modified the localization technique by reducing the number of anchor nodes employed. Initially we dropped one anchor node, then two anchor nodes and so on. The

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ones dropped selected according to the RSSI measurements. So the anchor nodes, which are far away, are not considered in the location estimates.

It is shown in Fig. 6 that as the number of neighboring anchor nodes increases the error decreases. As we drop the anchor nodes that are far away from the mobile node. The results become more accurate except case 4, where the average number of neighboring anchor nodes is four only.

We may conclude that nearly two third of the neighboring far anchor nodes could be omitted with the concern that the number of considered anchor nodes should not be smaller than three.

B. Testbed Results Obtained

The localization technique is implemented on the wireless sensor networks using 7 and 17 nodes. Considering the number of neighboring anchor nodes and the directions given in Section III, three anchor positions are used for position estimations.

Strength field in TOS_Msg struct of CC2420 module is used for RSSI measurement as below:

RSSI value (dBm) = (int8_t) TOS_Msg->strenght-45 (2)

Moreover, movement direction of mobile node is tried to be estimated. This is determined basically using the difference between previous two estimations of the mobile node.

The snapshot of the environment for 17-node case is shown in Fig. 5. Here, every anchor node is located 30 cm far from each other. One hop is approximately 40 cm when output power ratio module is taken as -25dBm.

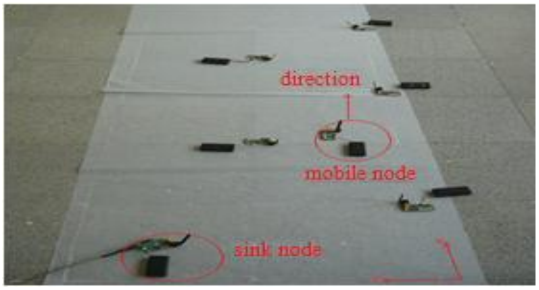
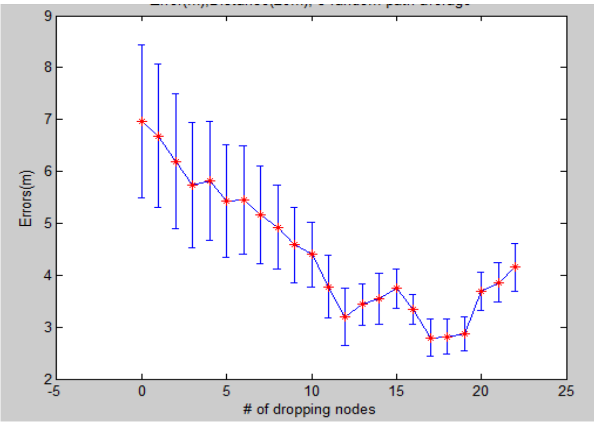
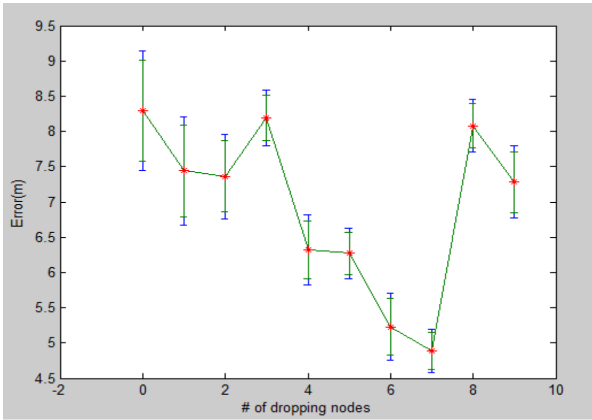


Figure 5. Test topology with 5 anchor nodes, 1 mobile node and 1 sink nodes

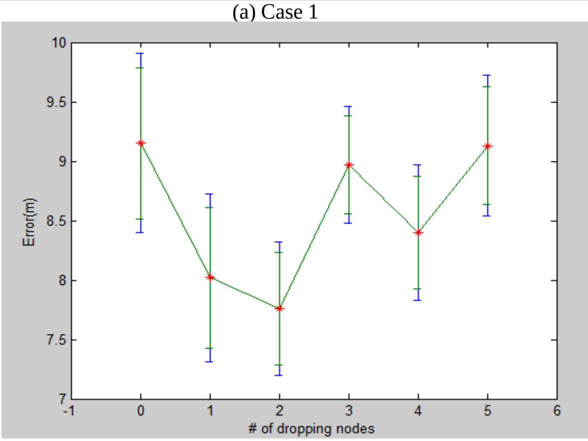
The results for the x-y coordinate estimates for 7-node and 17-node topologies are given in Fig. 7 and Fig. 8, respectively.



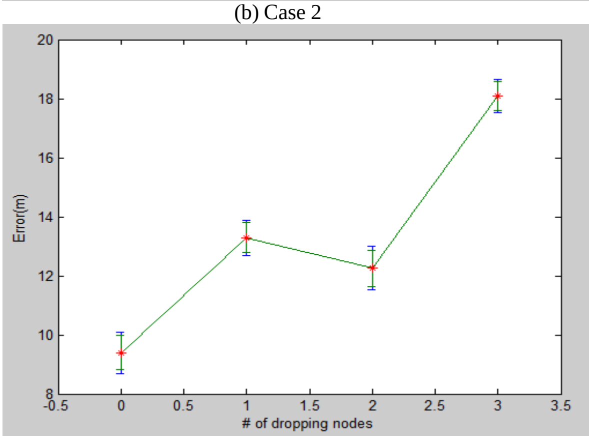
(a) Case 1



(b) Case 2



(c) Case 3



(d) Case 4

Figure 6. Error values for the cases studied

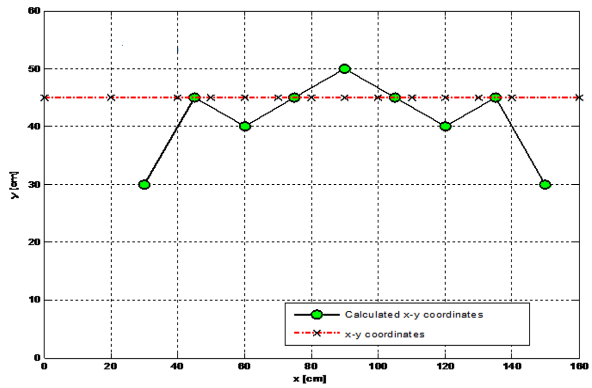


Figure 7. Estimated x-y coordinates and real x-y coordinates of mobile node (7 nodes)

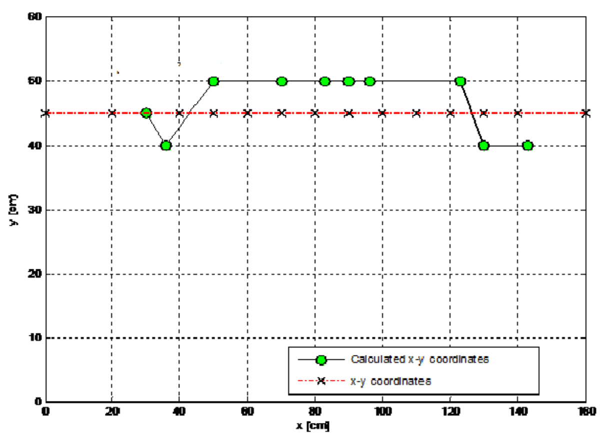


Figure 8. Estimated x-y coordinates and real x-y coordinates of mobile node (17 nodes)

Average numbers of neighboring anchor nodes are 3-4 in the 7-node topology and 7-9 in the 17-node topology. We get the best localization estimations when nearly two third of the neighboring far anchor nodes are omitted with the concern that the number of considered anchor nodes should not be smaller than three as explained in the previous sections. In the 7-node topology, the location estimations of the mobile node is calculated by using minimum number of anchor nodes (three anchor nodes). In the 17-node topology, two third of the neighboring nodes are omitted. Here, the location estimations of the mobile node is calculated by using three anchor nodes also. The 17-node topology gives better estimations as expected.

Environmental effects such as collisions and wifi networks disturb the efficiency of the results. However, despite of environmental conditions, our main assumptions are supported by the testbed results.

V. ENHANCING THE ENERGY EFFICIENCY OF THE NETWORK DEPLOYED

Energy efficiency is an important necessity for wireless sensor networks which have to work with energy constraint.

In suggested localization technique, packets which carry localization information are sent by anchor nodes periodically. However, the mobile node can only get such packets from anchor nodes in its coverage area. Therefore, localization packets should not be transmitted by anchor nodes, if anchor nodes are not in the communication range of a mobile node. We call this as *Energy Efficient WSN*. Here, the anchor nodes work in two states: *semi-active state*, and *active state*. The anchor nodes having a mobile node around broadcast their location information periodically (in the active state). Otherwise they go into semi-active state in which anchor nodes only send routing/data packets as necessary.

Anchor nodes keep IDs of all mobile nodes in the topology. It is not memory-consuming process even in large topologies. If an anchor node receives a routing package from a mobile node, it moves into the active state. Furthermore, a timer is set and starts to count. When the timer expires, the anchor node changes its state from active to semi-active.

Energy gain of the energy efficient WSN is determined by studying the decrease in the number of localization packets generated by the anchor nodes. Firstly, the power consumption to send localization packets is calculated as below [1].

$$P_{ct} = N_T \left[P_T (T_{on} + T_{st}) + P_{out} T_{on} \right] \quad (3)$$

where P_T denotes power consumption of CC2420 radio module when it is on transmission mode. This value is 62.64 mWatt for CC2420 when output power is 0 dBm. T_{st} is start-up time of CC2420 which is given as 1 ms. P_{out} is output power of CC2420 which is taken as 0 dBm. T_{on} is time duration which CC2420 stays on transmission mode. It can be calculated as L/R, where L denotes packet size and R data rate which are 20 byte and 250 kbps, respectively. N_T denotes number of activation of CC2420 radio module as transmitter. When these values are placed in (3), P_{ct} for 1 minute test duration becomes as seen in (4) where $N_T(5t)$ number of activation of CC2420 radio for transmission of localization packets in 5 seconds. The number of activations is evaluated from number of localization packets sent to the collector node in every 5 seconds during 1 minute test duration.

$$P_{ct}(5t) = \sum_{n=0}^{11} N_t(5t) \times [\left(62.64mW \times \left(\left(\frac{20byte}{250kbps} \right) + 0.001s \right) \right) + \left(1mW \times \left(\frac{20byte}{250kbps} \right) \right)] \quad (4)$$

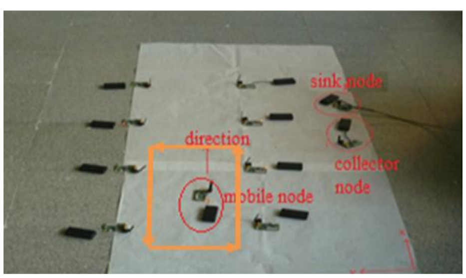
Power consumption during transmission of localization packets according to (4) is observed on two different test scenarios called Energy Efficient Localization in narrow region and wide region. Narrow region and wide region can be seen in Fig. 9. In the wide region scenario, the mobile node could move in overall region. In the narrow region scenario, the mobile node could move only a part of the region.

We run the introduced localization technique on the sensor nodes firstly. Then, the energy efficient WSN with the localization technique introduced is run on the sensor nodes by using both the wide area scenario and narrow area scenario. Power consumption considering transmission of localization packets is shown in Fig.10 for 60 second period. Energy Efficient WSN system uses 15 mWatt less power than the suggested localization technique during 1 minute test duration. Moreover, energy gain increases to 20 mWatt if the mobile node is moved in a narrow area. Because number of anchor nodes that send localization packets decrease in third test case.

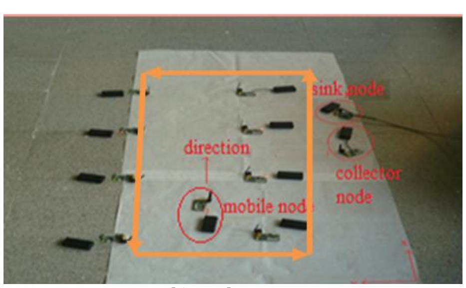
To sum up these results, using mobile nodes in a narrow area gives more energy efficient results. Using more mobile nodes in dedicated areas gives more energy efficient results.

VI. CONCLUSION

In this work, a range-free one-hop localization technique is improved by using the location information obtained from the closer neighboring anchor nodes. RSSI measurements are taken to determine the distance of the anchor nodes to a mobile node. An approach is introduced in order to use the location information coming from only some of the neighboring anchor nodes. Tests are done for various topologies. The system introduced is turned into a more energy efficient one by assigning two states to the anchor nodes: active state and semi-active state. Due to the environmental effects the test environment scaled down.



(a) Narrow region



(b) Wide region

Figure 9. Test topology with 8 anchor nodes, 1 mobile node, 1 collector node and 1 sink node

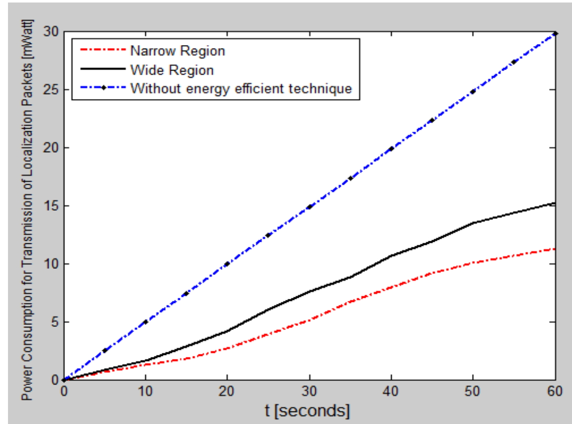


Figure 10. Power consumption comparison

Currently, we are operating the network by using 50 meter as the communication range of the sensor networks. Unfortunately, environmental effects are accumulating and disturbing the results.

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